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Implementation Strategy for Coral Reef Transplantation Methods in Support of Natural Resource Planning, Management and NEPA

NESDI Project Number 491

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ADMINISTRATIVE INFORMATION

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SB

EXECUTIVE SUMMARY

Without substantiated data to convince the regulatory community of effective use of transplantation methods, the Navy continues to rely on marginal or unsuccessful transplantation efforts that have been marginal or unsuccessful. To increase the success of the Navy's mitigation efforts, its chance of success, and wise expenditure of Navy funds for future coral reef transplantation projects, the Space and Naval Warfare Systems Center Pacific (SSC Pacific) created the Coral Reef Transplant Method Implementation Strategy (CRTMIS), funded by the Navy's Environmental Sustainability Development to Integration (NESDI) Program. This study describes, reviews and prioritizes potential transplant technologies that could be used to offset impacts to coral reefs. This study consists of the following:

- An introduction to the document, its intended use and purpose
- The definition and scope of the problem
- An assessment of coral transplant techniques used and lessons learned from their success/failure
- An assessment and description of methods might be used in the future
- Recommendations on what methods are successful or not successful for which types of coral species and marine ecosystem conditions
- A discussion of gaps in the literature
- Important factors to consider for any coral transplant method
- A detailed bibliography of references for further details of methods and study parameters
- Requirements for the establishment of coral nurseries[1]

This study provides a roadmap for making decisions when formulating mitigation packages presented to regulatory agencies. Natural resource planners, range managers, and other environmental team members can refer to CRTMIS for scientific evidence to determine coral reef transplant and mitigation methods. Conversely, CRTMIS provides information that would argue against the transplantation option under certain conditions. Overall, CRTMIS will serve as a tool to help meet the following Navy goals: keep submerged training lands available for use by the Navy, lower mitigation costs, provide scientifically defensible data to be used in National Environmental Policy Act (NEPA) consultations/agreements, and help select transplantation methods that will lead to an increase of genetic diversity among coral reefs and stronger, resilient ecosystems.

[1] Artificial coral reefs are not discussed in this document; they require a separate assessment.

CONTENTS

Figures

TABLES

1. INTRODUCTION

1.1. STRATEGIC PURPOSE

Coral reef ecosystems are unique and among the most complex and biodiverse ecosystems on Earth (U.S. Coral Reef Task Force, 2002). The United States contains an estimated 17,000 square kilometers (km^2) of coral reef habitat in Hawaii, Guam, American Samoa, Commonwealth of the Northern Mariana Islands (CNMI), Florida, Texas, U.S. Virgin Islands (USVI), and Puerto Rico (U.S. Coral Reef Task Force, 2002). Many laws were passed to protect coral reefs: Executive Order 13089: Coral Reef Protection; Executive Order (EO) 13547: Stewardship of the Ocean, Our Coasts, and the Great Lakes; National Environmental Policy Act (NEPA); The Clean Water Act (CWA); U.S. Coral Reef Task Force (USCRTF); and the Department of Defense Coral Reef Protection Implementation Plan (see Appendix A for a listing of laws and their impacts on coral transplantations). The National Action Plan to Conserve Coral Reefs states that if unavoidable impacts still exist after all attempts at avoidance and minimization were made, federal agencies must replace the resource's lost functions through compensatory mitigation (U.S. Coral Reef Task Force, 2002). DoD maintains military installations near coral reef ecosystems around the globe, including locations surrounding Hawaii, CNMI, Guam, Wake Atoll, Kwajalein Atoll, and Okinawa in the Pacific Ocean; Key West and Panama City, Florida; the Bahamas, Cuba, and the U.S. Virgin Islands in the Atlantic Ocean; and Diego Garcia in the Indian Ocean.

On October 20, 2009, the Center for Biological Diversity (CBD) petitioned the National Marine Fisheries Service to list 83 reef-building coral species as either threatened or endangered under the Endangered Species Act (ESA) and to designate critical habitat. In a Federal Register notice published on December 7, 2012, the National Marine Fisheries Service (NMFS) determined that 12 of the petitioned coral species warrant listing as endangered (5 Caribbean and 7 Indo-Pacific), 54 coral species warrant listing as threatened (2 Caribbean and 52 Indo-Pacific), and 16 coral species (all Indo-Pacific) do not warrant listing as threatened or endangered under the ESA. Additionally, based on the best scientific and commercial information available and efforts undertaken to protect the species, two Caribbean coral species currently listed warrant reclassification from threatened to endangered. In November 2012, the National Marine Fisheries Service (NMFS) proposed to list 66 of those petitioned species of corals as threatened or endangered under the ESA and reclassify the 2 Acropora corals currently listed as threatened to endangered. The decision on the final listing was extended by 6 months to solicit additional data. Data solicitation efforts were finished in October 2013, and in November of 2014, a final decision was released. Twenty-two species of coral are now protected under the ESA, including the two corals (elkhorn and staghorn) listed as threatened in 2006. Fifteen of the newly listed species occur in the Indo-Pacific and five in the Caribbean Sea. This decision impacts Continental United States (CONUS) operations at Naval Air Station (NAS) Key West (7 species); Joint Region Marianas (JRM) (3 species); Mariana Islands Training and Testing (MITT) Complex (5 species); South Florida Ocean Measurement Facility (7 species); Key West Range Complex (6 species); Puerto Rico/St. Croix Operating Area (7 species); U.S. Navy's Atlantic Undersea Test and Evaluation Center, Andros Island, Bahamas (AUTEC-Andros Operating Area) (7 species); the Gulf of Mexico Range Complex (3 species); and more than 37 DoD facilities worldwide. When a species is proposed for listing as endangered or threatened under the ESA, the Service must consider whether there are areas of habitat essential to the species' conservation. Those areas may be proposed for designation as "critical habitat." The designation of critical habitat affects activities that involve a federal permit, license, or funding, and are likely to destroy or adversely modify the area of critical habitat. All federal agencies must ensure that any actions they authorize, fund, or carry out are not likely to jeopardize the continued existence of a listed species, or destroy or adversely modify its designated critical habitat. In some cases, actions

are denied within the critical habitat area or additional regulatory requirements are applied to the actions that occur within that area.

1.2. NAVY NEED

There are more than 31 Navy/Marine Corps sites where the Navy has jurisdiction in coastal waters (Navy submerged lands). Operational risks of unsuccessful coral transplantation projects include potential loss of at-sea testing and training range availability and impacts to military construction (MILCON) activities such as lengthy delays and costly, unwarranted mitigation. Results from Navy-funded coral reef transplantation projects (during the last 20 years) are questionable. There is a lack of substantial scientific researches and widely-accepted results from Navy-funded or involved coral reef transplantation projects. Other mitigation efforts (e.g., eliminating habitat loss, performing watershed improvements, taking measures to stop the cause of reef damage and improve conditions at the coral reef sit) could benefit the coral reef community; however, without substantiated data to convince the regulatory community, the Navy will continue to rely on transplantation efforts that are costly and unsuccessful. As a result, no positive effects are generated for the coral reef community.

History of Navy-funded Coral Reef Mitigation Efforts:

- Guam: In 1984, as mitigation for the dredging associated with the construction of the Navy Ammunition Wharf in Outer Apra Harbor in 1984, the Navy created two reef reserve areas, Orote and Haputo Ecological Reserve Areas, for approximately $4 million.
- Hawaii: In 1998, 150 colonies of corals were transplanted away from an area was supposed to be degraded by an extension of a runway discharge culvert at Marine Corps Base Hawaii, Kaneohe Bay, Oahu, Hawaii.
- Guam: In 2008, the Navy transplanted corals directly impacted by the Kilo Wharf Extension to several new sites on Navy submerged lands in Apra Outer Harbor, Guam. The Navy also increased the Orote Ecological Reserve Area (Apra Harbor) to include increased acreages of Navy submerged lands as mitigation for impacts to coral from the Kilo Wharf Extension project. The Kila Wharf Extension Project extended Kilo Wharf 400 feet to provide adequate berthing facilities to support the new USNS *Lewis and Clark* class T-AKE multi-purpose dry cargo/ammunition ship, which will replace other supply and ammunition ships by 2009. The project will involve the dredging of approximately 60,000 cubic yards of submerged sediment.
- Hawaii: When USS Port Royal ran aground in Hawaii in February of 2009, the Navy spent $7 million dollars restoring the reef by having divers collected and reattached more than 5,400 loose stony coral colonies using hydraulic cement. Navy divers who surveyed this area following the mitigation said coral reef transplants did not survive, although a regulatory agency prescribed the effort. The results of this study may be used in this case to provide the Navy with scientifically-valid data. The Navy can present data to regulators to implement an ecologically-beneficial restoration strategy for similar situations in the future.
- Florida: In 2011, the Navy transplanted coral off an existing man-made structures at the NAS Key West Mole Pier. During the $450,000 mitigation project, the Navy spent $200,000 for this effort and 46.2 $m^2$of coral (0.0114 acres) was removed and transplanted from the NAS Key West Mole Pier (Terramar Environmental Services, Inc., 2010). This precedent-setting action could be deleterious for the Navy in the future as many piers (where healthy corals are growing) would face mitigation and monitoring if they require transplantation. This includes piers located in Florida, Guam, Hawaii, Japan, the Marianas Islands, and Diego Garcia.

Remaining funds from the project were allocated to wetland restoration, drainage system restoration, and public outreach.

The environmental risk of not having a CRTMIS-like study creates a disconnect in decision making among Navy natural resources managers and regulatory agencies. Natural resources planners, range managers, and other environmental team members can collectively use our strategy to provide scientific evidence when making decisions about coral reef transplant and mitigation methods. Conversely, our study provides information that would argue against the transplantation option under certain environment conditions. Overall, CRTMIS is a tool for environmental compliance and natural resource managers through Navy regions to keep training lands available for intended use, keep costs for mitigation down, provide scientifically defensible data used in NEPA consultations/agreements, and help select transplantation methods that will increase genetic diversity among reefs that will ultimately lead to stronger and more resilient ecosystems.

1.3. GUIDING PRINCIPLES

Transplantation is directed under specific regulatory conditions. Coral transplantation is just one option available to rehabilitate a reef. Transplantation is a cost-effective option for small-scale rehabilitation efforts that do not divert funding from other coastal management priorities (e.g., transplantation of corals to patches of denuded reef close to diving resorts funded by paying guests, or repair of the reef at ship-grounding sites where funding is available from damage compensation payments). Transplantation may also be necessary when development occurs (e.g., port or other coastal construction, channel dredging, pipeline laying) and reefs are threatened, or where corals may die unless moved to a safe location. The crucial prerequisite for coral transplantation is that any significant local anthropogenic impact on the reef is under some form of effective management. Otherwise, there is a high risk that transplanted corals will not survive.

Specific considerations when transplanting corals include (a) determining if the rehabilitation site has enough suitable transplants of coral species to survive, and (b) finding a suitable site to move corals due to mitigation exercises (where corals are relocated from an impacted site). Special attention should be paid to waves, currents, topography, biological factors, food chain dynamics, water quality, sediment quality, future coastal improvement plans, and weather.

1.4. DOCUMENT STRUCTURE AND INTENDED AUDIENCE

This technical document describes, reviews, and prioritizes potential transplant technologies to mitigate coral reef impacts. The goal of CRTMIS is to provide a decision-making roadmap when formulating mitigation packages presented to regulatory agencies.

The strategy consists of the following:

- An introduction to the document, its intended use and purpose
- The definition and scope of the problem
- Background information on coral biology, structure, and function (as it relates to transplants)
- An assessment of current coral transplant techniques, lessons learned from their success/failure
- An assessment of what methods to use for future coral transplantations
- Recommendations on what methods are successful or not successful for which types of coral species and marine ecosystem conditions
- A discussion of gaps in literature

- Important factors to consider for any coral transplant method
- A detailed bibliography of references for further details of methods and study parameters
- Requirements for the establishment of coral nurseries

1.5. POINTS TO CONSIDER

This technical document is a guidebook for environmental compliance staff and natural resource managers at Navy regions worldwide to evaluate a site and its coral transplant needs. It is intended for use along with other sources and methodologies that offer more specific guidelines for a specific need.

This guidebook serves as a complementary resource to help people understand the complexities of coral reef structure, function, ecology, and biology (factors impacting the success or failure of a coral reef transplantation).

We developed this practical and applicable strategy for scientists, researchers, natural resource managers, NEPA specialists, and other conservation practitioners. Methodologies presented in this guidebook reflect more approachable scientific methods rather than advanced methods. As such, data collection and analysis techniques are more simplistic rather than complex. We did this deliberately so that this guidebook would be a starting point to help users measure transplant technique effectiveness.

As stated by Ken Nedimeyer of the Coral Restoration Foundation, “Scientists are probably 5 years away from really being able to answer questions concerning the optimal design for coral restoration and transplant work while maintain genetic diversity” (Byrne, 2013). Each region and culture is viewed different. The Navy has to consider the intersection of culture and science when determining what objectives are realistic to ensure a successful coral mitigation effort globally.

2. STRATEGY METHODOLOGY

The goal of this implementation strategy is to provide users with a roadmap for making decisions about the various coral reef transplant methods when formulating coral reef mitigation programs. To meet this goal, it was critical to obtain end-user and regulatory input on various techniques, data gaps, and ideas to determine best methods for various morphologies of coral. During the compilation of this technical document, the project team built upon relationships fostered from past coral reef projects with the Strategic Environmental Research and Development Program (SERDP), Environmental Security Certification Program (ESTCP), and Navy Environmental Sustainability Development to Integration (NESDI), and built new relationships with regulators and non-governmental organizations (NGOs) who work specifically in the coral transplantation field.

Our method of data gathering for this strategy was conducted by two main methods:

1. Email communications, phone calls, and teleconferences between project staff and collaborators (see Table 2-1).
2. Extensive literature and Internet reviews of the methods
3. Compilation of a ranked coral transplant methodology matrix that highlights references pertinent to the transplant of corals.

2.1. COLLABORATIONS

Due to the scope of this project, collaborations focused on locating updated and uncatalogued sources of information on this topic and other "gray literature" and field reports. Table 1 lists organizations that were extremely helpful as they provided journal articles, reports, presentations, and other information found in this document.

Table 1. List of collaborators.

Organization
Naval Facilities Engineering Command Expeditionary Warfare Center
Naval Facilities Engineering Command Southeast
Naval Air Station key West
Naval Facilities Engineering Command Pacific
Joint Navy Base Marianas
U.S. Army Engineer Research & Development Center Environmental Laboratory
U.S. Army Corps of Engineers Planning Division
U.S. Army Corps of Engineers Honolulu District Office
U.S. Army Corps of Engineers Regulatory Division for South Florida
U.S. Fish &Wildlife Service Pacific Islands Fish and Wildlife Office
U.S. EPA Environmental Effects Research Laboratory Gulf Ecology Division/ORD
U.S. Geological Service

Table 1. List of collaborators (continued).

Organization
NOAA- Office of Response and Restoration
NOAA- National Marine Fisheries Service
NOAA- Coral Reef Ecosystem Division
Florida Keys National Marine Sanctuary
National Park Service
The Nature Conservancy
The Coral Restoration Foundation
Reef Tech Inc.
University of Buffalo
University of Miami
University of Guam
University of Hawaii
The Louisiana Universities Marine Consortium
Mote Marine Laboratory

2.2. LITERATURE REVIEW

Data on coral reef transplant projects and studies were obtained through electronic and manual literature searches, as well as personal communication with reef scientists, site managers, and institutional librarians. Electronic literature searches were conducted using databases provided by *Best Available Sciences (BAS) for Navy Environmental Research portal*[2]*; ESBCO; Elsevier B.V.; JSTOR; Nature; OVID; Oxford Journals, Oxford University Press Journals; ProQuest; and ReefBase.*

We used the following search terms: coral transplant, coral reef transplant, transplant method, and cost. Boolean and wildcard searching were conducted on each search term (see Table 2-2).

We verified all relevant references cited in publications found on these search engines. This assessment included references provided by other project staff and collaborators.

The only selection criterion for journal article incorporation into the matrix was employed whether or not the study reported success criteria and explanation of the specific method used. We searched for cost information, but results were minimal; therefore, it was not a deterministic criterion for not using an article in the matrix.

[2] Access the Best Available Sciences (BAS) for Navy Environmental Research portal at https://aimtc2.nuwc.navy.mil/basportal. This is an internal database. A login/password is required.

Table 2. Bibliographic search results.

Database	Total # of Hits on All Search Terms	Website
Aquatic Sciences and Fisheries Abstracts	18	https://aimtc2.nuwc.navy.mil/basportal
Catalog of Government Publications	81	https://aimtc2.nuwc.navy.mil/basportal
Coral Reef Information System (CoRIS)	7774	https://aimtc2.nuwc.navy.mil/basportal
Defense Technical Information Center	213	https://aimtc2.nuwc.navy.mil/basportal
Ecolex	2	https://aimtc2.nuwc.navy.mil/basportal
Federal Register	120	https://aimtc2.nuwc.navy.mil/basportal
Google Scholar	110	https://aimtc2.nuwc.navy.mil/basportal
National Sea Grant Library	526	https://aimtc2.nuwc.navy.mil/basportal
NOAA Scientific Publications Office	5	https://aimtc2.nuwc.navy.mil/basportal
PLoS One Biodiversity Hub	1,858	https://aimtc2.nuwc.navy.mil/basportal
ProQuest Aquatic Sciences Collection	981	https://aimtc2.nuwc.navy.mil/basportal
Scirus	116	https://aimtc2.nuwc.navy.mil/basportal
U.S.G.S Publications Warehouse	4	https://aimtc2.nuwc.navy.mil/basportal

2.3. RANKED TECHNOLOGY MATRIX

The matrix (per transplantation method type) used to assess each transplant methodology pooled the following data types:

1. Species
2. Morphology type
3. Biomarker
4. Reproduction strategy
5. Geographic location
6. Exposure conditions (temperature/storms/nutrient levels/chemicals of concern (COCs)/hydrodynamics)
7. Substrate
8. Water depth
9. Number of colony transplants
10. Year
11. Study metric of success
12. Quantitation of success
13. Cost data

3. BACKGROUND

3.1. CORAL REEF BIOLOGY AND ECOLOGY

The term coral should apply only to the species of the Corallium genus (Gorgonacea; red coral); however, coral is commonly misused to describe all creatures with a hard skeleton. The widespread use of the term coral helps the public understand its description.

The Navy uses the same definition of coral reefs used in the U.S. Coral Reef Task Force's National Coral Reef Action Strategy released in June 2002:

"CORAL: The term 'coral' means species of the phylum Cnidaria, including (A) all species of the orders *Antipatharia (*black corals), *Scleractinia* (stony corals), *Gorgonacea* (horny corals), *Stolonifera* (organpipe corals and others), *Alcyanacea* (soft corals), and *Coenothecalia* (blue coral), of the class *Anthozoa*; and (B) all species of the order *Hydrocorallina* (fire corals and hydrocorals) of the class *Hydrozoa*."

"CORAL REEF: The term coral reef means any reefs or shoals composed primarily of corals."

"CORAL REEF ECOSYSTEM: The term coral reef ecosystem means coral and other species of reef organisms (including reef plants) associated with coral reefs, and the nonliving environmental factors that directly affect coral reefs, that together function as an ecological unit in nature."

The coral reef ecosystem definition includes any reefs or shoals composed primarily of corals, actively accreting coral reefs and coral or gorgonian colonized hard-bottom, and seagrass beds and mangroves associated with coral reefs.

3.2. BASIC CORAL BIOLOGY

Although many corals resemble plants, they are actually members of the animal phylum Cnidaria. Most corals are colonial; this means each coral is composed of individual polyps (see Figure 3-1) connected by living tissue (the coenosarc). Each polyp has a cup-like shape with a ring of tentacles around a central opening (pharynx) that functions as both mouth and anus. The tentacles are tipped with stinging cells called nematocysts. Corals use the nematocysts to defend themselves and to capture prey. The body wall consists of three cell layers: the outer or ectoderm, the middle or mesoderm, and the inner or endoderm. There is no skeleton inside the polyp itself. Instead, the polyps sit on top of an external skeleton that is made from the polyp's secretions (Barnes, 1987; Levinton, 1995).

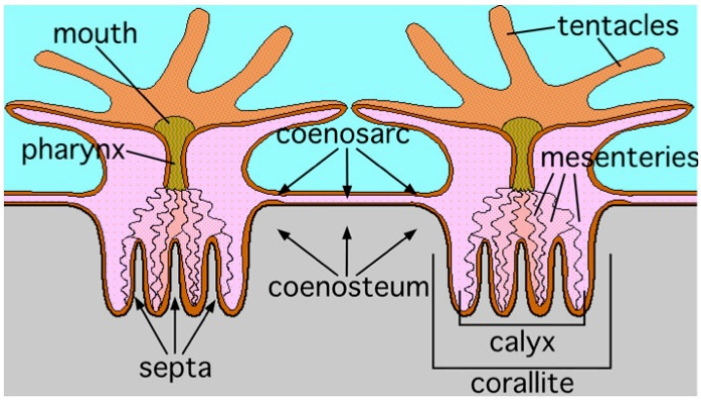

Figure 1. Drawing of a colonial polyp (David Krupp, University of Hawaii).

Corals are divided into two main types: hard corals (stony corals, or scleractinians) and soft corals (gorgonians or octocorals). As their names might suggest, these two types of corals have very different skeletal structures, but there are other differences, too. Soft corals have a flexible skeleton made of a protein called gorgonin. Their skeleton also contains calcium carbonate, but only in small clumps called spicules. Polyps of soft corals have eight tentacles (named octocoral since the word octo means eight) (Barnes, 1987; Levinton, 1995).

Stony corals are the major reef-building species because of their rigid calcium carbonate skeletons. Besides their skeleton, stony corals are also distinguished by their tentacles, which occur in multiples of six. There are 70 Caribbean species and 400 Indo-Pacific species. Hard corals have three types of morphologies or growth forms: massive forms such as brain corals, encrusting forms such as star corals, and branching forms such as elkhorn coral. The different growth forms represent adaptations to different environmental conditions. The massive and encrusting forms are wave resistant. Branching forms are less wave resistant, but they can survive higher sedimentation rates than many massive corals (Spalding, Ravilious, and Green, 2001).

Corals use their tentacles to capture zooplankton (small animals that live in the water). Most corals only extend their polyps and tentacles at night when zooplankton is most abundant, but some corals (especially soft corals) keep their polyps open throughout the day. Many corals have single-celled algae (called zooxanthellae) that live within the coral's innermost tissue layer. Both corals and zooxanthellae benefit from the arrangement. The algae use the sun’s energy to convert carbon dioxide from the seawater into energy-rich sugars and fats. Some of these sugars and fats help the coral grow and produce its skeleton faster than a coral without the zooxanthellae. The zooxanthellae also give the coral its color. In return, the algae have a safe place to live within the coral tissue and the algae uses the coral's waste nutrients for growth. This type of arrangement (where both organisms live together and benefit from the relationship) is called symbiosis. When both organisms benefit, it is a mutualistic symbiosis (Barnes, 1987; Levinton, 1995).

The obligate symbiosis between reef-building coral and unicellular algae of the genus *Symbiodinium*, commonly referred to as zooxanthellae, is a key feature of tropical coral reefs and is one in which organisms require a symbiotic relationship for both of them to survive. (Mieog et al., 2009). The zooxanthellae are photosynthetically active and provide up to 95% of the energy requirement of the coral host. In return, the coral host offers protection from predation and an environment with increased inorganic nutrients (Mieog, 2009).

The success of coral reefs and their capacity to thrive in oligotrophic tropical waters depends on this partnership. The coral-zooxanthellae symbiosis is very sensitive to increases in temperature; a 1 °C change above the average summer maximum can lead to a breakdown of the symbiosis. This breakdown results in expulsion and/or degradation of the algal partner, causing the phenomenon known as coral bleaching. When bleaching is severe, and the symbiosis is unable to re-establish itself, the coral dies. The genus Symbiodinium is highly diverse and consists of eight phylogenetic clades with each containing multiple subclades/types. Scleractinian corals form symbioses with members of six of these clades (A–D, F, G), but predominantly with those of clades A–D (Mieog et al., 2009).

Adaptation response of the zooxanthellae to changing conditions, specifically rising seawater temperatures, are attributed to the zooxanthellate partner (see Figure 2). Many studies have documented the functional differences that exist among taxa of zooxanthellae (Chang, Prezelin, and Trench, 1983;Warner, Fitt, and Schmidt, 1996; Iglesias-Prieto and Trench, 1997; Loram et al., 2007) and host–symbiont associations change predictably over

depth gradients (mostly in the Caribbean) (Frade et al., 2008; LaJeunesse, 2002; Warner, LaJeunesse, Robison, and Thur, 2006). For example, *Montastraea sp.* colonies harbour A-, B-, and D-type zooxanthellae in shallow water (< 6 m) and C-types in deeper water (Rowan and Knowlton, 1995; Rowan, Baker, and Jara, 1997). When environmental conditions change (most notably temperature), the symbiosis can break down (bleaching), sometimes causing widespread coral mortality (reviewed in Glynn, 1991; Coles and Brown, 2003). Bleaching threshold and severity depends on the specific partners involved (Lasker, Peters, and Cofforth, 1984; Rowan, Baker, and Jara, 1997; Glynn, Maté, Baker, and Calderón, 2001). After bleaching has occurred, different taxa of zooxanthellae might dominate the intracolonial symbionts community than before the disturbance (Baker, 2001; Glynn et al., 2001).

Figure 2. Zooxanthellae inside of a coral polyp (David Krupp, University of Hawaii).

3.3. CORAL MORPHOLOGY

For the purpose of this document, we classified corals into three morphological types: massive (and encrusting), branching (and columnar), and platy (and laminar and foliaceous) (see Figure 3). Massive corals are mound-shaped or encrusting colonies. Branching corals are colonies composed of elongate projections. Platy corals are flattened colonies with calices (concave depressions that house the polyps) on only one side (Barnes, 1987; Levinton, 1995; Sumich, 1996).

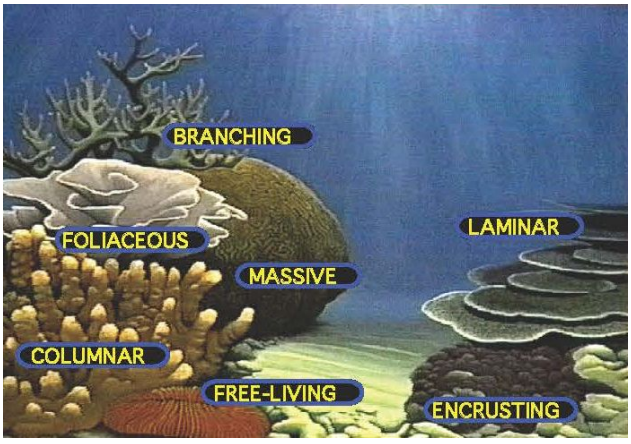

Figure 3. Depiction of the various coral morphologies. (David Krupp, University of Hawaii).

3.4. FORMATION OF REEFS

Charles Darwin (1846) originally described three major types of coral reefs: fringing reef, barrier reef, and an atoll. Barrier reefs begin as fringing reefs along the shores of a volcano. During millions of years, the volcano sinks lower into the sea and the sea level rises around the volcano. The coral grows upwards to ensure it remains within the photic zone. The outward side of the coral reef grows fastest since ocean currents bring in the plankton that the corals feed on. The water on the landward side of the reef is still, and there is less oceanic plankton. Here, the reef is unable to grow fast enough to keep up with the rising sea level and eventually drowned. A lagoon develops between the reef and the land, resulting in the characteristic barrier reef shape. The volcano continues sinking until it disappears under the sea surface. The result is an atoll, a ring of coral reefs surrounding the submerged, extinct volcano. Eventually, sand is trapped by reefs, and sandy islands (called cays) appear.

The first type of reef described by Darwin is the fringing reef, an area along the shore where coral colonies grow. Fringing reefs occur close to land and often extend out to sea for long distances. The second type of reef is a barrier reef, a well-defined coral zone separated from land by a lagoon. The lagoon is a shallow area with a sandy floor, patch reefs, and patches of seagrass. An atoll is the third type of reef. An atoll is a ring-like formation of reefs with a lagoon inside the ring (Sheppard, Davy, and Pilling, 2009; Spalding, Ravilious, and Green, 2001).

The majority of reef-building corals are found within tropical and subtropical waters. These typically occur between 30^{o} north and 30^{o} south latitudes. The red dots on the map shown in Figure 4 pinpoint the location of major stony coral reefs across the Earth.

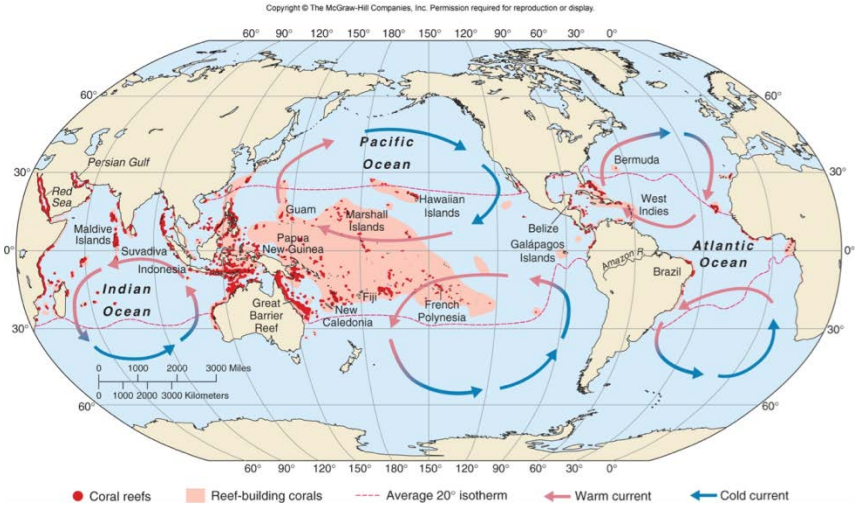

Figure 4. Stony coral reef distribution map from the NOAA Ocean Service Education website: http://oceanservice.noaa.gov/education/kits/corals/media/coralreefmap.jpg.

3.5. PHYSICAL PARAMETERS AFFECTING CORALS

Coral reefs are also called rainforests of the ocean. They have a complex ecosystem that includes a hard skeletal structure made of calcium carbonate. Coral reefs provide habitat for a vast array of creatures, including fish, shells, crabs, octopi, squid, sea anemones, sponges, worms, microscopic animals, and a diversity of algae. While these colorful and lively underwater habitats thrive in tropical and sub-tropical waters around the world, a number of factors can affect coral reefs and cause devastating outcomes to marine life. Abiotic factors

are non-living factors that influence ecosystems such as temperature, light, and available nutrients. Biotic factors are living organisms such as an animal or plant in the ecosystem and they include algae and viruses. Predation by an animal or a dominant algae taking up a large majority of space would prevent coral recruitment and is also an example of a physical factor. Key factors affecting corals include light, water depth, substrate, turbulence, temperature, and water quality (Sheppard, Davy, and Pilling, 2009; Mojetta, 2003; Veron, 2000).

3.5.1 Light

Light is a major limiting factor for coral reefs for several reasons. Light is critical in maintaining the symbiotic association between corals and symbiotic algae (zooxanthellae). The intensity of light greatly affects photosynthetic rates of the zooxanthellae, indirectly impacting coral growth and survival factors that alter the abundance of corals decreases rapidly with depth due to reduced light levels. In clear tropical waters, corals may live as deep as 150 feet (48 m), with very limited species found beyond that depth (Veron, 2000).

About half of all Scleractinia (stony corals) do not have symbiotic algae and are considered azooxanthellate species. Some azooxanthellate corals live on coral reefs, especially under overhangs or in caves. With the exception of a few species that are both symbiotic and non-symbiotic, all zooxanthellate corals need light. These are the only corals that build reefs. As a result, reefs are restricted to shallow sunlit waters. Azooxanthellate corals are not limited by light or by temperature, nor are they confined to shallow sunlit water; they live in a vast expanse of the ocean depth where there is less competition for space. These taxa cannot build reefs and must therefore live without food from photosynthesis: food can only come from the chance capture of passing plankton (Veron, 2000).

Corals growing in very shallow water (e.g., reef flats) have sunscreens (chemical agents in their tissues) to reduce the amount of light reaching their zooxanthellae. If this is not controlled, the zooxanthellae can produce toxic amounts of oxygen (the principal cause of mass bleaching). Factors that alter light in the marine environment will have a significant effect on calcification rates and reef development.

3.5.2 Water Depth

The depth in which zooxanthellate corals can grow is understated in most literature as corals live below depths inaccessible to scuba divers. Only a few zooxanthellate corals live below 100 meters where the water is very clear and the substrate does not slope so steeply that it is shaded. Leptoseris commonly forms extensive beds to at least 160 meters in the Red Sea and Hawaii and there are several records of moderately diverse coral communities at depths of over 100 meters elsewhere (Veron, 2000).

Turbidity has a dominant role to play in controlling light levels in all except clear-water habitats. Coral diversity decreases sharply below about 50 meters where the water is cloudy, (the case with some reefs near major land masses). Where the water is particularly muddy, (predominantly along coastal zones), the depth limit for any coral can be as little as 5 meters. However, clay from rivers can adversely affect corals. Not only does clay attenuate light, but it also requires the coral to expel the clay. This expulsion process can use corals' cilia on their tentacles and other methods (a costly activity in terms of metabolic energy) (Veron, 2000).

3.5.3 Substrate

Reef substrates are composed of calcium carbonate from living and dead scleractinian corals, limestone, and loose sand. Some corals also grow on dead or diseased coral. Substrate type and water clarity are always closely linked, especially when depth and turbulence are factored. White calcareous sand, although typically coarse-grained, is light; therefore, it is readily moved around by wave action and is capable of burying corals if suspended in sufficient quantity. However, clay from rivers that adversely affects corals; it attenuates light and requires cleaning, which corals do by using cilia on their tentacles and other methods (a costly activity in terms of metabolic energy).

Substrate is also significant to settle larvae. Larvae are unable to settle on sand or on substrates coated with bacterial slime. (It's common to find slime on degraded corals, which negatively affects larvae).

3.5.4 Turbulence

Wave action from turbulence produces dense skeletons during the coral skeleton formation process. Corals on a high-energy reef front typically have extremely hard, dense skeletons, whereas those in a protected lagoon have light, brittle skeletons. Low turbulence is necessary for corals so that sunlight is able to go through the water. If too many waves are present in a coral reef ecosystem, the coral is no longer able to capture food and waves can also damage the coral.

3.5.5 Temperature

Temperature sets limits on the latitudinal spread of corals throughout the world. Seawater temperatures are tolerated between 61–95°F (16–35 °C), with optimal coral growth occurring at temperatures of 73–77 °F (23–25 °C). These temperatures exist throughout most of the tropics with the exception of cool water currents off the west coasts of Africa and Australia. However, subtropical regions like those near Bermuda, can sustain reefs due to ocean currents moving warmer water from the tropics towards the north.

3.5.5.1 Low Temperature Limits

Corals can produce calcium carbonate at approximately 18 °C to fulfill their guild role as producers of building materials. This is achieved by creating three-dimensional habitats where herbivores, especially fish, can control algae for themselves. During lower temperatures, algae usually outgrow corals; however, corals are not affected by temperatures lower than 18 °C. This is seen along the Ryukyu Islands of Japan where there are extensive reefs yet further North, the sea temperature decreases until it reaches the critical 18 °C point. Most corals cannot reproduce temperatures lower than 18 °C, but there are a few that can tolerate 12 °C temperature (Veron, 2000).

Some scientists believed that corals in cold high latitude regions have an ephemeral existence, neither reproducing nor growing like their tropical counterparts; however, this is invalid. Based on existing research, corals can reproduce in high latitudes (Veron, 2000). Massive colonies of Porites and the Fungiidae family do well in colder waters (reason unknown).

3.5.5.2 High Temperature Limits

The effect of metabolic processes on zooxanthellae prevents a faster calcification and metabolic rate in warm water. Faster metabolic rates for zooxanthellae mean faster photosynthesis, which can lead to oxygen production at toxic rates. Corals are forced to expel

their increasingly poisonous zooxanthellae and “bleach,” a response to temperature and light acting in concert (see Section 3.2).

During high temperature limits, coral growth and reef growth are the same; they have the same upper limit as the ocean upper limit. This link is an evolutionary one and appears to have always existed. There is no evidence of a geological time where high temperature excluded reefs from equatorial regions. Here are general points about the effects of high temperature on coral and reefs:

- The Coral Triangle is a marine area located in the western Pacific Ocean. It includes the waters of Indonesia, Malaysia, the Philippines, Papua New Guinea, Timor Leste, and Solomon Islands. Habitat diversity and the close interlinking of surface currents contribute to the high diversity in the Coral Triangle that is seen nowhere else.
- Higher temperatures can lead to higher coral growth rates and produce oxygen at toxic rates. Higher rates are normally associated with weaker skeletons. Corals tissue outgrows its ability to form its own skeleton.

3.5.6 Water Quality

Corals can tolerate high salinity, but the lethal limit is unknown, while low salinities are deterrents to reef growth (Veron,2000).

There are other environmental factors hidden in water chemistry that affect reef building. When the role of change of the chemical composition of the ocean exceeds physical or biological thresholds, only specialized organisms can tolerate this change. This can happen when large tracts of ocean become anoxic, hydrogen sulphide concentrations become toxic, pH alters beyond tolerable limits for calcification, or other contaminants make the water uninhabitable. Such changes have played a significant role in the past to limit reef distribution and have the potential to do so in the future (Veron, 2000).

Different species of coral grow at different rates depending on water temperature, salinity, turbulence, and the availability of food. The massive corals are the slowest growing species, add4.ng between 5 and 25 millimeters (0.2–1 inch) per year to their length. Branching and staghorn corals can grow faster, adding a maximum of 20 centimeters (8 inches) to their branches each year (Shaish et al., 2008).

3.6. BIOLOGICAL PARAMETERS AFFECTING CORALS

3.6.1 Coral and Algae Dynamics

Water with high nutrients (euthrophication) is turbid. In this environment, corals receive less light and the rate of sedimentation increases as phytoplankton die and sink, decomposition can result in oxygen depletion. Algal blooms subsequently block sunlight, reducing coral growth. Algal competitors interfere with coral reproduction by competing for substrate. There is considerable complexity in coral–algae interactions; turf algae and macroalgae promote heterotrophic microbial overgrowth of coral, macroalgae also directly harm the corals via hydrophobic organic matter, whereas crustose coralline algae generally encourage benign microbial communities. In addition, complex flow patterns transport organic matter and pathogens from algae to downstream corals, and direct algal contact enhances their delivery (Barott and Rohwer, 2012). Therefore, it is imperative for the corals and the algal to live in balance with each other.

As described in the Relative Dominance Model (RDM) (Figure 5) proposed by Littler, Littler, and Brooks (2006), grazing physically reduces algal biomass (top-down) and

nutrients control production (bottom-up). The complex natural interactions between herbivory and nutrients are most dramatically impacted by large-scale catastrophic disturbances such as tropical storms (Done, 1992), warming events (Macintyre and Glynn, 1990; Lough, 1994), cold fronts (Precht and Miller, 2007), diseases (Santavy and Peters, 1997), and predator outbreaks (Cameron, 1977). These events serve to trigger or accelerate the ultimate long-term phase shifts postulated in the RDM. Such stochastic events selectively eliminate the longer-lived organisms in favor of faster-growing fleshy macroalgae, which are often competitively superior (Birkeland, 1977). However, nutrients and herbivory, in the absence of large-scale disturbances, are both sufficient to maintain phase shifts independently or in concert (Smith, Smith, and Hunter, 2001; Armitage and Fong, 2004; Littler, Litler, and Brooks, 2006).

The major tenets of the RDM are: (1) that competition for space and light is crucial in determining the relative abundances of major benthic photosynthetic organisms and (2) that the outcome of competition for these resources is most often, but not exclusively, controlled by the complex interactions of biological factors (top-down controls such as grazing) and environmental factors (bottom-up controls such as nutrient levels) (Littler, Littler, and Brooks (2009).

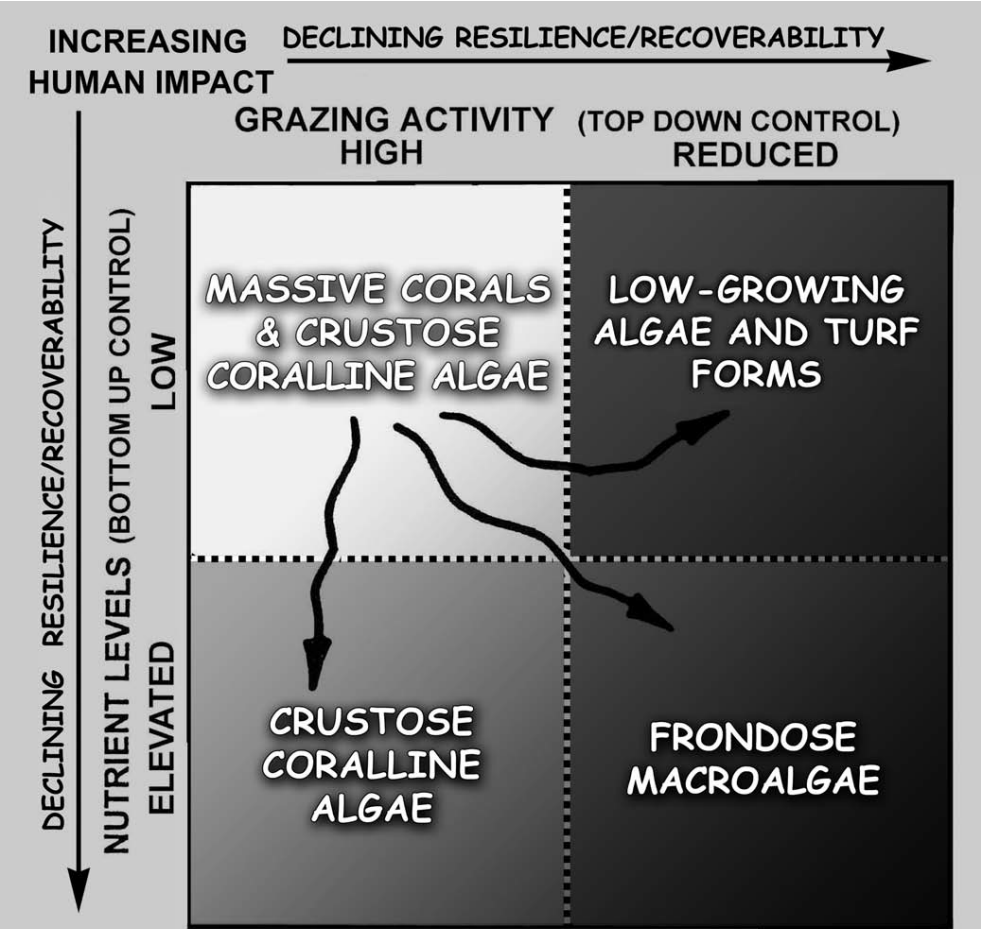

Figure 5. The competition-based relative dominance model (replicated from Littler, Littler, and Brooks, 2009).

Corals can inhibit algal growth or even overgrow and kill the algae (Meesters and Bak, 1993; Meesters, Pauchli, and Bak,1997). Algae may have no effect or even positive effects on corals (Jompa and McCook, 1998; Heyward and Negri, 1999) and overgrowth may not lead to coral death. Many areas experience seasonal blooms of ephemeral brown algae (Dictyota, Hyroclathrus, Chnoospora, Colpomenia), which entangle and overgrow corals for months without causing significant harm to coral populations (Coles, 1998). Competitive superiority is by no means fixed: turf algae may dominate coral or be overgrown by coral colonies. Turf dominance may prevent coral recruits from establishing or the opposite may occur with recruits overgrowing turf algae (Potts, 1977; Fishelson, 1973; Bak, Brouns, and Heys, 1977) and may exclude or be overgrown by coral recruits under different circumstances (Littler and Littler, 1997). Crustose corallines appear relatively invasive and aggressive to corals, but may also facilitate coral settlement (Heyward & Negri, 1999) and serve as “cement blocks” for coral establishment and to maintain coral structure.

Offshore and inshore reversals in coral and algal abundance may occur due to coral intolerance of inshore turbidity and algal susceptibility to the abundant herbivores on offshore reefs (McCook, 1996, 1997). The same pattern could also arise because corals are also killed by inshore sediment, allowing algae to persist (Umar, McCook, and Price, 1998).

Algae will rapidly colonize any area of coral tissue killed by other causes (corallivorous fish or invertebrate feeding, temporary sediment burial, and bleaching), whereas adjacent healthy coral tissue may continue to vigorously defend itself from algal recruitment or vegetative overgrowth. Thus, close matches between coral tissue damage and algal overgrowth may not indicate algal competitive success but rather the successful competitive exclusion of algal growth from areas of healthy coral tissue (deRuyter van Stevenick, Kamermans, and Breemams, 1988; McCook, Jompa, and Diaz-Pulido, 2001), unless experimental evidence is available. deRuyter van Stevenick, Kamermans, and Breemams (1988) documented inhibition of algal growth rates by proximity of corals (the only detailed demonstration of coral effects on algal). Coyer, Ambrose, Engle, and Carroll (1993) and Lirman (2001) noted polyp retraction in response to algal brushing, providing otherwise scarce evidence for the mechanisms of competition.

Herbivory is a key factor mediating the effects of algae on corals, since the standing crop of biomass (per unit area) of algae is largely controlled by herbivores (Hatcher and Larkum, 1983; Steneck, 1988; Carpenter, 1997; McCook, 1999) and the ability of algae to compete will depend on the accumulation of sufficient biomass to overgrow corals (Miller & Hay, 1996, 1998).

Diadema antillarum urchins are known to control grazing of benthic algae and enhance coral settlement. These urchins are found in the Caribbean. In areas that do not have *D. antillarum,* capturing wild *D. antillarum* and sequestering them onto a reef to create artificially increased densities is a moderate success (The Nature Conservancy, 2004).

Nutrients can only affect algal growth, which may or may not accumulate as increased biomass (depending on herbivory rates). Herbivory can only affect algal standing crop or biomass, although this may lead to changes in algal area by increased vegetative or sexual colonization. Substrate availability (determined by competitive inhibition by corals and disturbance) will affect algal areal abundance with potential subsequent competitive effects on coral recovery (Miller, 1998; McCook, 1999).

Massive corals are more vulnerable than branching corals to whiplash by larger algal fronds. The algae may become entangled in a branching coral, resulting in more damage to the algae than to the coral. Within life forms, there is also likely to be considerable

quantitative variation with both colony size and polyp sixe. Larger colonies are less liable to overgrowth or shading, and corals with larger polyps or tentacles can defend themselves against algae. However, there are considerable qualitative differences between adult life forms and coral recruits. Coral recruits appear vulnerable to more forms of algal competition than established corals (McCook, Jompa, and Diaz-Pulido, 2001).

Corals will also have vital indirect effects on algae, including the provision of habitat for herbivorous fish.

3.6.2 Coral Reproduction

Corals can reproduce either asexually by budding or sexually (Figure 6) by releasing gametes (sperm and eggs). Budding is the replication of new individuals and is the method by which coral colonies grow (Sumich, 1996).

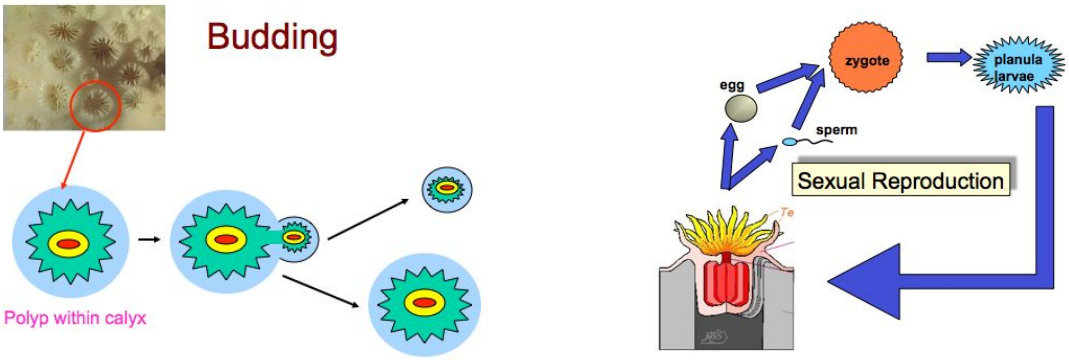

Figure 6. Schematics of both asexual and sexual reproductive methods in corals (David Krupp, University of Hawaii).

Like all animals, corals will take time to reach sexual maturity. Massive hard corals (e.g., such as Brain corals) grow slowly and will take approximately 8 years before they reach sexually maturity. Since branching corals grow faster, they reach sexual maturity a few years earlier. The individual coral polyp can be male, female, both or may lack reproductivity. If a polyp is just of one sex then it is termed gonochoric. A polyp that is both male and female is known as a hermaphrodite. The coral colony is made up of many of these individual coral polyps (or modules). Therefore, the sex of a coral is described at both polyp and colony levels. A coral colony may be comprised of all female or of all male polyps, thereby being of one sex, or gonochoric. Some colonies, however, are made up of both individual male and female polyps, or of hermaphroditic polyps. Therefore, the colony as a whole is a hermaphrodite (Barnes and Hughes, 1999).

A coral polyp's reproductive organs are contained inside the body cavity and lie on the mesenteries (or septa). Fertilization of the mature eggs by male sperm may take place within the female coral polyp (internal fertilization) or may be external (occurring in the water column). These are two major contrasting modes of reproduction and have many implications in reproductive ecology. A coral that releases all of its gametes externally into the water to fertilize is known as a broadcaster. Internal fertilization is only achieved by male gametes of the species liberated from polyps. These mature sperm swim through the water and find a polyp of the same species that has ripe eggs. The sperm enters the polyp through the mouth to

fertilize the eggs internally. A coral adopting this strategy is known as a brooder (Barnes & Hughes, 1999).

The following illustration shows the difference between broadcasting and brooding (Veron, 2000).

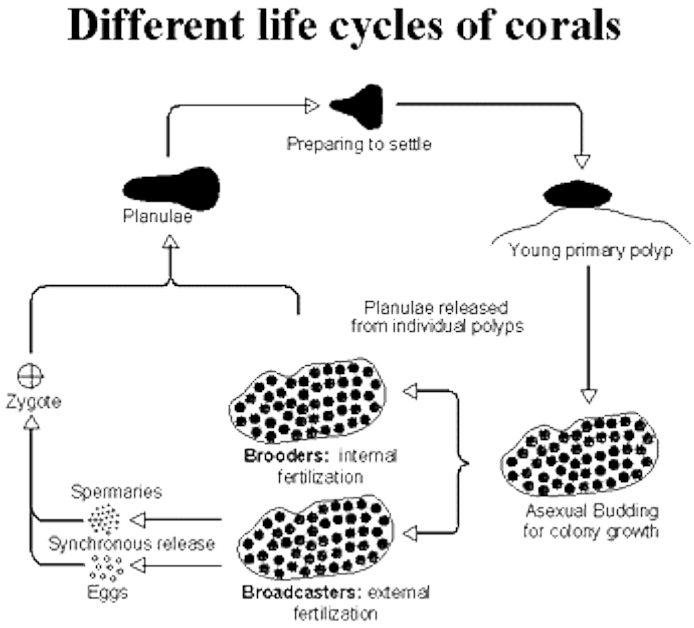

Figure 7. Different life cycles of corals.

The zygote that is formed after fertilization will develop into a larva, known as a planula. If the planula is the result of external fertilization of a broadcasting coral then this development will take place entirely within the water column. If internal fertilization occurs, the planula will develop within the maternal polyp (known as brooding) and will release into the water column. Many brooding corals will only release planulae over discrete seasons whilst others will planulate throughout the year. Broadcasting corals will release gametes during very specific times to ensure fertilization. If the broadcasting species is a hermaphrodite (individual polyps as male and female), then gametes are released together in packages, enhancing the success rate of fertilization. Corals coordinate this timing by using the lunar (moon) cycle and the light-dark regime (Veron, 2000).

Larval development occurs within the maternal polyp of brooding species. As a result, the released planulae spend very short periods of time in the water (a few days). In comparison, the planulae of broadcast corals spend longer in the water column (several days to months) as they mature. The length of time that the planulae spend in the water column will determine the distance in which they are dispersed away from the parent colony. The planulae have limited powers of locomotion and drift with the plankton. They are preyed upon by many reef invertebrates and by fish. Each survivor will settle on the bottom to become polyps and start a new colony. Polyps have a measure of control over selecting a surface suitable for settlement. Once the planula has landed and metamorphosis occurs, the coral can never move again. Growth of the new colony then takes place through asexual reproduction and the life cycle begins again (Jones and Endean, 1973).

A 2008 study assessed the settlement preferences of *Porites astreoides* for particular habitat conditions in the laboratory and evaluated how various habitat conditions affected

their in situ growth and survivorship during the post-settlement phase. Larvae responded strongly to substrate type, preferring to settle on surfaces conditioned in cryptic orientations in shallow waters (3- to 5-meter depth), or on rubble pieces, and avoided surfaces conditions in exposed orientations. Individuals had the highest survivorship in the turf-dominated areas on downward facing tiles. Overall, survivorship was low, with an average survivor rate of 10% within 2 weeks. These results suggest that *Porites astreoides* has a complex set of larval settlement behaviors, responding to multiple cues concurrently to select appropriate settlement microhabitats, including the substrate community type and the light intensity of the environment. (Cooper, 2008).

3.6.3 Genetic Diversity

An important factor in coral reproduction is its effect on the genetic diversity of the reef. Genetic diversity is defined as several levels in organisms that have sexual and asexual reproductive modes such as corals and plants (reviewed in Toro and Caballero, 2005). Genetic diversity sensu strictu (or gene diversity) refers to the amount of variation on the level of individual genes in a population. Genetic diversity is expressed as heterozygosity or allelic richness. Genetic variation is neutral or adaptive; different methods are used to detect and measure these two types of genetic diversity. In contrast, genotypic diversity is defined as the number of unique multilocus genotypes present in a population and varies on the level of whole organisms. A multilocus genotype (genet) may occur several times (ramets) in a population only as a result of asexual replication (identity by descent). The number and relative abundance of ramets from different genets determine the genotypic richness and genotypic evenness, respectively (Baums, 2008).

Founder effects, in which new colonies are started by a few members of the original population, may occur in natural and captive populations when these populations are descendent from a limited number of individuals (Wares, Hughes, and Grosberg, 2005). Population bottlenecks occur when a population's size is reduced for at least one generation. This may result from initial colonization of a new site in the wild, or the initiation of a breeding program with individuals that capture only a small portion of the natural diversity of the source population. The severity of a genetic bottleneck depends on population growth, the mating system, frequency of immigration and the initial genetic diversity (Hedrick and Kalinowski, 2000). Of these factors, coral restoration programs can directly influence initial genetic and genotypic diversity of repopulated areas, mostly through propagule selection.

Fragmentation is caused by external physical disturbance, such as coral pieces broken off as a result of wave or storm action. It is common in branching acroporids (Baums, Miller, and Hellberg, 2006; Tunnicliffe, 1981), *Madracis* (Vermeij, Sandin, and Samhouri, 2007), *Porites* (Hunter, 1993), and *Pavona* (Willis and Ayre, 1985) but is also reported for massive *Montastraea* species (Foster, Baum, and Mumby, 2007). Fragments have a higher chance of survival when they are large (Lirman, 2000) ; dispersal is limited but, over time, genets can extend over tens of meters (Neigel and Avise, 1983; Baums, Miller, and Hellberg, 2006; Foster, Baum, and Mumby, 2007).

In brooding corals, eggs are retained in the maternal polyp. Although most corals are hermaphrodites, sperm originating in a different colony typically fertilizes the eggs within the polyps of brooding corals. Thereafter, the larvae are brooded until they are relatively well developed, and then released into the water. Such larvae receive their symbiotic algae from the parent, small numbers of lipid-rich larvae are produced, and released larvae can settle to a suitable surface closely after release. It is possible brooded coral larvae to settle close to their parents; aggregated patterns of small colonies are often a clear sign of this reproductive

strategy. While brooded larvae are competent to settle almost immediately following releases, they have the capacity to remain in the water column for lengthy periods (results from one species suggest this time can exceed 100 days). In nearly each case, the period in which brooeded larvae remain free swimming in the natural environment is unknown (Edmunds, 2000).

Several brooding species release asexually produced planulae as evidenced by having multilocus genotypes identical to their mothers' (Stoddart, 1983; Stoddart, Babcock, and Heyward, 1988; Brazeau, Gleason, and Morgan, 1998; Sherman, Ayre, and Miller, 2006). Asexually produced planulae have the same dispersal potential as their sexually produced counterparts and thus could be transported further than fragments (Stoddart 1983). Several clones of *Pocillopora damicornis* in Hawaii were found distributed over eight reefs (Stoddart, 1983).

Selfing, or self-fertilization, contributes to inbreeding in at least some coral species. Hermaphroditic coral species are capable of selfing under laboratory conditions in the absence of nonself sperm. Nonself sperm may be preferred under natural conditions (Willis, Babcock, Harrison, and Wallace, 1997; Hatta et al., 1999; van Oppen, Willis, Van Reede, and Miller, 2002) so that the contribution of selfing to reproduction in wild populations of broadcast spawning corals is mostly unknown. Only two studies on brooding corals report selfing rates based on progeny array analysis and compared them to heterozygosity deficits of adult populations (Stoddart, Babcock, and Heyward, 1988; Ayre and Miller, 2006).

Tables 1 and 2 from Baums (2008) list studies that used molecular methods to assess the contribution of inbreeding and asexual reproduction in tropical scleractinian corals for the Atlantic/Caribbean.[3]

Hybrids stemming from intraspecific mating may show fitness advantages or disadvantages compared to their parents when grown in their parent's habitat. Fitness advantages of F_1 hybrids (hybrid vigor or heterosis) may result from mating between parents from diverged populations (Johansen-Morris and Latta, 2006). Such mating can mask recessive deleterious alleles or confer a fitness advantage through superior performance of heterozygotes (overdominance) (Pujolar, Maes, Vancoillio, and Volvkaert, 2005; Pace et al., 2006). Hybrids may harbour novel allele combinations that result in new favorable multilocus genotypes (epistasis). Detection of outbreeding (and inbreeding) depression requires careful experimentation including breeding studies, common garden experiments and reciprocal transplants of hybrid individuals (Hufford and Mazer, 2003). Breeding studies are difficult due to infrequent sexual reproduction in scleractinian corals (Harrison, Collins, Alexander, and Harrision,1990), difficulties in raising coral larvae in captivity, and long maturation times.

Breeding and out-planting efforts can have detrimental consequences on the long-term survival of the species mainly through two effects (Baums, 2008):

- Inbreeding depression, a reduction in fitness due to mating of relatives
- Outbreeding depression can result from mating between distantly related individuals (through the breakdown of co-adapted gene complexes) or mating between individuals that are strongly adapted to local conditions (ecotypes)

[3] For references listed in Tables 1 and 2, electronic literature searches were conducted using Web of Science and ReefBase databases.

4. LITERATURE REVIEW & EVALUATION OF TRANSPLANTATION METHODS

Coral transplantation is defined as the physical relocation of coral from a site of inhospitable conditions to where the coral is more likely to thrive. Coral transplantation may be implemented in order to move live coral in danger of destruction or poor conditions at one location to a transplantation site that may provide a more hospitable environment, or it may be implemented in order to assist in rebuilding a damaged or deteriorating site by moving coral from a healthy site to the less healthy one. In literature reviewed for this technical document, we found common when discussing the transplantation of corals:

1. Accelerate reef recovery after ship groundings
2. Replace corals killed by sewage, thermal effluents or other pollutants
3. Save coral communities or locally rare species threatened by pollution, land reclamation or pier construction
4. Accelerate recovery of reefs after damage by Crown-of-thorns starfish or red tides
5. Aid recovery of reefs following dynamite fishing or coral quarrying
6. Mitigate damage caused by tourists engaged in water-based recreational activities
7. Enhance the attractiveness of underwater habitat in tourism areas
   Restore a reef back to a state where its natural recovery processes function adequately enough so that corals can reproduce and recruit new generations, grow to create topographic diversity, harbor fish etc., which in time, will add species diversity to the reef

As you read through this technical document, keep in mind that it is useful to distinguish between methods of "physical restoration," which focuses on repairing the reef environment with an engineering focus (such as methods stated in Sections 4.1, 4.2, and 4.3) and methods of "biological restoration," which focuses biota restoration and ecological processes (like those mentioned in Section 4.4 and 4.5).

From a biological standpoint, the effectiveness of coral transplantation depends on water quality, exposure, and degree of substrate consolidation of the receiving area. Transplantation depends on the receiving area is failing to recruit naturally. It has been shown that without management actions, transplants are likely to persist as just a single exogenous generation and die within a few years (Edwards, 2008).

The local setting will have significant influence on the rate of recovery. For example, in Japan, common reef-building corals such as the genera Acropora and Pocillopora have the capability to grow rapidly and mature early, and reefs can revive within 5 to 10 years. Recovering coral reefs by eliminating negative factors is the basic necessity for effective restoration. Unless chronic stresses are reduced, propagation of corals is retarded, the reef continues to degrade, and active restoration with artificial approaches is futile (Omori, 2011). Florida is another good example of how the local environment impacts the rate of coral recovery. After 1 to 2 years, crustose coralline algae, sponges, octocorals, zooanthids, and pioneering stony corals begin to settle and exploit the open space. Pioneering corals such as the Octocoral genus Pseudopterogorgia and the stony coral *Favia fragum* recruit and start to grow. After 8 to 10 years an area will have a high density of sponges and octocorals with a moderate density of pioneering stony corals: *Agaricia agaricites, Porites porites, Porites astreoides*, *Favia fragum*, and *Colpophyllia natans*. Because octocorals recruit and grow at a relatively rapid rate, they may recover to pre-disturbance population densities in 10 to 15 years. Stony corals recruit and grow at a much slower rate than the octocorals, and their

recovery may require several decades to a century. Two corals (*Acropora palmata* and *Montastraea annularis*) were documented as principal reef framework builders in Florida and many parts of the Caribbean (Shinn, Hudson, Halley, and Lidz, 1977). In Florida, *Acropora palmata* has an average annual growth rate of 72.5 mm, while *M. annularis* has an annual growth rate of 7.3 mm (Shinn et al., 1977). Florida Keys reefs have a growth rate of 0.65–4.85 m per 1000 years (Shinn et al., 1977). Because reef recovery and growth rate is slow, (even under optimal conditions) restoration actions that will enhance recovery are beneficial (Jaap, 2000). Jaap (2000) documents a typical reef recovery scenario:

- One-year post restoration: Recruitment and settlement of benthic algae and sponges begins. Mobile invertebrates moving into the area include gastropod mollusks and small crustaceans. The resident fish include gobies and blennies that find refuge in small fissures in the structures and reef surface. Larger fish such as parrotfish, wrasses, grunts, and angelfish frequent the area.
- Two-year post restoration: Crustose coralline algae begin to replace fleshy algae. Sponges, octocorals, and a few stony corals are evident on the surfaces of restoration structures and on the disturbed reef surfaces. Growth from initial process increases biomass, diversity, and competition for space. The mobile invertebrates include more gastropod mollusks, crustaceans and echinoderms. In particular, herbivore elements dominate the fauna. The fish now include grunts, snappers, jacks, and the occasional grouper.
- Four-years post restoration: By now recruitment and success of restoration should be very visible. Octocorals are predominant, and the genus Pseudopterogorgia is particularly abundant in settling and growing on disturbed reef rock; however, other octocorals are also successful. Sponges, stony corals, zoanthids, and other species have settled, following the pioneers.

Ecosystems do not recover from anthropogenic stress without manipulation (Pratt, 1994). Heavy destruction requires 10 to 20 years for full recovery. Severe damage may require several decades for complete recovery (Stoddart, 1974; Hughes, 1994). If a chronic perturbation (e.g., oil pollution) is present in the area, recovery of the damaged reef may be further prolonged or may not occur at all (Rinkevich and Loya, 1977; Loya, 1986).

There are two major categories that transplant methods fall into (Rinkevich & Loya, 1977; Loya, 1986): physical and biological

1. Physical:
    a. Attachment using glue/cement/epoxy
    b. Attachment using nails/cable ties/rods
    c. Leaving in place/laying down
2. Biological:
    a. Reproductive methods
    b. Nurseries

4.1. PHYSICAL RESTORATION METHOD 1: ATTACHMENT USING GLUE/CEMENT/ EPOXY

4.1.1 Introduction

Divers tasked with coral transplantation typically use hydraulic cement or Portland cement supplemented with muddling plaster and sand. Cement will enter solution and generate a plume; therefore, divers should exercise caution to minimize deposition of cement residue

around the work site. Epoxy (Figure 8) is an alternative to cement (Jaap and Morelock, 1997), which is expensive but works well for reattaching smaller, fragile corals. A method used to cement corals back on a reef starts with one to four liters of Portland type II mortar mix (Neeley, 1988).

Figure 8. Coral fragment attachment with epoxy (photo courtesy of NOAA).

The mixed mortar is put in a watertight container (plastic bag, a bowl with a sealed top, or a length of sealed PVC pipe). A diver swims the cement to the work site, or it can be sent to the bottom on a line. The surface area is cleaned, all or part of the mortar is used to build a mound of cement on the reef platform, the coral, sponge or octocoral is inserted into the cement mound. The diver works the cement around the edges of the transplanted organism (Jaap, 2000).

If the area experiences currents and wave surge, soft dive weights or a sand bag can be placed around the base of the organisms to stabilize the transplant while the cement hardens. Adding molding plaster to the cement during the mixing will speed the cement curing time. (Caution is suggested as the plaster is chemically reactive and causes the cement mixture to become hot.) The mixer and diver should wear rubber gloves to protect their hands. Commercial products such as the Waterplug® Hydraulic Cement will also rapidly set. Cement will dissolve underwater, leaving grey silt on the sea floor. Placing soft dive weights around the base of the cemented organisms and fanning the area removes residue from the sea floor. Marine epoxy works well to reattach small to medium-sized organisms back on the reef platform. Liquid Rock 500 epoxy and hardener are dispensed from twin tubes placed in an applicator with a nozzle containing internal mixing spirals. The surface is cleaned with a wire brush. If the organism is going to be transplanted on a vertical surface, a small hole is drilled into the reef surface, the back of the coral, and a small brass or stainless rod is fitted into the hole in the coral. Epoxy is applied to back of the coral and the rod. Both coral and rod are placed on the reef surface with special care so that the rod is inserted into the holes (Jaap, 2000).

4.1.2 Literature Review

As seen in Table 3, we found 22 studies where this methodology was utilized.

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies.

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/Nutrient Levels)	Substrate	Water depth (m)	Number of Colonies Transplanted/ Rametes Settled	Year	Study Metric of success	Quantitation of success	Cost data	Reference
Acropora cervicornis	Branching	N/A	Spawners	tank & Bock Cay, Bahamas	Not specified	Epoxied to PVC plates & reefmounts	1–3	12 colonies	1997	% of coral living	8%-10%	N/A	Becker and Mueller, 2001
Acropora palmata	Branching	N/A	Spawners	tank & Bock Cay, Bahamas	Not specified	Epoxied to PVC plates & reef mounts	5.5	12 colonies	1997	% of coral living	8%-14%	N/A	Becker and Mueller, 2001
Acropora cervicornis	Branching	N/A	Spawners	Punta Cana region of the Dominican Republic	Reef flat	Transplants were attached using small plastic cable ties to 4" masonry nails and driven into reef substrate; or glued with epoxy and cement; to a nursery made of epoxy-coated wire mesh, metal poles, rods and rebar	3–4.5	25 fragments from 4 donor colonies	Not specified	Survival and retention rates of transplants to other sites	97.4% survival and an 85% retention rate.	N/A	Bowden-Kerby et al., in Johnson et al., 2011
Acropora palifera	Submassive species with thick branches	N/A	Brooder	Quezon, Philippines	Exposed & clear to sheltered & turbid	Silt, sand, rubble & live coral cemented onto substrate or attached to plastic screens with putty.	2–7	48 colonies	2000–2001	Growth and survival	Growth = 0.7 cm per quarter; 94% survival	N/A	Dizon & Yap, 2006
Astreopora micropthalma	Branching coral	N/A	Spawners	Pangasinan, Philippines	Exposed & clear to sheltered & turbid	Silt, sand, rubble & live coral cemented onto substrate or attached to plastic screens with putty.	2–5	51 colonies	2001–2002	Growth and survival	Growth = 1.7 cm per quarter; 8% survival	N/A	Dizon & Yap, 2006
Astreopora micropthalma	Branching coral	N/A	Spawners	Cangaluyan, Philippines	Exposed & clear to sheltered & turbid	Silt, sand, rubble & live coral cemented onto substrate or attached to plastic screens with putty.	2–5	51 colonies	2001–2002	Growth and survival	Growth = 1.7 cm per quarter; 8% survival	N/A	Dizon & Yap, 2006
Porites cylindrica	Branching	N/A	Spawners	Pangasinan, Philippines	Exposed & clear to sheltered & turbid	Silt, sand, rubble & live coral cemented onto substrate or attached to plastic screens with putty.	2–5	51 colonies	2001–2002	Growth and survival	Growth = 0.7 cm per quarter; 73% survival	N/A	Dizon & Yap, 2006
Porites cylindrica	Branching	N/A	Spawners	Cangaluyan, Philippines	Exposed & clear to sheltered & turbid	Silt, sand, rubble & live coral cemented onto substrate or attached to plastic screens with putty.	2–5	51 colonies	2001–2002	Growth and survival	Growth= 0.7 cm per quarter; 73% survival	N/A	Dizon & Yap, 2006

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/Nutrient Levels)	Substrate	Water depth (m)	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost data	Reference
Porites cylindrica	Branching	N/A	Spawners	Quezon, Philippines	Exposed & clear to sheltered & turbid	Silt, sand, rubble & live coral cemented onto substrate or attached to plastic screens with putty.	2–7	48 colonies	2000–2001	Growth and survival	growth= 0.6 cm per quarter; 83% survival	N/A	Dizon & Yap, 2006
Acropora yongei	Branching	N/A	Spawners	Bunaken National Park, Indonesia	Wide range of current conditions.	Terra cotta tiles installed in rubble fields of a former blast site.	6–10	140 nubbins, ~ 10 cm long with 204 radial branches. 82 nubbins were attached with wire to other pieces of rubble and were free to move in the current; 58 were attached to PVC pipe with wire and cable ties and were stabilized by being driven down to the level of the rubble.	1998–1999	Growth measured 6 and 12 months after transplantation ; natural recruitment.	65% survival of the stabilized nubbins; 3-20 spat per tile laid.	No	Fox, Pet, Dahuri, and Caldwell, 2003
Montipora digitata	Branching	N/A	Spawners	Bolinao, Northern Philippines	Lagoon area north of the Island of Santiago.	Fragments were glued using epoxy putty inside auger-made depressions in rock and gaps were filled with epoxy clay. There were 4 treatments: (1) low-horizontal (30 cm spacing between fragments planted horizontally); (2) low-vertical (30 cm spacing between fragments planted vertically); (3) high-horizontal (15 cm spacing between fragments planted horizontally); (4) high-vertical (15 cm spacing between fragments planted vertically). vertically).	1–2	960 healthy, loose fragments that were 5–10 cm in height with 2–3 branches or points of growth per fragment.	N/A	Survivorship and growth	Low-vertical and Low-horizontal had the lowest survival; High-horizontal and High-vertical had the best survival. After 21 months, only 71 of the 960 fragments were alive. Vertical growth for low density sites was between 3.8–8.2 mm/day and between 0.8–5.0 mm/day for high density sites. Radial growth at low density sites was between 2.3–4.8 mm/day and 0.6–2.4 mm/day for high density ones.	No	Gomez, Yap, Cabaitan, and Dizon, 2011

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/Nutrient Levels)	Substrate	Water Depth	# Of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Stylophora pistillata	Branching	N/A	Brooder	Lizard Island, Northern Great Barrier Reef, Australia	On two different bommies	Exposed & unexposed (to air) corals attached to freshly drilled and chiseled holes in the substratum sing an underwater epoxy.	Not specific	4 fragments 5–10 cm in maximum dimension	1994	% mortality; % bleaching and # of tips of branches	Unexposed corals attached using cement, not cable-ties, did the best.	Yes	Kaly, 1995
Pocillopora eydouxi	Branching	N/A	Not specified down to species level	Aua, Tutuila, America Samoa	Shallow reef flat ship grounding area	Natural coral blocks on the reef flat	Not specific	More than 300 corals transplanted into footprint of vessel grounding using Quick setting cement (Portland Type II cement to one part Molding Plaster)	2005	% survival	58–81% survival after 4 years	No	Kolinski, 2006
Pocillopora eydouxi	Branching	N/A	Not specified down to species level	Aua, Tutuila, America Samoa	Shallow reef flat ship grounding area	Region of coralline algae pavement near the reef crest	Not specific	More than 300 corals transplanted into footprint of vessel grounding using Quick setting cement (Portland Type II cement to one part Molding Plaster)	2005	% survival	58%–81% survival after 4 years	No	Kolinski, 2006
Antipathes dichotoma	Branching	N/A	Budding	Makena, Maui, Hawaii (Site D)	Deep water reef	Reef hole filled with epoxy (Z-Spar Splash Zone compound) that the fragment was inserted into; cable tie at glued to base of coral fragment acted as anchor.	25 m	10 fragments	2000	% survival; height	70% survival and a decreased in size by 9.63 cm in height due to skeletal breaking & epizoic growth.	No	Montgomery. 2002
Antipathes dichotoma	Branching	N/A	Budding	Kahuku, Hawaii (Site C)	Deep water reef	Reef hole filled with epoxy (Z-Spar Splash Zone compound) that the fragment was inserted into; cable tie at glued to base of coral fragment acted as anchor.	25 m	9 fragments	2000	% survival; height	44% survival and decreased in size by 8.7 cm in height due to skeletal breaking.	No	Montgomery, 2002

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation Of Success	Cost Data	Reference
Antipathes ulex	Branching	N/A	Budding	Makua, Oahu, Hawaii (Site A)	Deep water reef	Reef hole filled with epoxy (Z-Spar Splash Zone compound) that the fragment was inserted into; cable tie at glued to base of coral fragment acted as anchor.	45.7 m	1 colony	2000	% survival; height	0% growth; 0% survival; died in 1999 showing signs of pinnulation.	No	Montgomery, 2002
Porites porites	Branching	N/A	Spawner	Broward County, Florida	Coral of opportunity were taken from the offshore Reefs of Broward County, FL	Transplanted to nurseries composed of Warren & DERM modules within the inner reef patch of Broward County on sand substrate using Portland Type II cement.	13 m	6 (5–40 cm in length)	2001	# of survivors	6	No	Monty et al., 2006
Acropora palmata	Branching	N/A	Spawners	Vera Cruz, Mexico	Reef lagoon, shallow, limited wave action, with donor colony nearby.	Fixed nursery made of PVC and PET connectors to which transplants are attached by cement.	3–6 m	3600 corals	2008	Survivorship of outplants	85% after 3 years	N/A	Nava-Martinez et al., in Johnson et al., 2011
Acropora tenuis	Branching	N/A	Spawner	Akajima Marine Science Laboratory, Okinawa, Japan	Bommies	Bommies	?	2,000 clusters of colonies were transplanted using epoxy cement and concrete nails.	2006	% survival; growth	89% colonies survived after 6 months and after 3 years, the colonies grew in size to 15–20 cm.	No	Omori, 2008
Acropora echinata	Branching	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site A, western corner	3-6 cm nubbins glued to terra cotta bricks with epoxy and placed on rubble and sand-veneered reef rock substrate	1–2 m	8 nubbins/brick, 2 bricks, 16 nubbins total	1981–1982	Survival, growth	81.2% survival; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/Nutrient Levels)	Substrate	Water Depth	# Of Colonies Transplanted/Rametes Settled	Year	Study Metric of success	Quantitation of success	Cost data	Reference
Acropora echinata	Branching	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site B, eastern corner	3–6 cm nubbins glued to terra cotta bricks with epoxy and placed on rubble and sand-floored depression on surface of small patch reef	3–5 m	8 nubbins/brick, 2 bricks, 16 nubbins total	1981–1982	Survival, growth	25.0% survival; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987
Acropora echinata	Branching	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site C, northern corner	3–6 cm nubbins glued to terra cotta bricks with epoxy and placed on upper surface of coral rubble mound	10–22 m	8 nubbins/brick, 2 bricks, 16 nubbins total	1981–1982	Survival, growth	75.0% survival; mean growth = 0.64 mm (s.d. = 0.28 mm)	No	Plucer-Rosario and Randall, 1987
Acropora echinata	Branching	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site A, reef slope along south side of bay	3–6 cm nubbins glued to terra cotta bricks with epoxy and placed on rubble and sand substrate	1–2 m	8 nubbins/brick, 2 bricks, 16 nubbins total	1981–1982	Survival, growth	81.2% survival; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987
Acropora echinata	Branching	N/a	Spawners	Guam, Marianas Islands	Cetti Bay, Site B, reef slope along south side of bay	3–6 cm nubbins glued to terra cotta bricks with epoxy and placed on rubble and sand substrate	3–5 m	8 nubbins/brick, 2 bricks, 16 nubbins total	1981–1982	Survival, growth	12.5% survival; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987
Acropora echinata	Branching	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Cite C, reef slope along south side of bay	3–6 cm nubbins glued to terra cotta bricks with epoxy and placed on coral rubble substrate	10–22 m	8 nubbins/brick, 2 bricks, 16 nubbins total	1981–1982	Survival, growth	37.5% survival; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987
Pocillopora damicornis	Branching	N/A	Brooder	Silliman University Marine Laboratory/ Bantayan Reef, Philippines	Reef conditions not specified; tank conditions: 24–30 °C, salinity constant at 35‰ (water circulated directly from reef)	Planulae collected in laboratory and seeded onto seasoned, roughened marine limestone commercial tiles; laboratory-reared colonies sorted by size class and transplanted onto reef using epoxy	4 m	80 colonies per cohort, n = 3 recipient sites	1997–1999	Survival, growth, reproduction	Colony size class <3 mm: 0% survival at one year, see Figure 1	No	Raymundo and Maypa, 2004

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/Nutrient Levels)	Substrate	Water Depth	# Of Colonies Transplanted/Rametes Settled	Year	Study Metric of success	Quantitation of success	Cost data	Reference
Pocillopora damicornis	Branching	N/A	Brooder	Silliman University Marine Laboratory/ Bantayan Reef, Philippines	Reef conditions not specified; tank conditions: 24–30 °C, salinity constant at 35‰ (water circulated directly from reef)	Planulae collected in laboratory and seeded onto seasoned, roughened marine limestone commercial tiles; laboratory-reared colonies sorted by size class and transplanted onto reef using epoxy	4 m	80 colonies per cohort, n = 3 recipient sites	1997–1999	Survival, growth, reproduction	Colony size class 3-6 mm: 2.5% survival at one year, see figure 1	No	Raymundo and Maypa, 2004
Pocillopora damicornis	Branching	N/A	Brooder	Silliman University Marine Laboratory /Bantayan Reef, Philippines	Reef conditions not specified; tank conditions: 24–30 °C, salinity constant at 35‰ (water circulated directly from reef)	Planulae collected in laboratory and seeded onto seasoned, roughened marine limestone commercial tiles; laboratory-reared colonies sorted by size class and transplanted onto reef using epoxy	4 m	80 colonies per cohort, n = 3 recipient sites	1997–1999	Survival, growth, reproduction	Colony size class 6.1-10 mm: 16.3% survival at one year, see figure 1	No	Raymundo and Maypa, 2004
Pocillopora damicornis	Branching	N/A	Brooder	Silliman University Marine Laboratory/ Bantayan Reef, Philippines	Reef conditions not specified; tank conditions: 24-30 °C, salinity constant at 35‰ (water circulated directly from reef)	Planulae collected in laboratory and seeded onto seasoned, roughened marine limestone commercial tiles; laboratory-reared colonies sorted by size class and transplanted onto reef using epoxy	4 m	80 colonies per cohort, n = 3 recipient sites	1997–1999	Survival, growth, reproduction	Colony size class 10.1-25 mm: 47.5% survival at one year, see figure 1	No	Raymundo and Maypa, 2004

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/Nutrient Levels)	Substrate	Water depth	# of colonies transplanted/rametes settled	Year	Study Metric of success	Quantitation of success	Cost data	Reference
Herpolitha limax	Strongly elongate colonies with rounded ends	N/A	Broadcast spawner	Bora Bora lagoon at Matira's Point, French Polynesia	Shallow lagoon with high hydrodynamic energy, low turbidity, strong light	Glued to irregularly-shaped concrete blocks (2, 10 and 17 tonnes in weight; arranged singly or in groups of 2, 3 or 4) on sand-filled, previously-dredged reef flat areas	2–3 m	1 colony	1999–2003	Survival and growth	100% survival through 2001; 0% survival following localized phytoplankton bloom and subsequent anoxia (early 2002) combined with widespread coral reef bleaching episode (mid 2002)	Yes (estimated total only)	Schrimm et al., 2006
Pocillopora damicornis	Branching	N/A	Brooder	Bora Bora lagoon at Matira's Point, French Polynesia	Shallow lagoon with high hydrodynamic energy, low turbidity, strong light	Glued to irregularly-shaped concrete blocks (2, 10 and 17 tonnes in weight; arranged singly or in groups of 2, 3 or 4) on sand-filled, previously-dredged reef flat areas	2–3 m	13 colonies	1999–2003	Survival and growth	85% survival through 2001, natural recruitment recorded (19 colonies); 0% survival following localized phytoplankton bloom and subsequent anoxia (early 2002) combined with widespread coral reef bleaching episode (mid 2002)	Yes (estimated total only)	Schrimm et al., 2006
Pocillopora verrucosa	Branching	N/A	Brooder	Bora Bora lagoon at Matira's Point, French Polynesia	Shallow lagoon with high hydrodynamic energy, low turbidity, strong light	Glued to irregularly-shaped concrete blocks (2, 10 and 17 tonnes in weight; arranged singly or in groups of 2, 3 or 4) on sand-filled, previously-dredged reef flat areas	2–3 m	11 colonies	1999–2003	Survival and growth	82% survival through 2001; 0% survival following localized phytoplankton bloom and subsequent anoxia (early 2002) combined with widespread coral reef bleaching episode (mid 2002)	Yes (estimated total only)	Schrimm et al., 2006

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/Nutrient Levels)	Substrate	Water depth	# of colonies transplanted/rametes settled	Year	Study Metric of success	Quantitation of success	Cost data	Reference
Acropora gemmifera	Bushy shape with branching	N/A	Spawners	Ofu Island, National Park of American Samoa	Pool 300 has higher temperature, lower salinity, is smaller and shallower than Pool 400	Epoxied to a wire-brushing horizontal dead coral substrate in the reef flat/rubble area exposed to southeast Trade Winds.	1.0-m low tide depth	28 transplants	2004–2006	Survival and growth	75% survival	N/A	Smith, Wirshing, Baker, and Brkeland, 2007
Pocillopora damicornis	Branching	Yes	Brooder	Ofu Island, National Park of American Samoa	Pool 300 has higher temperature, lower salinity, is smaller and shallower than Pool 400	Epoxied to a wire-brushing horizontal dead coral substrate in the reef flat/rubble area exposed to southeast Trade Winds.	1.0-m low tide depth	28 transplants	2004–2006	Survival and growth	0% survival and 0 growth, due to being wiped out by asymmetric predation.	N/A	Smith et al., 2007
Pocillopora eydouxi	Branching	Zooxanthellae genotypes of C1c, C42,D,D1a in Pool 300 and C1c in pool 400	Spawners	Ofu Island, National Park of American Samoa	Pool 300 has higher temperature, lower salinity, is smaller and shallower than Pool 400	Epoxied to a wire-brushing horizontal dead coral substrate in the reef flat/rubble area exposed to southeast Trade Winds.	1.0-m low tide depth	28 transplants	2004–2006	Survival and growth	96.4% survival; mean linear extension of 37.2 mm for Pool 300 and 22.4 mm for Pool 400; Skeletal mass and linear extension were both affected by transplant site not source population.	N/A	Smith et al., 2007
Porites cyclindrica	Bushy shape with branching	N/A	Spawners	Ofu Island, National Park of American Samoa	Pool 300 has higher temperature, lower salinity, is smaller and shallower than Pool 400	Epoxied to a wire-brushing horizontal dead coral substrate in the reef flat/rubble area exposed to southeast Trade Winds.	1.0-m low tide depth	28 transplants	2004–2006	Survival and growth	50% survival	N/A	Smith et al., 2007
Pocillipora damicornis	Branching	N/A	Brooder	Backreef of Cangaluyan Island, Pangasinan, Philippines		Epoxied to cleared rock	1 m	30 transplants 74 cm^2 in projected area)	1983	Growth & mortality	0.1 to 22.9 cm^2 per month growth rate; medium mortality.	No	Yap et al., 1992

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# Of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Echinopora gemmacea	Massive, sometimes forming contorted branches	N/A	Spawners	North Coral Gardens, Mombosa, Africa	Strong tidal currents	Epoxied to coral skeleton or epoxied to slightly elevated racks	1.0 meter at mean low water	5 colonies	Not specified	Growth and survivorship	Growth was 0.0015 mm^2 mm^{-2} day-1 on racks and -0.0005 mm^2 mm^{-2} day^{-1} on natural substrate; 56% survivorship on natural substrate and 42% survivorship on racks.	Yes	Tamelander and Obura, 2002
Goniopora sp.	Massive with tentacles	N/A	Spawners	North Coral Gardens, Mombosa, Africa	Strong tidal currents	Epoxied to coral skeleton or epoxied to slightly elevated racks	1.0 m at mean low water	5 colonies	Not specified	Growth and survivorship	Growth was 0.0015 mm^2 mm^{-2} day^{-1} on racks and -0.0005 mm^2 mm^{-2} day^{-1} on natural substrate; 56% survivorship on natural substrate and 42% survivorship on racks.	Yes	Tamelander & Obura, 2002
Porites harrisoni	Massive with columns	N/A	Brooder	North Coral Gardens, Mombosa, Africa	Strong tidal currents	Epoxied to coral skeleton or epoxied to slightly elevated racks	1.0 m at mean low water	5 colonies	Not specified	Growth and survivorship	Growth was 0.0015 mm^2 mm^{-2} day^{-1} on racks and -0.0005 mm^2 mm^{-2} day-1 on natural substrate; 56% survivorship on natural substrate and 42% survivorship on racks.	Yes	Tamelander & Obura, 2002
Porites lutea	Massive with branches	N/A	Brooder	North Coral Gardens, Mombosa, Africa	Strong tidal currents	Epoxied to coral skeleton or epoxied to slightly elevated racks	1.0 m at mean low water	5 colonies	Not specified	Growth and survivorship	Growth was 0.0015 mm^2 mm^{-2} day^{-1} on racks and -0.0005 mm^2 mm^{-2} day^{-1} on natural substrate; 56% survivorship on natural substrate and 42% survivorship on racks.	Yes	Tamelander and Obura, 2002

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies (continued

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Porites nigrescens	Massive with branches	N/A	Brooder	North Coral Gardens, Mombosa, Africa	Strong tidal currents	Epoxied to coral skeleton or epoxied to slightly elevated racks	1.0 m at mean low water	5 colonies	not specified	Growth and survivorship	Growth was 0.0015 mm^2 mm^{-2} day^{-1} on racks and -0.0005 mm^2 mm^{-2} day^{-1} on natural substrate; 56% survivorship on natural substrate and 42% survivorship on racks.	Yes	Tamelander and Obura, 2002
Acropora hyacinthus	Massive with columns	N/A	Spawners	Backreef of Cangaluyan Island, Pangasinan, Philippines		Epoxied to cleared rock	1 m	30 transplants (115 cm^2 in projected area)	1983	Growth & mortality	0 to 31.9 cm^2 per month growth rate; high mortality.	No	Yap et al., 1992
Echinopora lamellosa	Foliose coral	N/A	Spawners	Pangasinan, Philippines	Exposed & clear to sheltered & turbid	Silt, sand, rubble & live coral cemented onto substrate or attached to plastic screens with putty.	2–5 meters	51 colonies	2001–2002	Growth and survival	Growth = 1.6 cm per quarter; 14% survival	N/A	Dizon & Yap, 2006
Echinopora lamellosa	Foliose coral	N/A	Spawners	Cangaluyan, Philippines	Exposed & clear to sheltered & turbid	Silt, sand, rubble & live coral cemented onto substrate or attached to plastic screens with putty.	2–5 m	51 colonies	2001–2002	Growth and survival	Growth= 1.6 cm per quarter; 14% survival	N/A	Dizon & Yap, 2006
Porites lobata	Massive form	N/A	Spawners	Quezon, Philippines	Exposed & clear to sheltered & turbid	Silt, sand, rubble & live coral cemented onto substrate or attached to plastic screens with putty.	2–7 m	72 colonies	2000–2001	Growth and survival	Growth = 0.3 cm per quarter; 85% survival	N/A	Dizon & Yap, 2006
Favia stelligera	Massive	N/A	Spawner	Lizard Island, Northern Great Barrier Reef, Australia	On 2 different bommies	Exposed & unexposed (to air) corals attached with cable ties to masonry nails that were hammered into the substrate.	Not specific	4 fragments 5–10 cm in maximum dimension	1994	% mortality; % bleaching and # of tips of branches	All methods did equally as well.	Yes	Kaly, 1995

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of colonies Transplanted/ Rametes Settled	Year	Study Metric of success	Quantitation of Success	Cost Data	Reference
Favia stelligera	Massive	N/A	Spawner	Lizard Island, Northern Great Barrier Reef, Australia	On 2 different bommies	Exposed & unexposed (to air) corals attached to freshly drilled and chiseled holes in the substratum sing an underwater epoxy.	Not specific	4 fragments 5–10 cm in maximum dimension	1994	% mortality; % bleaching and # of tips of branches	All methods did equally as good.	Yes	Kaly, 1995
Porites sp.	Lobate	N/A	Not specified down to species level	Aua, Tutuila, America Samoa	Shallow reef flat ship grounding area	Natural coral blocks on the reef flat	Not specific	Over 300 corals transplanted into footprint of vessel grounding using quick setting cement (Portland Type II cement to one part molding plaster)	2005	% survival	86%–95% survival after 4 years	No	Kolinski, 2006
Porites sp.	Lobate	N/A	Not specified down to species level	Aua, Tutuila, America Samoa	Shallow reef flat ship grounding area	Region of coralline algae pavement near the reef crest	Not specific	Over 300 corals transplanted into footprint of vessel grounding using quick setting cement (Portland Type II cement to one part molding plaster)	2005	% survival	86%–95% survival after 4 years	No	Kolinski, 2006
Colpophyllia natans	Lobate	N/A	Broadcast spawner	Broward County, Florida	Coral of opportunity were taken from the offshore reefs of Broward County, FL	Transplanted to nurseries composed of Warren & DERM modules within the inner reef patch of Broward County on sand substrate using Portland Type II cement.	13 m	6 (5–40 cm in length)	2001	# of survivors	5	No	Monty et al., 2006
Dichocoenia stokesii	Large domes	N/A	Broadcast spawner	Broward County, Florida	Coral of opportunity were taken from the offshore reefs of Broward County, FL	Transplanted to nurseries composed of Warren & DERM modules within the inner reef patch of Broward County on sand substrate using Portland Type II cement.	13 m	12 (5–40 cm in length)	2001	# of survivors	8	No	Monty et al., 2006

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Montastrea cavernosa	Loabte	N/A	Spawner	Broward County, Florida	Coral of opportunity were taken from the offshore reefs of Broward County, FL	Transplanted to nurseries composed of Warren & DERM modules within the inner reef patch of Broward County on sand substrate using Portland Type II cement.	13 m	42 (5–40 cm in length)	2001	# of survivors	42	No	Monty et al., 2006
Poites asteroides	Large domes	N/A	Spawner	Broward County, Florida	Coral of opportunity were taken from the offshore reefs of Broward County, FL	Transplanted to nurseries composed of Warren & DERM modules within the inner reef patch of Broward County on sand substrate using Portland Type II cement.	13 m	11 (5–40 cm in length)	2001	# of survivors	11	No	Monty et al., 2006
Siderastrea siderea	Lobate	N/A	Spawner	Broward County, Florida	Coral of opportunity were taken from the offshore reefs of Broward County, FL	Transplanted to nurseries composed of Warren & DERM modules within the inner reef patch of Broward County on sand substrate using Portland Type II cement.	13 m	78 (5–40 cm in length)	2001	# of survivors	78	No	Monty et al., 2006
Colpophyllia natans	Large smooth domes	N/A	Broadcast spawner	Enrique Reef, La Parguera, Puerto Rico	Not specified; storm surge due to Hurricane Georges (September 1998) encountered	Glued (5:1 Portland cement/ molding plaster with ~ 3 parts water) to upper surface of dead coral head	10–15 ft	2 small (< 20 cm diameter) colonies	1998–1999	Survival, attachment	50% survival at one year, none lost (detached)	No	Ortiz-Prosper et al., 2001
Colpophyllia natans	Large smooth domes	N/A	Broadcast spawner	Mario Reef, La Parguera, Puerto Rico	Not specified; storm surge due to Hurricane Georges (September 1998) encountered	Glued (5:1 Portland cement/ molding plaster with ~ 3 parts water) to upper surface of dead coral head	10–15 ft	2 small (< 20 cm diameter) colonies	1998–1999	Survival, attachment	100% survival at one year, none lost (detached)	No	Ortiz-Prosper et al., 2001

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Diploria strigosa	Massive	N/A	Broadcast spawner	Mario Reef, La Parguera, Puerto Rico	Not specified; storm surge due to Hurricane Georges (September 1998) encountered	Glued (5:1 Portland cement/ molding plaster with ~ 3 parts water) to upper surface of dead coral head	10–15 ft	4 small (< 20 cm diameter) colonies	1998–1999	Survival, attachment	75% survival at one year, none lost (detached)	No	Ortiz-Prosper et al., 2001
Monastrea annularis	Massive mounds, tiers of irregularly bumpy mounds and plates, thick columns, or smooth plates	N/A	Broadcast spawner	Enrique Reef, La Parguera, Puerto Rico	Not specified; storm surge due to Hurricane Georges (September 1998) encountered	Glued (5:1 Portland cement/ molding plaster with ~ 3 parts water) to upper surface of dead coral head	10–15 ft	4 small (< 20 cm diameter) colonies	1998–1999	Survival, attachment	100% survival at one year, none lost (detached)	No	Ortiz-Prosper et al., 2001
Monastrea annularis	Massive mounds, tiers of irregularly bumpy mounds and plates, thick columns, or smooth plates	N/A	Broadcast spawner	Mario Reef, La Parguera, Puerto Rico	Not specified; storm surge due to Hurricane Georges (September 1998) encountered	Glued (5:1 Portland cement/ molding plaster with ~ 3 parts water) to upper surface of dead coral head	10–15 ft	4 small (< 20 cm diameter) colonies	1998–1999	Survival, attachment	100% survival at one year, none lost (detached)	No	Ortiz-Prosper et al., 2001
Poites rus	Massive plates	N/A	Spawners	Sumay Seamount, Apra Harbor (inner channel dredge site)	Anchor damage and algae overgrowth	Epoxied to the existing rubble	15–30 m	10 fragments	2008	Survival and growth	93.3% survival after 18 months and 0.8 mm of growth /month	N/A	Rojas, Raymundo, and Myers, 2008
Porites cylindrica	Massive form (can grow in columns)	N/A	Spawners	Sumay Seamount, Apra Harbor (inner channel dredge site)	Anchor damage and algae overgrowth	Epoxied to the existing rubble	15–30 m	10 fragments	2008	Survival and growth	23.3% survival after 18 months and 0.07 mm of growth /month	N/A	Rojas, Raymundo, and Myers, 2008
Porites (Synarea) rus	Large colonies of small plates and branches	N/A	Spawners	Bora Bora lagoon at Matira's Point, French Polynesia	Shallow lagoon with high hydrodynamic energy, low turbidity, strong light	Glued to irregularly-shaped concrete blocks (2, 10 and 17 tonnes in weight; arranged singly or in groups of 2, 3 or 4) on sand-filled, previously dredged reef flat areas	2–3 m	23 colonies	1999–2003	Survival and growth	87% survival through 2001; 4% survival following localized phytoplankton bloom and subsequent anoxia (early 2002) combined with widespread coral reef bleaching episode (mid 2002)	Yes (estimated total only)	Schrimm et al., 2006

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Porites lobata	Massive	Zooxanthellae genotypes of C15 in both Pool 300 and Pool 400	Spawners	Ofu Island, National Park of American Samoa	Pool 300 has higher temperature, lower salinity, is smaller and shallower than Pool 400	Epoxied to a wire-brushing horizontal dead coral substrate in the reef flat/rubble area exposed to southeast Trade Winds.	1.0-m low tide depth	48 transplants	2004–2006	Survival and growth	58.3% survival; mean linear extension of 14.3 mm for pool 300 and 14.8 mm for pool 400; neither skeletal mass nor linear extension was affected by transplant site, source population or source colony.	N/A	Smith et al., 2007
Hydnophora micronos	Massive	N/A	Spawners	North Coral Gardens, Mombosa, Africa	Strong tidal currents	Epoxied to coral skeleton or epoxied to slightly elevated racks	1.0 m at mean low water	5 colonies	Not specified	Growth and survivorship	Growth was 0.0015 mm^2 mm^{-2} day^{-1} on racks and -0.0005 mm^2 mm^{-2} day^{-1} on natural substrate; 56% survivorship on natural substrate and 42% survivorship on racks.	Yes	Tamelander & Obura, 2002
Pavona decussata	Massive (forming plates)	N/A	Spawners	North Coral Gardens, Mombosa, Africa	Strong tidal currents	Epoxied to coral skeleton or epoxied to slightly elevated racks	1.0 meter at mean low water	5 colonies	Not specified	Growth and survivorship	Growth was 0.0015 mm^2 mm^{-2} day^{-1} on racks and -0.0005 mm^2 mm-2 day^{-1} on natural substrate; 56% survivorship on natural substrate and 42% survivorship on racks.	Yes	Tamelander and Obura, 2002

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Dichocoenia stokesii	Large domes or submassive plates	N/A	Broadcast spawner	North Dade County, Florida	Exposed & clear	Cemented (50/50 Portland cement/ molding plaster) to WWTP outfall pipe concrete block "armor" sections	13–18 m	6 colonies	1997–1999	Survival and growth	67% colony survival after 27 months (33% mortality, none missing); 2.86 (±1.30) mm mean radius increase/ year (n=3); 5.33 (±1.16) cm^2 mean surface area increase/ year (n=3)	No	Thornton et al., 2000
Diploria labyrinthiformis	Massive	N/A	Brooder	North Dade County, Florida	Exposed & clear	Cemented (50/50 Portland cement/ molding plaster) to WWTP outfall pipe concrete block "armor" sections	13–18 m	2 colonies	1997–1999	Survival and growth	100% colony survival after 27 months (0% mortality, none missing); 2.36 mm mean radius increase/ year (n=1); 9.96 cm^2 mean surface area increase/ year (n=1)	No	Thornton et al., 2000
Diploria strigosa	Massive	N/A	Broadcast spawner	North Dade County, Florida	Exposed & clear	Cemented (50/50 Portland cement/ molding plaster) to WWTP outfall pipe concrete block "armor" sections	13–18 m	4 colonies	1997–1999	Survival and growth	100% colony survival after 27 months (0% mortality, none missing); 7.59 (± 3.49) mm mean radius increase/ year (n=2); 40.70 (± 37.45) cm^2 mean surface area increase/ year (n=2)	No	Thornton et al., 2000
Meandrina meandrites	Large domes or flat plates	N/A	Brooder	North Dade County, Florida	Exposed & clear	Cemented (50/50 Portland cement/ molding plaster) to WWTP outfall pipe concrete block "armor" sections	13–18 m	1 colony	1997–1999	Survival and growth	0% colony survival after 27 months (0% mortality, 100% missing)	No	Thornton et al., 2000

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Montastrea annularis	Large domes (massive), flat plates or irregular low columns (bumpy)	N/A	Broadcast spawner	North Dade County, Florida	Exposed & clear	Cemented (50/50 Portland cement/ molding plaster) to WWTP outfall pipe concrete block "armor" sections	13–18 meters	1 colony	1997–1999	Survival and growth	100% colony survival after 27 months (0% mortality, none missing); 3.30 mm mean radius increase/ year (n=1); 11.08 cm^2 mean surface area increase/ year (n=1)	No	Thornton et al., 2000
Montastrea cavernosa	Large domes	N/A	Broadcast spawner	North Dade County, Florida	Exposed & clear	Cemented (50/50 Portland cement/ molding plaster) to WWTP outfall pipe concrete block "armor" sections	13–18 meters	7 colonies	1997–1999	Survival and growth	86% colony survival after 27 months (14% mortality, none missing);4.53 (± 2.47) mm mean radius increase/year (n=5); 10.27 (± 6.53) cm^2 mean surface area increase	No	Thornton et al., 2000
Siderasterea siderea	Large smooth domes	N/A	Broadcast spawner	North Dade County, Florida	Exposed & clear	Cemented (50/50 Portland cement/ molding plaster) to WWTP outfall pipe concrete block "armor" sections	13–18 meters	129 colonies	1997–1999	Survival and growth	90% colony survival after 27 months (7% mortality, 3% missing); 2.37 (±1.54) mm mean radius increase/ year (n=69); 4.30 (±4.17) cm^2 mean surface area increase/ year (n=69)	No	

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Stephanocoenia michelinii	Low domes or encrusting	N/A	Broadcast spawner	North Dade County, Florida	Exposed & clear	Cemented (50/50 Portland cement/ molding plaster) to WWTP outfall pipe concrete block "armor" sections	13–18 m	15 colonies	1997–1999	Survival and growth	93% colony survival after 27 months (0% mortality, 7% missing); 2.55 (±1.56) mm mean radius increase/year (n=9); 4.69 (±2.73) cm^2 mean surface area increase/ year (n=9)	No	Thornton et al., 2000
Pavona frondifera	Massive	N/A	Spawners	backreef of Cangaluyan Island, Pangasinan, Philippines		Epoxied to cleared rock	1 m	30 transplants (89 cm^2 in projected area)	1983	Growth & mortality	5.7 to 39.7 cm^2 per month growth rate; no mortality	No	Yap et al., 1992
Agaricia agaricites	Plate-like in shallow water, lumpy domes in deeper water	N/A	Brooder	Broward County, Florida	Coral of opportunity were taken from the offshore reefs of Broward County, FL	Transplanted to nurseries composed of Warren & DERM modules within the inner reef patch of Broward County on sand substrate using Portland Type II cement.	13 m	2 (5–40 cm in length)	2001	# of survivors	2	No	Monty et al., 2006
Echinopora lamellosa	Plate-like in shallow water, lumpy domes in deeper water	N/A	Spawner	Lizard Island, Northern Great Barrier Reef, Australia	On 2 different bommies	Exposed & unexposed (to air) corals attached with cable ties to masonry nails that were hammered into the substrate.	Not specific	4 fragments 5–0 cm in maximum dimension	1994	% Mortality; % bleaching and # of tips of branches	Did the worst	Yes	Kaly, 1995

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Echinopora lamellosa	Plate-like in shallow water, lumpy domes in deeper water	N/A	Spawner	Lizard Island, Northern Great Barrier Reef, Australia	On 2 different bommies	Exposed & unexposed (to air) corals attached to freshly drilled and chiseled holes in the substratum sing an underwater epoxy.	Not specific	4 fragments 5–10 cm in maximum dimension	1994	% mortality; % bleaching and # of tips of branches	Unexposed corals attached using cement, not cable-ties, did the best.	Yes	Kaly, 1995
Diplora strigosa	Mound/plate-like	N/A	Broadcast spawner	Broward County, Florida	Coral of opportunity were taken from the offshore reefs of Broward County, FL	Transplanted to nurseries composed of Warren & DERM modules within the inner reef patch of Broward County on sand substrate using Portland Type II cement.	13 m	2 (5–40 cm in length)	2001	# of survivors	2	No	Monty et al., 2006
Eusmilia fastigiata	Mound	N/A	Spawner	Broward County, Florida	Coral of opportunity were taken from the offshore reefs of Broward County, FL	Transplanted to nurseries composed of Warren & DERM modules within the inner reef patch of Broward County on sand substrate using Portland Type II cement.	13 m	3 (5–40 cm in length)	2001	# of survivors	2	No	Monty et al., 2006
Montastrea faveolata	Plate-like in shallow water, lumpy domes in deeper water	N/A	Spawner	Broward County, Florida	Coral of opportunity were taken from the offshore reefs of Broward County, FL	Transplanted to nurseries composed of Warren & DERM modules within the inner reef patch of Broward County on sand substrate using Portland Type II cement.	13 m	5 (5–40 cm in length)	2001	# of survivors	4	No	Monty et al., 2006

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Solenastrea bournoni	Plate-like in shallow water, lumpy domes in deeper water	N/AA	Spawner	Broward County, Florida	Coral of opportunity were taken from the offshore reefs of Broward County, FL	Transplanted to nurseries composed of Warren & DERM modules within the inner reef patch of Broward County on sand substrate using Portland Type II cement.	13 m	26 5–40 cm in length	2001	# of survivors	26	No	Monty et al., 2006
Siderasterea sidereal	Plate-like in shallow water, lumpy domes in deeper water	N/a	Spawner	Broward County, Florida	Coral of opportunity were taken from the offshore reefs of Broward County, FL	Transplanted to nurseries composed of Warren & DERM modules within the inner reef patch of Broward County on sand substrate using Portland Type II cement.	13 m	21 (5–40 cm in length)	2001	# of survivors	20	No	Monty et al., 2006
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	NA	Not determined	Guam, Marianas Islands	Cocos Lagoon, Site A, western corner	3–6 cm nubbins glued to terra cotta bricks with epoxy and placed on rubble and sand-veneered reef rock substrate	1–2 m	8 nubbins/brick, 7 bricks, 56 nubbins total	1981–1982	Survival, growth	0% survival; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cocos Lagoon, Site B, eastern corner	3–6 cm nubbins glued to terra cotta bricks with epoxy and placed on rubble and sand-floored depression on surface of small patch reef	3–5 m	8 nubbins/brick, 7 bricks, 56 nubbins total	1981–1982	Survival, growth	0% survival; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cocos Lagoon, Site C, northern corner	3–6 cm nubbins glued to terra cotta bricks with epoxy and placed on upper surface of coral rubble mound	10–22 m	8 nubbins/brick, 7 bricks, 56 nubbins total	1981–1982	Survival, growth	21.4% survival; mean growth = 0.81 mm (s.d. = 0.03 mm)	No	Plucer-Rosario and Randall, 1987

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cetti Bay, Site A, reef slope along south side of bay	3–6 cm nubbins glued to terra cotta bricks with epoxy and placed on rubble and sand substrate	1-2 m	8 nubbins/brick, 7 bricks, 56 nubbins total	1981–1982	Survival, growth	14.2% survival; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cetti Bay, Site B, reef slope along south side of bay	3–6 cm nubbins glued to terra cotta bricks with epoxy and placed on rubble and sand substrate	3-5 m	8 nubbins/brick, 7 bricks, 56 nubbins total	1981–1982	Survival, growth	10.7% survival; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cetti Bay, Cite C, reef slope along south side of bay	3–6 cm nubbins glued to terra cotta bricks with epoxy and placed on coral rubble substrate	10-22 m	8 nubbins/brick, 7 bricks, 56 nubbins total	1981–1982	Survival, growth	12.5% survival; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site A, western corner	3–6 cm nubbins glued to terra cotta bricks with epoxy and placed on rubble and sand-veneered reef rock substrate	1-2 m	8 nubbins/brick, 7 bricks, 56 nubbins total	1981–1982	Survival, growth	0% survival; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site B, eastern corner	3–6 cm nubbins glued to terra cotta bricks with epoxy and placed on rubble and sand-floored depression on surface of small patch reef	3–5 m	8 nubbins/brick, 7 bricks, 56 nubbins total	1981–1982	Survival, growth	9.6% survival; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site C, northern corner	3–6 cm nubbins glued to terra cotta bricks with epoxy and placed on upper surface of coral rubble mound	10–22 m	8 nubbins/brick, 7 bricks, 56 nubbins total	1981–1982	Survival, growth	32.1% survival; mean growth = 0.5. mm (s.d. = 2.1 mm)	No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site A, reef slope along south side of bay	3–6 cm nubbins glued to terra cotta bricks with epoxy and placed on rubble and sand substrate	1–2 m	8 nubbins/brick, 7 bricks, 56 nubbins total	1981–1982	Survival, growth	1.8% survival; mean growth = 0.35 mm (s.d. = 0.10 mm)	No	Plucer-Rosario and Randall, 1987

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site B, reef slope along south side of bay	3–6 cm nubbins glued to terra cotta bricks with epoxy and placed on rubble and sand substrate	3–5 m	8 nubbins/brick, 7 bricks, 56 nubbins total	1981–1982	Survival, growth	8.1% survival; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Cite C, reef slope along south side of bay	3–6 cm nubbins glued to terra cotta bricks with epoxy and placed on coral rubble substrate	10–22 m	8 nubbins/brick, 7 bricks, 56 nubbins total	1981–1982	Survival, growth	0% survival; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site A, western corner	3–6 cm nubbins glued to terra cotta bricks with epoxy and placed on rubble and sand-veneered reef rock substrate	1–2 m	8 nubbins/brick, 7 bricks, 56 nubbins total	1981–1982	Survival, growth	64.2% survival; mean growth = 1.35 mm (s.d. = 0.85 mm)	No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site B, eastern corner	3–6 cm nubbins glued to terra cotta bricks with epoxy and placed on rubble and sand-floored depression on surface of small patch reef	3–5 m	8 nubbins/brick, 7 bricks, 56 nubbins total	1981–1982	Survival, growth	53.5% survival; mean growth = 1.48 mm (s.d. = 0.88 mm)	No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site C, northern corner	3–6 cm nubbins glued to terra cotta bricks with epoxy and placed on upper surface of coral rubble mound	10–22 me	8 nubbins/brick, 7 bricks, 56 nubbins total	1981–1982	Survival, growth	98.2% survival; mean growth = 1.29 mm (s.d. = 0.40 mm)	No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site A, reef slope along south side of bay	3–6 cm nubbins glued to terra cotta bricks with epoxy and placed on rubble and sand substrate	1–2 m	8 nubbins/brick, 7 bricks, 56 nubbins total	1981–1982	Survival, growth	14.2% survival; mean growth = 0.78 mm (s.d. = 0.38 mm)	No	Plucer-Rosario and Randall, 1987

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site B, reef slope along south side of bay	3–6 cm nubbins glued to terra cotta bricks with epoxy and placed on rubble and sand substrate	3–5 m	8 nubbins/brick, 7 bricks, 56 nubbins total	1981–1982	Survival, growth	37.5% survival; mean growth = 0.50 mm (s.d. = 0.36 mm)	No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Cite C, reef slope along south side of bay	3–6 cm nubbins glued to terra cotta bricks with epoxy and placed on coral rubble substrate	10–22 m	8 nubbins/brick, 7 bricks, 56 nubbins total	1981–1982	Survival, growth	57.0% survival; mean growth = 1.29 mm (s.d. = 0.40 mm)	No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Broadcast spawner	Bora Bora lagoon at Matira's Point, French Polynesia	Shallow lagoon with high hydrodynamic energy, low turbidity, strong light	Glued to irregularly-shaped concrete blocks (2, 10 and 17 tonnes in weight; arranged singly or in groups of 2, 3 or 4) on sand-filled, previously-dredged reef flat areas	2–3 m	74 colonies	1999–2003	Survival and growth	80% survival through 2001, natural recruitment recorded (6 colonies); 4% survival following localized phytoplankton bloom and subsequent anoxia (early 2002) combined with widespread coral reef bleaching episode (mid 2002)	Yes (estimated total only)	Schrimm et al., 2006

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Porites astreoides	Plate-like in shallow water, lumpy domes in deeper water	N/A	Brooder	North Dade County, Florida	Exposed & clear	Cemented (50/50 Portland cement/ molding plaster) to WWTP outfall pipe concrete block "armor" sections	13–18 m	7 colonies	1997–1999	Survival and growth	100% colony survival after 27 months (0% mortality, none missing); 7.75 (±5.62) mm mean radius increase/ year (n=4); 26.72 (±33.69) cm^2 mean surface area increase/ year (n=4)	No	Thornton et al., 2000
Solenastrea bournoni	Small domes, occasionally w/ bumps	N/A	Broadcast spawner	North Dade County, Florida	Exposed & clear	Cemented (50/50 Portland cement/ molding plaster) to WWTP outfall pipe concrete block "armor" sections	13–18 m	93 colonies	1997–1999	Survival and growth	90% colony survival after 27 months (7% mortality, 3% missing); 3.81 (±3.06) mm mean radius increase/ year (n=56); 10.56 (±8.99) cm^2 mean surface area increase/ year (n=56)	No	Thornton et al., 2000
Rumphella sp.	Soft-bodies	N/A	Not specified down to species level	Lizard Island, Northern Great Barrier Reef, Australia	On 2 different bommies	Exposed & unexposed (to air) corals attached with cable ties to masonry nails that were hammered into the substrate.	Not specific	4 fragments 5–10 cm in maximum dimension	1994	% Mortality; % bleaching and # of tips of branches	Did the worst	Yes	Kaly, 1995
Rumphella sp.	Soft-bodies	N/A	Not specified down to species level	Lizard Island, Northern Great Barrier Reef, Australia	On 2 different bommies	Exposed & unexposed (to air) corals attached to freshly drilled and chiseled holes in the substratum sing an underwater epoxy.	Not specific	4 fragments 5–10 cm in maximum dimension	1994	% Mortality; % bleaching and # of tips of branches	Unexposed corals attached using cement, not cable-ties, did the best.	Yes	Kaly, 1995

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# Of Colonies Transplanted/Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora spp.	Not identified to species level	N/A	Spawners	Bora Bora lagoon at Matira's Point, French Polynesia	Shallow lagoon with high hydrodynamic energy, low turbidity, strong light	Glued to irregularly-shaped concrete blocks (2, 10 and 17 tonnes in weight; arranged singly or in groups of 2, 3 or 4) on sand-filled, previously-dredged reef flat areas	2–3 m	86 colonies	1999–2003	Survival and growth	97% survival through 2001, natural recruitment recorded (26 colonies); 0% survival following localized phytoplankton bloom and subsequent anoxia (early 2002) combined with widespread coral reef bleaching episode (mid 2002)	Yes (estimated total only)	Schrimm et al., 2006
Cyphastrea sp.	Not identified to species level	N/A	Spawners	Bora Bora lagoon at Matira's Point, French Polynesia	Shallow lagoon with high hydrodynamic energy, low turbidity, strong light	Glued to irregularly-shaped concrete blocks (2, 10 and 17 tonnes in weight; arranged singly or in groups of 2, 3 or 4) on sand-filled, previously-dredged reef flat areas	2–3 m	1 colony	1999–2003	Survival and growth	100% survival through 2001; 0% survival following localized phytoplankton bloom and subsequent anoxia (early 2002) combined with widespread coral reef bleaching episode (mid 2002)	Yes (estimated total only)	Schrimm et al., 2006
Fungia spp.	Not identified to species level	N/A	Spawners	Bora Bora lagoon at Matira's Point, French Polynesia	Shallow lagoon with high hydrodynamic energy, low turbidity, strong light	Glued to irregularly-shaped concrete blocks (2, 10 and 17 tonnes in weight; arranged singly or in groups of 2, 3 or 4) on sand-filled, previously-dredged reef flat areas	2–3 m	11 colonies	1999–2003	Survival and growth	73% survival through 2001; 0% survival following localized phytoplankton bloom and subsequent anoxia (early 2002) combined with widespread coral reef bleaching episode (mid 2002)	Yes (estimated total only)	Schrimm et al., 2006

Table 3. Literature Summary Matrix for Glue/Epoxy and other chemical adhesive transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# Of Colonies Transplanted/Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Montipora spp.	Not identified to species level	N/A	Broadcast spawner	Bora Bora lagoon at Matira's Point, French Polynesia	Shallow lagoon with high hydrodynamic energy, low turbidity, strong light	Glued to irregularly-shaped concrete blocks (2, 10 and 17 tonnes in weight; arranged singly or in groups of 2, 3 or 4) on sand-filled, previously-dredged reef flat areas	2–3 m	73 colonies	1999–2003	Survival and growth	97% survival through 2001, natural recruitment recorded (2 colonies); 0% survival following localized phytoplankton bloom and subsequent anoxia (early 2002) combined with widespread coral reef bleaching episode (mid 2002)	Yes (estimated total only)	Schrimm et al., 2006
Porites spp.	Not identified to species level	N/A	Brooder	Bora Bora lagoon at Matira's Point, French Polynesia	Shallow lagoon with high hydrodynamic energy, low turbidity, strong light	Glued to irregularly-shaped concrete blocks (2, 10 and 17 tonnes in weight; arranged singly or in groups of 2, 3 or 4) on sand-filled, previously-dredged reef flat areas	2–3 m	15 colonies	1999–2003	Survival and growth	93% survival through 2001; 60% survival following localized phytoplankton bloom and subsequent anoxia (early 2002) combined with widespread coral reef bleaching episode (mid 2002)	Yes (estimated total only)	Schrimm et al., 2006
Psammocora	Not identified to species level	N/A	Broadcast spawner	Bora Bora lagoon at Matira's Point, French Polynesia	Shallow lagoon with high hydrodynamic energy, low turbidity, strong light	Glued to irregularly-shaped concrete blocks (2, 10 and 17 tonnes in weight; arranged singly or in groups of 2, 3 or 4) on sand-filled, previously-dredged reef flat areas	2–3 m	3 colonies	1999–2003	Survival and growth	100% survival through 2001; 0% survival following localized phytoplankton bloom and subsequent anoxia (early 2002) combined with widespread coral reef bleaching episode (mid 2002)	Yes (estimated total only)	Schrimm et al., 2006

The use of adhesives for coral reef transplantation is the most documented methodology. Of the 118 experiments analyzed using adhesive methods of glue/epoxy or cement, only 38 experiments resulted in 100% success (Table 4). Glue, epoxy, and cement worked best on dome, lobate, and massive corals; however, adhesives were least successful on branching corals. Ten studies showed 100% mortality, disease, predation, algal blooms, and high temperature stress were causes. Of the 38 studies that had 100% success rates, success was attributed to grooming and pruning of the branches to increase coral productivity; the removal of snails and other predatory and algal species; low tidal flow; lack of frequent storms and turbid waters; and selection of donor corals that did not have disease, signs of predation or mortality.

Table 4. Success/failure of the glue/epoxy/cements methodology based on coral morphology.

Success Rate (10 = 100%; 0 = 0%)	Branching Coral Studies	Massive with Branches Studies	Dome/ Lobate/Massive Studies	Mound/ Plate Studies	Soft Coral Studies	Species Not Identified Studies
10	8	0	18	7	N/A	5
9	10	0	3	2	N/A	0
8	5	0	2	0	N/A	1
7	3	0	2	2	N/A	0
6	2	5	3	2	N/A	0
5	2	0	0	0	N/A	0
4	1	0	0	2	N/A	0
3	2	0	1	0	N/A	0
2	7	0	2	1	N/A	0
1	7	0	0	3	N/A	0
0	6	1	1	2	N/A	0

4.2. PHYSICAL RESTORATION-METHOD 2: ATTACHMENT USING NAILS/CABLE TIES/RODS

4.2.1 Introduction

Methods included in this section contain the use of stainless steel wire and plastic cable ties (Figure 9) for reattaching branching corals (Iliff, Goodwin, Hudson, and Miller, 1999; Bruckener and Bruckener, 2001). Octocorals (plumes and sea fans) require a rod or other structure for support.

Figure 9. Coral fragment attachment with cable ties (Photo courtesy of NOAA SE DARRP).

4.2.2 Literature Review

As seen in Table 5, we found nine studies in which this methodology was utilized.

Table 5. Literature summary matrix for rod/cables/ties transplant methodologies.

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora cervicornis	Branching	N/A	Spawners	Punta Cana region of the Dominican Republic	Reef flat	Transplants were attached using small plastic cable ties to 4" masonry nails and driven into reef substrate; or glued with epoxy and cement; to a nursery made of epoxy-coated wire mesh, metal poles, rods and rebar	3–4.5 m	25 fragments from 4 donor colonies	Not specified	Survival and retention rates of transplants to other sites	97.4% survival and an 85% retention rate.	N/A	Bowden-Kerby et al., in Johnson et al., 2011
Acropora palmata	Branching	N/A	Spawners	M/V Fortuna Reefer Ship Grounding off Mona Island, Puerto Rico.	Over the course of the study, the site was hit with the boring sponge (Cliona spp.) Invasion, white banding disease, ciliate infections, white patch disease, corallivorous gastropod invasion, parrotfish predation and algal overgrowth.	Fragments 15–340 cm in length were secured to the reef by wrapping stainless steel wire over coral fragments and around stainless steel nails that we pre-drilled into pilot holes.	2–6 m	1857 fragments	1997	% Fragment survival	5.6% fragment survival after 11 years.	No	Bruckner, Bruckner, and Hill, 2008
Acropora palmata	Branching	N/A	Spawners	M/V Fortuna Reefer Ship Grounding off Mona Island, Puerto Rico.	Over the course of the study, the site was hit with the boring sponge (Cliona spp.) Invasion, white banding disease, ciliate infections, white patch disease, corallivorous gastropod invasion, parrotfish predation and algal overgrowth.	Fragments 15–340 cm in length were secured to the reef by wrapping stainless steel wire over coral fragments and around stainless steel nails that we pre-drilled into pilot holes.	2–6 m	1857 fragments	1997	Fragment growth	3-23 new branches; 15-70 cm growth in length and 20-80 cm growth in height of the remaining fragments.	No	Bruckner, Bruckner, and Hill, 2008

Table 5. Literature summary matrix for rod/cables/ties transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora cervicornis	Branching	N/A	Spawners	Reefs within Virgin islands National Park;	Sandy or bare substrate unfavorable for survival due to abrasion and tumbling were transplanted to degraded reefs at Trunk Cay and Whistling Cay.	Inert nylon cable ties were selected over uncoated wire, monofilament line, and underwater epoxy to secure the fragments to dead, *A. palamata* skeletons or other reef framework.	1–3 m	15 fragments	1999–2011	0% survival of transplants after 12 years; 47% of which was due to disease, predation, high temperature stress or some combo of these factors.	% survival and colony growth	Yes	Garrison & Ward, 2012
Acropora palmata	Branching	N/A	Spawners	Reefs within Virgin islands National Park;	Sandy or bare substrate unfavorable for survival due to abrasion and tumbling were transplanted to degraded reefs at Trunk Cay and Whistling Cay.	Inert nylon cable ties were selected over uncoated wire, monofilament line, and underwater epoxy to secure the fragments to dead, *A. Palamata* skeletons or other reef framework.	1–3 m	30 fragments	1999–2011	3% survival of transplants after 12 years; (56% of which was mortality in place); diameter increased more than sixfold in the 12 years from 20 cm to 130 cm.	% survival and colony growth	Yes	Garrison & Ward, 2012

Table 5. Literature summary matrix for rod/cables/ties transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Porites porites	Branching	N/A	Spawners	Reefs within Virgin islands National Park;	Sandy or bare substrate unfavorable for survival due to abrasion and tumbling were transplanted to degraded reefs at Trunk Cay and Whistling Cay.	Inert nylon cable ties were selected over uncoated wire, monofilament line, and underwater epoxy to secure the fragments to dead, *A. Palamata* skeletons or other reef framework.	1–3 m	15 fragments	1999–2011	13% survival of transplants after 12 years; 27% of which as due to disease, predation, high temperature stress or some combo of these factors.	% survival and colony growth	Yes	Garrison & Ward, 2012
Acropora sp.	Branching	N/A	Spawners	Green Island Reef, Australia	Forereef and backreef sites	Substratum	2.5–3 m	(a) Branched fragments attached w/ string in forereef site, (b) branched fragments placed in forereef site, (c) branched fragments scattered in forereef site, (d) unbranched fragments scattered in backreef site, (e) branched fragments attached with string in backreef site, (f) branched fragments scattered in backreef site, and (g) unbranched fragments scattered in backreef site; n = 14 fragments per treatment.	1986	Survival	Two unbranched and 11 branched fragments survived at the forereef site; 7 unbranched and 10 branched fragments survived at the backreef site. No significant differences in survival rate due to location or attachment method.	No	Harriott & Fisk, 1995 (Experiment 6)
Acropora formosa	Branching	N/A	Spawners	Majanohama beach, Akajima Island, Okinawa (26 degrees/ 3 min/ 52 sec N, 127 degrees/ 5 min/ 30 sec E)	Temperature range = 21.3–30.3 °C; time-averaged water velocity = 4.08 x 10^2 m/s; turbidity and sedimentation rates relatively high (see text for data); mean light intensity = 8.4 MJ/m^2 (January) - 20.5 MJ/m^2 (July)	Small (5 ±0.06 cm) branch tips (oocytes present) attached vertically with polyethylene cable tie to exposed portion of concrete nail embedded in coral pavement; date of transplant = 1999-11-07	2–3 m	6–10 fragments	1999–2003	Survival, spawning	29.0% ±15.9% survival after 18 months, 0% spawning	No	Okubo, Tanuguchi, and Motokawa, 2005

Table 5. Literature Summary Matrix for rod/cables/ties transplant methodologies.

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/Rametes Settled	Year	Study Metric Of Success	Quantitation of Success	Cost Data	Reference
Acropora formosa	Branching	N/A	Spawners	Majanohama beach, Akajima Island, Okinawa (26 degrees/ 3 min/ 52 sec N, 127 degrees/ 5 min/ 30 sec E)	Temperature range = 21.3–-30.3 °C; time-averaged water velocity = 4.08 x 10^2 m/s; turbidity and sedimentation rates relatively high (see text for data); mean light intensity = 8.4 MJ/m^2 (January) - 20.5 MJ/m^2 (July)	Small (5 ±0.06 cm) branch tips (oocytes present) attached vertically with polyethylene cable tie to exposed portion of concrete nail embedded in coral pavement; date of transplant = 1999-11-07	2–3 m	6–10 fragments	1999–2003	Growth rate	5.3% ±3.1% per month (6-month average, see Tables 3 and 4 for statistical analyses))	No	Okubo, Tanuguchi, and Motokawa, 2005
Acropora formosa	Branching	N/A	Spawners	Majanohama beach, Akajima Island, Okinawa (26 degrees/ 3 min/ 52 sec N, 127 degrees/ 5 min/ 30 sec E)	Temperature range = 21.3–-30.3 °C; time-averaged water velocity = 4.08 x 10^2 m/s; turbidity and sedimentation rates relatively high (see text for data); mean light intensity = 8.4 MJ/m^2 (January) - 20.5 MJ/m^2 (July)	Small (5 ±0.06 cm) branch tips (oocytes present) attached horizontally with polyethylene cable tie to exposed portion of concrete nail embedded in coral pavement;	2–3 m	6–10 fragments	1999–2003	Survival, spawning	7.3% ±5.7% survival after 18 months, 0% spawning	No	Okubo, Tanuguchi, and Motokawa, 2005
Acropora formosa	Branching	N/A	Spawners	Majanohama beach, Akajima Island, Okinawa (26 degrees/ 3 min/ 52 sec N, 127 degrees/ 5 min/ 30 sec E)	Temperature range = 21.3–30.3 °C; time-averaged water velocity = 4.08 x 10^2 m/s; turbidity and sedimentation rates relatively high (see text for data); mean light intensity = 8.4 MJ/m^2 (January) - 20.5 MJ/m^2 (July)	Small (5 ±0.06 cm) branch tips (oocytes present) attached horizontally with polyethylene cable tie to exposed portion of concrete nail embedded in coral pavement; date of transplant = 1999-11-07	2–3 m	6–10 fragments	1999–2003	Growth rate	7.4% ±3.9% per month (6-month average, see Tables 3 and 4 for statistical analyses)	No	Okubo, Tanuguchi, and Motokawa, 2005

Table 5. Literature Summary Matrix for rod/cables/ties transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Trans planted/Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora formosa	Branching	N/A	Spawners	Majanohama beach, Akajima Island, Okinawa (26 degrees/ 3 min/ 52 sec N, 127 degrees/ 5 min/ 30 sec E)	Temperature range = 21.3–30.3 °C; time-averaged water velocity = 4.08 x 10^2 m/s; turbidity and sedimentation rates relatively high (see text for data); mean light intensity = 8.4 MJ/m^2 (January) - 20.5 MJ/m^2 (July)	Medium (10 ±0.07 cm) branch tips (oocytes present) attached vertically with polyethylene cable tie to exposed portion of concrete nail embedded in coral pavement; date of transplant = 1999-11-07	2–3 m	6–10 fragments	1999–2003	Survival, spawning	83.5% ±10.4% survival after 18 months, 4.0% ±6.4% spawning (May), 0% spawning (June)	No	Okubo, Tanuguchi, and Motokawa, 2005
Acropora formosa	Branching	N/A	Spawners	Majanohama beach, Akajima Island, Okinawa (26 degrees/ 3 min/ 52 sec N, 127 degrees/ 5 min/ 30 sec E)	Temperature range = 21.3–30.3 °C; time-averaged water velocity = 4.08 x 10^2 m/s; turbidity and sedimentation rates relatively high (see text for data); mean light intensity = 8.4 MJ/m^2 (January) - 20.5 MJ/m^2 (July)	Medium (10 ±0.07 cm) branch tips (oocytes present) attached horizontally with polyethylene cable tie to exposed portion of concrete nail embedded in coral pavement; date of transplant = 1999-11-07	2–3 m	6–10 fragments	1999–2003	Growth rate	7.3% ±3.1% per month (6-month average, see Tables 3 and 4 for statistical analyses)	No	Okubo, Tanuguchi, and Motokawa, 2005

Table 5. Literature Summary Matrix for rod/cables/ties transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/Rametes Settled	Year	Study Metric of Success	Quantitation Of Success	Cost Data	Reference
Acropora formosa	Branching	N/A	Spawners	Majanohama beach, Akajima Island, Okinawa (26 degrees/ 3 min/ 52 sec N, 127 degrees/ 5 min/ 30 sec E)	Temperature Range = 21.3–30.3 °C; Time-Averaged Water Velocity = 4.08 X 10^2 M/S; Turbidity And Sedimentation Rates Relatively High (See Text For Data); Mean Light Intensity = 8.4 MJ/M^2 (January) - 20.5 MJ/M^2 (July)	Medium (10 ±0.07 cm) branch tips (oocytes present) attached horizontally with polyethylene cable tie to exposed portion of concrete nail embedded in coral pavement; date of transplant = 1999-11-07	2–3 m	6–10 fragments	1999–2003	Survival, spawning	0% survival after 18 months, 0% spawning	No	Okubo, Tanuguchi, and Motokawa, 2005
Acropora formosa	Branching	N/A	Spawners	Majanohama Beach, Akajima Island, Okinawa (26 degrees/ 3 min/ 52 sec N, 127 degrees/ 5 min/ 30 sec E)	Temperature Range = 21.3–30.3 °C; Time-Averaged Water Velocity = 4.08 X 10^2 M/S; Turbidity And Sedimentation Rates Relatively High (See Text For Data); Mean Light Intensity = 8.4 MJ/M^2 (January) - 20.5 MJ/M^2 (July)	Large (20 ± 0.40 cm) branch tips (oocytes present) attached vertically with polyethylene cable tie to exposed portion of concrete nail embedded in coral pavement; date of transplant = 1999-11-07	2–3 m	6–10 fragments	1999–2003	Growth rate	4.4% ±2.5% per month (6-month average, see Tables 3 and 4 for statistical analyses)	No	Okubo, Tanuguchi, and Motokawa, 2005

Table 5. Literature Summary Matrix for rod/cables/ties transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora formosa	Branching	N/A	Spawners	Majanohama beach, Akajima Island, Okinawa (26 degrees/ 3 min/ 52 sec N, 127 degrees/ 5 min/ 30 sec E)	Temperature range = 21.3–30.3 °C; time-averaged water velocity = 4.08 x 10^2 m/s; turbidity and sedimentation rates relatively high (see text for data); mean light intensity = 8.4 MJ/m^2 (January) - 20.5 MJ/m^2 (July)	Large (20 ±0.40 cm) branch tips (oocytes present) attached vertically with polyethylene cable tie to exposed portion of concrete nail embedded in coral pavement; date of transplant = 1999-11-07	2–3 m	6–10 fragments	1999–2003	Survival, Spawning	98.3% ±4.1% survival after 18 months, 40.2% ±8.8% spawning (May), 40.5% ±9.5% spawning (June)	No	Okubo, Tanuguchi, and Motokawa, 2005
Acropora formosa	Branching	N/A	Spawners	Majanohama beach, Akajima Island, Okinawa (26 degrees/ 3 min/ 52 sec N, 127 degrees/ 5 min/ 30 sec E)	Temperature range = 21.3–30.3 °C; time-averaged water velocity = 4.08 x 10^2 m/s; turbidity and sedimentation rates relatively high (see text for data); mean light intensity = 8.4 MJ/m^2 (January) - 20.5 MJ/m^2 (July)	Large (20 ±0.40 cm) branch tips (oocytes present) attached vertically with polyethylene cable tie to exposed portion of concrete nail embedded in coral pavement; date of transplant = 1999-11-07	2–3 m	6–10 fragments	1999–2003	Growth Rate	4.9% ±3.9% per month (6-month average, see Tables 3 and 4 for statistical analyses)	No	Okubo, Tanuguchi, and Motokawa, 2005

Table 5. Literature Summary Matrix for rod/cables/ties transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# Of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora formosa	Branching	N/A	Spawners	Majanohama beach, Akajima Island, Okinawa (26 degrees/ 3 min/ 52 sec N, 127 degrees/ 5 min/ 30 sec E)	Temperature range = 21.3–30.3 °C; time-averaged water velocity = 4.08 x 10² m/s; turbidity and sedimentation rates relatively high (see text for data); mean light intensity = 8.4 MJ/m² (January) - 20.5 MJ/m² (July)	Large (20 ±0.40 cm) branch tips (oocytes present) attached horizontally with polyethylene cable tie to exposed portion of concrete nail embedded in coral pavement; date of transplant = 1999-11-07	2–3 m	6–10 fragments	1999–2003	Survival, spawning	91.8% ± 9.3% survival after 18 months, 16.4% ±6.2% spawning (May), 3.3% ±5.2% spawning (June)	No	Okubo, Tanuguchi, and Motokawa, 2005
Acropora formosa	Branching	N/A	Spawners	Majanohama Beach, Akajima Island, Okinawa (26 degrees/ 3 min/ 52 sec N, 127 degrees/ 5 min/ 30 sec E)	Temperature range = 21.3–30.3 °C; time-averaged water velocity = 4.08 x 10² m/s; turbidity and sedimentation rates relatively high (see text for data); mean light intensity = 8.4 MJ/m² (January) - 20.5 MJ/m² (July)	Small (5 ±0.06 cm) branch tips (oocytes present) attached vertically with polyethylene cable tie to exposed portion of concrete nail embedded in coral pavement; date of transplant = 2000-03-15	2–3 m	6–10 fragments	1999–2003	Growth rate	3.9% ±2.4% per month (6-month average, see Tables 3 and 4 for statistical analyses)	No	Okubo, Tanuguchi, and Motokawa, 2005

Table 5. Literature Summary Matrix for rod/cables/ties transplant methodologies (continued).

Species	Morphology Type	Biomarker	Spawners	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# Of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora formosa	Branching	N/A	Spawners	Majanohama beach, Akajima Island, Okinawa (26 degrees/ 3 min/ 52 sec N, 127 degrees/ 5 min/ 30 sec E)	Temperature range = 21.3–30.3 °C; time-averaged water velocity = 4.08 x 10^2 m/s; turbidity and sedimentation rates relatively high (see text for data); mean light intensity = 8.4 MJ/m^2 (January) - 20.5 MJ/m^2 (July)	Medium (10 ±0.07 cm) branch tips (oocytes present) attached vertically with polyethylene cable tie to exposed portion of concrete nail embedded in coral pavement; date of transplant = 2000-03-15	2–3 m	6–10 fragments	1999–2003	Survival, spawning	93.3% ± 7.8% survival after 18 months, 20.1% ±7.9% spawning (May), 0% spawning (June)	No	Okubo, Tanuguchi, and Motokawa, 2005
Acropora formosa	Branching	N/A	Spawners	Majanohama beach, Akajima Island, Okinawa (26 degrees/ 3 min/ 52 sec N, 127 degrees/ 5 min/ 30 sec E)	Temperature range = 21.3–30.3 °C; time-averaged water velocity = 4.08 x 10^2 m/s; turbidity and sedimentation rates relatively high (see text for data); mean light intensity = 8.4 MJ/m^2 (January) - 20.5 MJ/m^2 (July)	Large (20 ±0.40 cm) branch tips (oocytes present) attached vertically with polyethylene cable tie to exposed portion of concrete nail embedded in coral pavement; date of transplant = 2000-03-15	2–3 m	6–10 fragments	1999–2003	Survival, spawning	93.3% ±7.8% survival after 18 months, 20.1% ±7.9% spawning (May), 0% spawning (June)	No	Okubo, Tanuguchi, and Motokawa, 2005
Acropora formosa	Branching	N/A	Spawners	Majanohama beach, Akajima Island, Okinawa (26 degrees/ 3 min/ 52 sec N, 127 degrees/ 5 min/ 30 sec E)	Temperature range = 21.3–30.3 °C; time-averaged water velocity = 4.08 x 10^2 m/s; turbidity and sedimentation rates relatively high (see text for data); mean light intensity = 8.4 MJ/m^2 (January) - 20.5 MJ/m^2 (July)	Small (5 ±0.06 cm) branch tips (oocytes present) attached vertically with polyethylene cable tie to exposed portion of concrete nail embedded in coral pavement; date of transplant = 2000-03-15	2–3 m	6–10 fragments	1999–2003	Survival, spawning	86.6% ±1.4% survival after 18 months, 19.6% ±11.9% spawning (May), 0% spawning (June)	No	Okubo, Tanuguchi, and Motokawa, 2005

Table 5. Literature Summary Matrix for rod/cables/ties transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# Of Colonies Transplanted /Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora formosa	Branching	N/A	Spawners	Majanohama beach, Akajima Island, Okinawa (26 degrees/ 3 min/ 52 sec N, 127 degrees/ 5 min/ 30 sec E)	Temperature range = 21.3–30.3 °C; time-averaged water velocity = 4.08 x 10^2 m/s; turbidity and sedimentation rates relatively high (see text for data); mean light intensity = 8.4 MJ/m^2 (January) - 20.5 MJ/m^2 (July)	Medium (10 ±0.07 cm) branch tips (oocytes absent) attached vertically with polyethylene cable tie to exposed portion of concrete nail embedded in coral pavement; date of transplant = 2000-08-08	2–3 m	6–10 fragments	1999–2003	Survival, spawning	100% survival after 18 months, 48.2% ±14.1% spawning (May), 51.8% ±14.1% spawning (June)	No	Okubo, Tanuguchi, and Motokawa, 2005
Acropora formosa	Branching	N/A	Spawners	Majanohama beach, Akajima Island, Okinawa (26 degrees/ 3 min/ 52 sec N, 127 degrees/ 5 min/ 30 sec E)	Temperature range = 21.3–30.3 °C; time-averaged water velocity = 4.08 x 10^2 m/s; turbidity and sedimentation rates relatively high (see text for data); mean light intensity = 8.4 MJ/m^2 (January) - 20.5 MJ/m^2 (July)	Large (20 ± 0.40 cm) branch tips (oocytes absent) attached vertically with polyethylene cable tie to exposed portion of concrete nail embedded in coral pavement; date of transplant = 2000-08-08	2–3 m	6–10 fragments	1999–2003	Survival, spawning	100% survival after 18 months, 0% spawning (May), 46.4% ±11.0% spawning (June)	No	Okubo, Tanuguchi, and Motokawa, 2005

Table 5. Literature Summary Matrix for rod/cables/ties transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora formosa	Branching	N/A	Spawners	Majanohama beach, Akajima Island, Okinawa (26 degrees/ 3 min / 52 sec N, 127 degrees/ 5 min/ 30 sec E)	Temperature range = 21.3–30.3 °C; time-averaged water velocity = 4.08 x 10^2 m/s; turbidity and sedimentation rates relatively high (see text for data); mean light intensity = 8.4 MJ/m^2 (January) - 20.5 MJ/m^2 (July)	Large (20 ±0.40 cm) branch tips (oocytes absent) attached vertically with polyethylene cable tie to exposed portion of concrete nail embedded in coral pavement; date of transplant = 2000-08-08	2–3 m	6–10 fragments	1999–2003	Survival, spawning	100% survival after 18 months, 0% spawning	No	Okubo, Tanuguchi, and Motokawa, 2005
Acropora formosa	Branching	N/A	Spawners	Majanohama Beach, Akajima Island, Okinawa , Japan	Weak currents, turbidity and sedimentation.	Coral pavement	2–3 m	9–13 fragments were fastened to an 8-cm long concrete nail drove into the coral pavement with polyethylene cable ties.	1999–2000	% survival	Large-sized fragments= 98.3%-74.4% survival; medium-sized fragments= 83.5%-69.4% survival; small-sized fragments= 48.3%-29.2% survival.	No	Okubo, Motokawa, and Omori, 2007

Table 5. Literature Summary Matrix for rod/cables/ties transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora formosa	Branching	N/A	Spawners	Majanohama Beach, Akajima Island, Okinawa , Japan	Weak currents, turbidity and sedimentation.	Coral pavement	2–3 m	9–13 fragments were fastened to an 8cm long concrete nail drove into the coral pavement with polyethylene cable ties.	1999–2000	Oocyte development	Oocytes disappeared within 1 month in the small-sized fragments; oocytes disappeared within 2 months in the medium-sized fragments; oocytes developed after 1 month in the larger-sized fragments.	No	Okubo, Motokawa, and Omori, 2007
Acropora formosa	Branching	N/A	Spawners	Majanohama Beach, Akajima Island, Okinawa , Japan	Weak currents, turbidity and sedimentation.	Coral pavement	2–3 m	9–13 fragments were fastened to an 8cm long concrete nail drove into the coral pavement with polyethylene cable ties.	1999–2000	Spawning occurrence	Large and medium-sized fragments spawned but the small-sized fragments did not spawn at all.	No	Okubo, Motokawa, and Omori, 2007
Acropora cervicornis	Branching	N/A	Spawners	Discovery Bay, Jamaica	Columbus Park Reef (CPR); turbid with visibility frequently <5 m, bottom composed of red / brown silt	5-14 cm fragments attached using plastic cable ties to each side of plastic coated wire mesh "A-frames" (parallelogram mesh 3 x 6 cm and rectangular 20 x 20 cm) cut to a size of 0.8 x 1.2 m, and bent in the middle at 90°)	6 m	5 frames, 50 fragments total	2004-2005	Survival, growth	68% survival after 62 wks., mean growth rate at 39 wks. = 15.3 cm (s.e. = 4.6 cm; n=40); see Figures 4 and 5	No	Quinn and Kojis, 2006

Table 5. Literature Summary Matrix for rod/cables/ties transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora cervicornis	Branching	N/A	Spawners	Discovery Bay, Jamaica	East Back Reef (EBR) - 18 degrees 28.09 min N; 77 degrees 24.15 min W; clear and subject to breaking waves (typically ~10-m visibility), bottom composed of sand and rubble with some *Thalassia testudinum*	5–14 cm fragments attached using plastic cable ties to each side of plastic coated wire mesh "A-frames" (parallelogram mesh 3 x 6 cm and rectangular 20 x 20 cm) cut to a size of 0.8 x 1.2 m, and bent in the middle at 90°)	4 m	5 frames, 50 fragments total	2004–2005	Survival, growth	See figs. 4 and 5	No	Quinn and Kojis, 2006
Acropora cervicornis	Branching	N/A	Spawners	Discovery Bay, Jamaica	Blue Hole (BH) - 18 degrees 28.10 min N, 77 degrees 24.51 min W; back reef, lagoon environment with slightly turbid water (typically < 9-m visibility), mixed sand and rubble bottom	5–14 cm fragments attached using plastic cable ties to each side of plastic coated wire mesh "A-frames" (parallelogram mesh 3 x 6 cm and rectangular 20 x 20 cm) cut to a size of 0.8 x 1.2 m, and bent in the middle at 90°)	2 m	3 frames, 30 fragments total	2004–2005	Survival, growth	29% survival after 62 wks; see Figures 4 and 5	No	Quinn and Kojis, 2006

Table 5. Literature Summary Matrix for rod/cables/ties transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora cervicornis	Branching	N/A	Spawners	Discovery Bay, Jamaica	Canoe Channel (CC) - 18 degrees 28.15 min N, 77 degrees 24.54 min W; behind reef crest at WFR in inter-reef sandy area receiving clear ocean water as waves break over crest, sand bottom with *T. testudinum* and surrounded by algal-dominated remnant coral structures; black plastic shade cloth suspended over A-frames to reduce light intensity and approximate light levels at depth of source population (9 m)	5–14 cm fragments attached using plastic cable ties to each side of plastic coated wire mesh "A-frames" (parallelogram mesh 3 x 6 cm and rectangular 20 x 20 cm) cut to a size of 0.8 x 1.2 m, and bent in the middle at 90°)	2 m	3 frames, 30 fragments total	2004–2005	Survival, growth	4% survival after 62 wks (result of wave action from Hurricane Ivan, which passed south of Jamaica in September 2004 according to authors), mean growth rate at 39 wks = 1.1 cm (s.e. = 0.6 cm; n=16); see Figs. 4 and 5	No	Quinn and Kojis, 2006
Acropora cervicornis	Branching	N/A	Spawners	Discovery Bay, Jamaica	West Fore Reef (WFR) outside Discovery Bay - 18 degrees 28.19 min N, 77 degrees 24.53 min W;	5–14 cm fragments attached using plastic cable ties to each side of plastic coated wire mesh "A-frames" (parallelogram mesh 3 x 6 cm and rectangular 20 x 20 cm) cut to a size of 0.8 x 1.2 m, and bent in the middle at 90°)	6 m	4 frames, 40 fragments total	2004–2005	Survival, growth	see Figures. 4 and 5	No	Quinn and Kojis, 2006

Table 5. Literature Summary Matrix for rod/cables/ties transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora cervicornis	Branching	N/A	Spawners	Discovery Bay, Jamaica	Not specified	Small (<7 cm) fragment secured to ~ 5 cm 1:1 cement/sand disk with monofilament line and attached to wire mesh sheet	Not specified	190 fragments	2004–2005	Survival, Growth	19% survival at 37 wks., mean annualized growth rate = 23 cm/year (s.e. = 9.2 cm/year) at 40 wks.; mortality claimed by authors primarily due to damage to colonies by Hurricane Ivan	No	Quinn and Kojis, 2006
Acropora cervicornis	Branching	N/A	Spawners	Discovery Bay, Jamaica	June 2004 experiment - Canoe Channel (CC), stored in shaded buckets for ~ 4 hours. After collection from source prior to deployment; black plastic shade cloth suspended over line to reduce light intensity	Attached to monofilament nylon lines and suspended ~ 0.5 m above sandy bottom	1.5 m	16 fragments	2004–2005	Survival, growth	100% bleaching after 5 days	No	Quinn and Kojis, 2006
Acropora cervicornis	Branching	N/A	Spawners	Discovery Bay, Jamaica	September 2004 experiment - Canoe Channel (CC), deployed within 30 min after collection from source; black plastic shade cloth suspended over line to reduce light intensity; Hurricane Ivan passes south of Jamaica at 2-week mark	Attached to monofilament nylon lines and suspended ~ 0.5 m above sandy bottom	1.5 m	40 fragments	2004–2005	Survival, growth	86% survival at 12 wks., 32% survival at 26 wks., mean annualized linear growth = 21.0 cm (s.e. = 7.5 cm)	No	Quinn and Kojis, 2006
Acropora prolifera	Branching	N/A	Spawners	Discovery Bay, Jamaica	Not specified	Small (<7 cm) fragment secured to ~ 5 cm 1:1 cement/sand disk with monofilament line and attached to wire mesh sheet	Not specified	21 fragments	2004–2005	Survival, growth	0% survival at 12 wks.; mortality primarily due to damage to colonies by Hurricane Ivan according to authors	No	Quinn and Kojis, 2006

Table 5. Literature Summary Matrix for rod/cables/ties transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted /Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora cervicornis	Branching	N/A	Spawners	Punta Soldado and Arrecife El Banderote, Luis Pena Channel Natural Reserve, Culebra, Puerto Rico	Aquaculture farm; sandy/rubble bottom	60 x 45 cm concrete block with 20 PVC plastic sticks where coral fragments were attached using plastic ties in a nursery	4–5 m	500 fragments total (15 cm in length each)	2005	Fragment survival, growth rate and branchiness	90% Survival after 6 months at PS; 89% at AEB; Branch production had a mean of 5 to 20 new branches per fragment.	N/A	Hernández-Delgado, Soto-Ayala, and Feliciano, 2009
Acropora cervicornis	Branching	N/A	Spawners	Punta Soldado and Arrecife El Banderote, Luis Pena Channel Natural Reserve, Culebra, Puerto Rico	Restocking of 2 bomb-cratered coral reefs	10 x 10 M plots made of masonry nails or 1/8" rebar in a nursery	4–5 meters	100 fragments total (15-25 cm in length each)	2006	Fragment survival, growth rate and branchiness	97% survival rate after one year.	N/A	Hernández-Delgado, Soto-Ayala, and Feliciano, 2009
Montipora verrucosa	Massive With Bumps	N/A	Spawners	lagoon of Kaneohe Bay, Hawaii	Atop a patch reef which was dredged in 1939; visibility is between 4 and 6 meters; no surge currents.	Course sand, pebbles and rubble to which iron bedframes were laid and corals attached with insulated wire strands.	3 m	3 small colony (<10 cm); 8 medium colonies (11–120 cm) and 2 large colony (>20 cm)	1971	Growth, survival/loss of transplants	Small colony growth rate of 98 cm^2/colony; 84 cm^2/colony for medium colony size and 323 cm^2 per colony for large colony size; 0% of small colonies were lost, 8% of medium colonies were lost and 2% of large colonies were lost; 4 colonies settled per bedframe	No	Maragos, 1974

Table 5. Literature Summary Matrix for rod/cables/ties transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Montipora verucosa	Massive with bumps	N/A	Spawners	Lagoon of Kaneohe Bay, Hawaii	On top of a sandy section of a patch reef dredged in 1939; sewage is discharged here; water visibility is 2–3 m.	Reef substrates to which iron bedframes were laid and corals attached with insulated wire strands.	3 m	3 small colony (<10 cm) ; 9 medium colonies (11–120 cm) and 4 large colony (> 20 cm)	1971	Growth, survival/loss of transplants	Small colony growth rate of 39 cm^2/colony; 114 cm^2/colony for medium colony size and 160 cm^2 per colony for large colony size; 0% of small colonies were lost, 0% of medium colonies were lost and 0% of large colonies were lost; 0 colonies settled per bedframe	No	Maragos, 1974
Porites compressa	Massive with branching	N/A	Spawners	Lagoon of Kaneohe Bay, Hawaii	Leeward edge of shallow, broad reef flat ; water visibility is 8 m or more; sand-sized sediment is frequently suspended in the water column.	Sand, rubble, consolidated coral rock to which iron bedframes were laid and corals attached with insulated wire strands.	1–2 meters	1 small colony (<10 cm) ; 11 medium colonies (11–120 cm) and 1 large colony (>20 cm)	1971	Growth, survival/loss of transplants	Small colony growth rate of 9 cm^2/colony; 65 cm^2/ colony for medium colony size and 264 cm^2 per colony for large colony size; 9% of small colonies were lost, 5% of medium colonies were lost and 0% of large colonies were lost; 1.5 colonies settled per bedframe.	No	Maragos, 1974

Table 5. Literature Summary Matrix for rod/cables/ties transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Porites compressa	Massive with branching	N/A	Spawners	lagoon of Kaneohe Bay, Hawaii	Atop a patch reef which was dredged in 1939; visibility is between 4 and 6 meters; no surge currents.	Course sand, pebbles and rubble to which iron bedframes were laid and corals attached with insulated wire strands.	3 m	6 small colony (<10 cm) ; 50 medium colonies (11-120 cm) and 5 large colony (>20 cm)	1971	Growth, survival/loss of transplants	Small colony growth rate of 77 cm^2/ colony; 109 cm^2/colony for medium colony size and 132 cm^2 per colony for large colony size; 17% of small colonies were lost, 0 % of medium colonies were lost and 0% of large colonies were lost; 4 colonies settled per bedframe	No	Maragos, 1974
Acropora hyacinthus	Plate-like or tabular	N/A	Spawners	Majanohama beach, Akajima Island, Okinawa (26 degrees 3 min 52 sec N, 127 degrees 5 min 30 sec E)	Temperature range = 21.3–30.3 °C; time-averaged water velocity = 4.08 x 10^2 m/s; turbidity and sedimentation rates relatively high (see text for data); mean light intensity = 8.4 MJ/m^2 (January) - 20.5 MJ/m^2 (July)	Small (5 ± 0.06 cm) branch tips (oocytes absent) attached horizontally with polyethylene cable tie to exposed portion of concrete nail embedded in coral pavement; date of transplant = 2001-07-13	2–3 m	10 fragments	1999–2003	Survival, spawning	32.0% ±13.0% survival after 14 months, 0.4% ±0.9% spawning (May), 0% spawning (June)	No	Okubo, Tanuguchi, and Motokawa, 2005

Table 5. Literature Summary Matrix for rod/cables/ties transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora hyacinthus	Plate-Like or Tabular	N/A	Spawners	Majanohama beach, Akajima Island, Okinawa (26 degrees 3 min 52 sec N, 127 degrees 5 min 30 sec E)	Temperature range = 21.3–30.3 °C; time-averaged water velocity = 4.08 x 10^2 m/s; turbidity and sedimentation rates relatively high (see text for data); mean light intensity = 8.4 MJ/m² (January) - 20.5 MJ/m² (July)	Small (5 ± 0.06 cm) branch tips (oocytes absent) attached horizontally with polyethylene cable tie to exposed portion of concrete nail embedded in coral pavement; date of transplant = 2001-07-13	2–3 m	10 fragments	1999–2003	Survival, spawning	2.0% ±4.5% survival after 14 months, 0% spawning	No	Okubo, Tanuguchi, and Motokawa, 2005
Acropora hyacinthus	Plate-Like or Tabular	N/A	Spawners	Majanohama beach, Akajima Island, Okinawa (26 degrees 3 min 52 sec N, 127 degrees 5 min 30 sec E)	Temperature range = 21.3–30.3 °C; time-averaged water velocity = 4.08 x 10^2 m/s; turbidity and sedimentation rates relatively high (see text for data); mean light intensity = 8.4 MJ/m² (January) - 20.5 MJ/m² (July)	Small (5 ± 0.06 cm) branch tips (oocytes present) attached vertically with polyethylene cable tie to exposed portion of concrete nail embedded in coral pavement; date of transplant = 2002-02-20	2–3 m	10 fragments	1999–2003	Survival, spawning	100% survival after 14 months, 18.3% ±13.8% spawning (May), 0% spawning (June)	No	Okubo, Tanuguchi, and Motokawa, 2005

Out of 40 experiments using ties/cabling/rods, 10 experiments resulted in a 100% success rate (Table 6). Ties/rods/cables performed best on branching coral and was least successful on mound/plate corals. Hurricanes, bleaching, and high temperature stress caused the 100% mortality rate in three studies. In 10 studies with a 100% success rate, we vertically attached branching corals in low current conditions, transplanted corals within shallow depth environments in areas devoid of loose rubble. We provided enough space between transplants to reduce the attraction of predators and transmission of disease among outplants.

Table 6. Success/failure of the tie/rod/cabling methodology based on coral morphology.

Success Rate (10=10%0=0%)	Branching Coral Studies	Massive with Branches Studies	Dome/lobate/ Massive Studies	Mound/ Plate Studies	Soft Coral Studies	Species Not Identified studies
10	9	N/A	N/A	1	N/A	N/A
9	11	N/A	N/A	0	N/A	N/A
8	0	N/A	N/A	0	N/A	N/A
7	1	N/A	N/A	0	N/A	N/A
6	0	N/A	N/A	0	N/A	N/A
5	0	N/A	N/A	0	N/A	N/A
4	0	N/A	N/A	1	N/A	N/A
3	2	N/A	N/A	0	N/A	N/A
2	1	N/A	N/A	0	N/A	N/A
1	10	N/A	N/A	1	N/A	N/A
0	3	N/A	N/A	0	N/A	N/A

4.3. PHYSICAL RESTORATION-METHOD 3: LEAVE-IN-PLACE OR LAYING DOWN

4.3.1 Introduction

This section discusses studies that researched the leave-on-place method or laying down method for coral transplantation. This method is best exemplified by a coral breaking into pieces after a storm and have the pieces fall naturally onto the substrate.

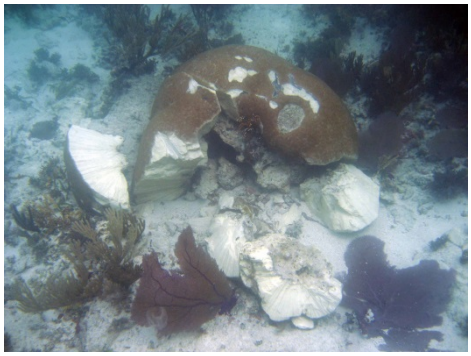

Figure 10. Damaged coral left in place in Biscayne Bay National Park, Miami, FL.

4.3.2 Literature Review

As seen in Table 7, we found five studies where this methodology was utilized.

Table 7. Literature Summary matrix for the leaving in place transplant methodologies.

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora prolifera	Branching	N/A	Spawners	Puerto Rico	N/A	Reef flat rubble; 3–5 cm fragment attached with plastic cable lines to a monofilament line.	2 m	Not specified	1997	Fragment % survival	82% alive after 3 months	No	Bowden-Kerby, 1997
Acropora prolifera	Branching	N/A	Spawners	Puerto Rico	N/A	Reef flat rubble; 8–12 cm fragment attached with plastic cable lines to a monofilament line.	2 m	Not specified	1997	Fragment % survival	82% alive after 3 months	No	Bowden-Kerby, 1997
Acropora prolifera	Branching	N/A	Spawners	Puerto Rico	N/A	Reef flat rubble; 15–22 cm fragment attached with plastic cable lines to a monofilament line.	2 m	Not specified	1997	Fragment % survival	88% alive after 3 months	No	Bowden-Kerby, 1997
Acropora aspera	Branching	N/A	Spawners	Pohnpei, Micronesia	N/A	Back reef sand; 25-, 30-, 40-cm fragment wedges together in pairs and into the sandy bottom.	2–4 m	125 colonies	1997	Fragment % survival	2.4% alive within 2 month to a year.	No	Bowden-Kerby, 1997
Acropora aspera	Branching	N/A	Spawners	Pohnpei, Micronesia	N/A	Back reef sand; 25-, 30-,40-cm fragments wedges together in pairs and into the sandy bottom.	2–4 m	125 colonies	1997	Fragment growth	34.4 cm average growth above the substrate	No	Bowden-Kerby, 1997

Table 7. Literature Summary matrix for the leaving in place transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora cervicornis	Branching	N/A	Spawners	Puerto Rico	N/A	Reef flat rubble; 3–5 cm fragments attached with plastic cable lines to a monofila ment line.	2 m	Not specified	1997	Fragment % survival; coral cover	80% alive after 3 months; barren rubble showed 2.2% coral cover after planting; it showed 24.5% coral cover after 1 year.	No	Bowden-Kerby, 1997
Acropora cervicornis	Branching	N/A	Spawners	Puerto Rico	N/A	Reef flat rubble; 8–12 cm fragment attached with plastic cable lines to a monofila ment line.	2 m	Not specified	1997	Fragment % survival	84% alive after 3 months	No	Bowden-Kerby, 1997
Acropora cervicornis	Branching	N/A	Spawners	Puerto Rico	N/A	Reef flat rubble; 15–22 cm fragment attached with plastic cable lines to a monofila ment line.	2 m	Not specified	1997	Fragment % survival	100% alive after 3 months	No	Bowden-Kerby, 1997
Acropora sp.	Branching	N/A	Spawners	Green Island Reef, Australia	Forereef and backreef sites	Rubble or sand	2–3	(a) 31 branched fragments placed on rubble in forereef site, (b) 30 unbranched fragments placed on rubble in forereef site, (c) 31 branched fragments placed on rubble in backreef site, (d) 30 unbranched fragments placed on rubble in backreef site, and (e) 31 branched fragments placed on sand in backreef site; fragment size = 20-30 cm each.	1985	Survival	After 2 months, the branched corals in the backreef area on rubble (c) did the best. The unbranched ones in the forereef on rubble (b) did the worst.	No	Harriott & Fisk, 1995 (Experiment 3)

Table 7. Literature Summary matrix for the leaving in place transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation Of Success	Cost Data	Reference
Acropora echinata	Branching	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site A, western corner	Complete 5-10 cm heads placed on rubble and sand-veneered reef rock substrate	1–2 m	5 complete heads	1981–1982	Survival, growth	46.0% survival, pooled size class data - no significant difference in survival between size classes; mean growth = 1.49 mm (s.d. = 0.57 mm)	No	Plucer-Rosario and Randall, 1987
Acropora echinata	Branching	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site A, western corner	Complete 10-15 cm heads placed on rubble and sand-veneered reef rock substrate	1–2 m	5 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Acropora echinata	Branching	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site A, western corner	Complete 15-20 cm heads placed on rubble and sand-veneered reef rock substrate	1–2 m	5 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Acropora echinata	Branching	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site B, eastern corner	Complete 5-10 cm heads placed on rubble and sand-floored depression on surface of small patch reef	3–5 m	5 complete heads	1981–1982	Survival, growth	46.0% survival, pooled size class data - no significant difference in survival between size classes; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987

Table 7. Literature Summary matrix for the leaving in place transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora echinata	Branching	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site B, eastern corner	Complete 10–15 cm heads placed on rubble and sand-floored depression on surface of small patch reef	3–5 m	5 complete heads	1981–1982	Survival, growth	46.0% survival, pooled size class data - no significant difference in survival between size classes; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987
Acropora echinata	Branching	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site B, eastern corner	Complete 15–20 cm heads placed on rubble and sand-floored depression on surface of small patch reef	3–5 m	5 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Acropora echinata	Branching	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site C, northern corner	Complete 5–10 cm heads placed on upper surface of coral rubble mound	10–22 m	5 complete heads	1981–1982	Survival, growth	93.3% survival, pooled size class data - no significant difference in survival between size classes; mean growth = 2.27 mm (s.d. = 0.58 mm)	No	Plucer-Rosario and Randall, 1987
Acropora echinata	Branching	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site C, northern corner	Complete 10–15 cm heads placed on upper surface of coral rubble mound	10–22 m	5 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Acropora echinata	Branching	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site C, northern corner	Complete 15–20 cm heads placed on upper surface of coral rubble mound	10–22 me	5 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987

Table 7. Literature Summary matrix for the leaving in place transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora echinata	Branching	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site A, reef slope along south side of bay	Complete 5–10 cm heads placed on rubble and sand substrate	1–2 m	5 complete heads	1981–1982	Survival, growth	13.3% survival, pooled size class data - no significant difference in survival between size classes; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987
Acropora echinata	Branching	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site A, reef slope along south side of bay	Complete 10–15 cm heads placed on rubble and sand substrate	1–2 m	5 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Acropora echinata	Branching	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site A, reef slope along south side of bay	Complete 15–20 cm heads placed on rubble and sand substrate	1–2 m	5 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Acropora echinata	Branching	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site B, reef slope along south side of bay	Complete 5–10 cm heads placed on rubble and sand substrate	3–5 m	5 complete heads	1981–1982	Survival, growth	53.3% survival, pooled size class data - no significant difference in survival between size classes; mean growth = 1.24 mm (s.d. = 0.65 mm)	No	Plucer-Rosario and Randall, 1987
Acropora echinata	Branching	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site B, reef slope along south side of bay	Complete 10–15 cm heads placed on rubble and sand substrate	3–5 m	5 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Acropora echinata	Branching	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site B, reef slope along south side of bay	Complete 15–20 cm heads placed on rubble and sand substrate	3–5 m	5 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987

Table 7. Literature Summary matrix for the leaving in place transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora echinata	Branching	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Cite C, reef slope along south side of bay	Complete 5–10 Cm heads placed n coral rubble substrate	10–22 m	5 complete heads	1981–1982	Survival, growth	6.6% survival, pooled size class data - pooled size class data - no significant difference in survival between size classes; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987
Acropora echinata	Branching	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Cite C, reef slope along south side of bay	Complete 10–15 cm heads placed on coral rubble substrate	10–22 m	5 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Acropora echinata	Branching	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Cite C, reef slope along south side of bay	Complete 15–20 cm heads placed on coral rubble substrate	10–22 m	5 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Acropora intermedia	Branching	N/A	Spawners	North Reef, Lizard Island, Great Barrier Reef, Australia (12 degrees 40 min S, 145 degrees 28 min E)	reef flat, 10-12 m inshore from the crest	Small (6–9 cm) fragments deployed on coral pavement and rubble	0.5–3 m (depending on tide)	5 quadrats, 10 fragments per quadrat, 50 fragments total	Not specified (1996–1997?)	Survival, reattachment fecundity	31% survival after 17 months; see Figure 3 for combined reattachment results, Table 4 for combined fecundity results	No	Smith and Hughes, 1999

Table 7. Literature Summary matrix for the leaving in place transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora intermedia	Branching	N/A	Spawners	North Reef, Lizard Island, Great Barrier Reef, Australia (12 degrees 40 min S, 145 degrees 28 min E)	Reef flat, 10–12 m inshore from the crest	Large (18–20 cm) fragments deployed on coral pavement and rubble	0.5–3 m (depending on tide)	5 quadrats, 10 fragments per quadrat, 50 fragments total	Not specified (1996–1997?)	Survival, reattachment, fecundity	81% survival after 17 months; see Figure 3 for combined reattach-ment results, Table 4 for combined fecundity results	No	Smith and Hughes, 1999
Acropora intermedia	Branching	N/A	Spawners	North Reef, Lizard Island, Great Barrier Reef, Australia (12 degrees 40 min S, 145 degrees 28 min E)	Reef crest	Small (6–9 cm) fragments deployed among live coral dominated by tabular colonies of *Acropora hyacinthus* and live coral fragments	~ 30 cm shallower than reef flat	5 quadrats, 10 fragments per quadrat, 50 fragments total	Not specified (1996–1997?)	Survival, reattachment, fecundity	14% survival after 17 months; see Figure 3 for combined reattachme nt results, Table 4 for combined fecundity results	No	Smith and Hughes, 1999
Acropora intermedia	Branching	N/A	Spawners	North Reef, Lizard Island, Great Barrier Reef, Australia (12 degrees 40 min S, 145 degrees 28 min E)	Reef crest	Large (18–20 cm) fragments deployed among live coral dominated by tabular colonies of *Acropora hyacinthus* and live coral fragments	~ 30 cm shallower than reef flat	5 quadrats, 10 fragments per quadrat, 50 fragments total	Not specified (1996–1997?)	Survival, reattachment, fecundity	38% survival after 17 months; see Figure 3 for combined reattachme nt results, Table 4 for combined fecundity results	No	Smith and Hughes, 1999
Acropora intermedia	Branching	N/A	Spawners	North Reef, Lizard Island, Great Barrier Reef, Australia (12 degrees 40 min S, 145 degrees 28 min E)	Reef slope 5 m offshore from the crest	Small (6–9 cm) fragments deployed on sand with sparse coral cover	6–8 m deeper than reef crest	5 quadrats, 10 fragments per quadrat, 50 fragments total	Not specified (1996–1997?)	Survival, reattachment, fecundity	4% survival after 17 months; see Figure 3 for combined reattachme nt results, Table 4 for combined fecundity results	No	Smith and Hughes, 1999

Table 7. Literature Summary matrix for the leaving in place transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora intermedia	Branching	N/A	Spawners	North Reef, Lizard Island, Great Barrier Reef, Australia (12 degrees 40 min S, 145 degrees 28 min E)	Reef slope 5 m offshore from the crest	Large (18–20 cm) fragments deployed on sand with sparse coral cover	6–8 m deeper than reef crest	5 quadrats, 10 fragments per quadrat, 50 fragments total	Not specified (1996–1997)	Survival, reattachment, fecundity	37% survival after 17 months; see Figure 3 for combined reattachment results, Table 4 for combined fecundity results	No	Smith and Hughes, 1999
Montipora capitata	Massive form	N/A	Spawners	Kaneohe Bay, Hawaii	Not specified	Placed on sandy-rubble area within a dredged reef patch	12.3–4.5 m	200 square meters of coral	2005	Growth	Colonies placed on sand are thriving; rapid coral growth is evident as overgrowth of wires; large branched corals placed on their sides have formed new branches that are growing vertically; small colonies placed on sand are growing rapidly.	N/A	Jokiel, Rodgers, and Farrell, 2005

Table 7. Literature Summary matrix for the leaving in place transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Porites compressa	Massive form	N/A	Spawners	Kaneohe Bay, Hawaii	Not specified	Placed on sandy-rubble area within a dredged reef patch	12.3–4.5 m	200 square meters of coral	2005	Growth	Colonies placed on sand are thriving; rapid coral growth is evident as overgrowth of wires; large branched corals placed on their sides have formed new branches that are growing vertically; small colonies placed on sand are growing rapidly.	N/A	Jokiel, Rodgers, and Farrell, 2005
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cocos Lagoon, Site A, western corner	Complete 5–10 cm heads placed on rubble and sand-veneered reef rock substrate	1–2 m	10 complete heads	1981–1982	Survival, growth	0% survival, no pooled size class data - significant difference in survival between size classes; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cocos Lagoon, Site A, western corner	Complete 10–15 cm heads placed on rubble and sand-veneered reef rock substrate	1–2 m	10 complete heads	1981–1982	Survival, growth	0% survival, no pooled size class data - significant difference in survival between size classes; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cocos Lagoon, Site A, western corner	Complete 15–20 cm heads placed on rubble and sand-veneered reef rock substrate	1–2 m	10 complete heads	1981–1982	Survival, growth	0% survival	No	Plucer-Rosario and Randall, 1987

Table 7. Literature Summary matrix for the leaving in place transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# Of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cocos Lagoon, Site A, western corner	2–4 cm shards scattered on rubble and sand-veneered reef rock substrate	12 m	200 shards	1981–1982	Survival	0% survival	No	Plucer-Rosario and Randall, 1987
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cocos Lagoon, Site B, eastern corner	complete 5–10 cm heads placed on rubble and sand-floored depression on surface of small patch reef	3–5 m	10 complete heads	1981–1982	Survival, growth	16.6% survival, pooled size class data - no significant difference in survival between size classes; mean growth = 1.19 mm (s.d. = 0.27 mm)	No	Plucer-Rosario and Randall, 1987
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cocos Lagoon, Site B, eastern corner	complete 10–15 cm heads placed on rubble and sand-floored depression on surface of small patch reef	3–5 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cocos Lagoon, Site B, eastern corner	complete 15–20 cm heads placed on rubble and sand-floored depression on surface of small patch reef	3–5 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cocos Lagoon, Site B, eastern corner	2–4 cm shards scattered on rubble and sand-floored depression on surface of small patch reef	3–5 m	200 shards	1981–1982	Survival	0% survival	No	Plucer-Rosario and Randall, 1987

Table 7. Literature Summary matrix for the leaving in place transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cocos Lagoon, Site C, northern corner	Complete 5–10 cm heads placed on upper surface of coral rubble mound	10–22 m	10 complete heads	1981–1982	Survival, growth	76.0% survival, pooled size class data - no significant difference in survival between size classes; mean growth = 1.21 mm (s.d. = 0.53 mm)	No	Plucer-Rosario and Randall, 1987
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cocos Lagoon, Site C, northern corner	Complete 10–15 cm heads placed on upper surface of coral rubble mound	10–22 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cocos Lagoon, Site C, northern corner	Complete 15–20 cm heads placed on upper surface of coral rubble mound	10–22 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cocos Lagoon, Site C, northern corner	2–4 cm shards scattered on upper surface of coral rubble mound	10–22 m	200 shards	1981–1982	Survival	11.5% survival	No	Plucer-Rosario and Randall, 1987
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cetti Bay, Site A, reef slope along south side of bay	Complete 5–10 cm heads placed on rubble and sand substrate	1–2 m	10 complete heads	1981–1982	Survival, growth	36.6% survival, pooled size class data - no significant difference in survival between size classes; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cetti Bay, Site A, reef slope along south side of bay	Complete 10–15 cm heads placed on rubble and sand substrate	1–2 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cetti Bay, Site A, reef slope along south side of bay	Complete 15–20 cm heads placed on rubble and sand substrate	1–2 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987

Table 7. Literature Summary matrix for the leaving in place transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation Of Success	Cost Data	Reference
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cetti Bay, Site A, reef slope along south side of bay	2–4 cm shards scattered on rubble and sand substrate	1–2 m	200 shards	1981–1982	Survival	0% survival	No	Plucer-Rosario and Randall, 1987
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cetti Bay, Site B, reef slope along south side of bay	Complete 5–10 cm heads placed on rubble and sand substrate	3–5 m	10 complete heads	1981–1982	Survival, growth	13.3% survival, pooled size class data - no significant difference in survival between size classes; mean growth = 0.61 mm (s.d. = 0.16 mm)	No	Plucer-Rosario and Randall, 1987
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cetti Bay, Site B, reef slope along south side of bay	Complete 10–15 cm heads placed on rubble and sand substrate	3–5 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cetti Bay, Site B, reef slope along south side of bay	Complete 15–20 cm heads placed on rubble and sand substrate	3–5 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cetti Bay, Site B, reef slope along south side of bay	2–4 cm shards scattered on rubble and sand substrate	3–5 m	200 shards	1981–1982	Survival	2.0% survival	No	Plucer-Rosario and Randall, 1987
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cetti Bay, Cite C, reef slope along south side of bay	Complete 5–10 cm heads placed on coral rubble substrate	10–22 m	10 complete heads	1981–1982	Survival, growth	30.0% survival, pooled size class data - no significant difference in survival between size classes; mean growth = 0.81 mm (s.d. = 0.05 mm)	No	Plucer-Rosario and Randall, 1987
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cetti Bay, Cite C, reef slope along south side of bay	Complete 10–15 cm heads placed on coral rubble substrate	10–22 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987

Table 7. Literature Summary matrix for the leaving in place transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cetti Bay, Cite C, reef slope along south side of bay	Complete 15–20 cm heads placed on coral rubble substrate	10–22 m	10 complete heads	1981–1982	Survival, growth	30.0% survival, pooled size class data - no significant difference in survival between size classes; mean growth = 0.81 mm (s.d. = 0.05 mm)	No	Plucer-Rosario and Randall, 1987
Leptoseris gardineri	Large colonies with horizontal, unifacial, subdividing fronds	N/A	Not determined	Guam, Marianas Islands	Cetti Bay, Cite C, reef slope along south side of bay	2–4 cm shards scattered on coral rubble substrate	10–22 m	200 shards	1981–1982	Survival	4.5% survival	No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site A, western corner	Complete 5–10 cm heads placed on rubble and sand-veneered reef rock substrate	1–2 m	10 complete heads	1981–1982	Survival, growth	10.0% survival, pooled size class data - no significant difference in survival between size classes; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site A, western corner	Complete 10–15 cm heads placed on rubble and sand-veneered reef rock substrate	1–2 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site A, western corner	Complete 15–20 cm heads placed on rubble and sand-veneered reef rock substrate	1–2 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site A, western corner	2–4 cm shards scattered on rubble and sand-veneered reef rock substrate	1–2 m	200 shards	1981–1982	Survival	0% survival	No	Plucer-Rosario and Randall, 1987

Table 7. Literature Summary matrix for the leaving in place transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site B, eastern corner	Complete 5–10 cm heads placed on rubble and sand-floored depression on surface of small patch reef	3–5 m	10 complete heads	1981-1982	Survival, growth	26.6% survival, pooled size class data - no significant difference in survival between size classes; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site B, eastern corner	Complete 10–15 cm heads placed on rubble and sand-floored depression on surface of small patch reef	3–5 m	10 complete heads	1981-1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site B, eastern corner	Complete 15–20 cm heads placed on rubble and sand-floored depression on surface of small patch reef	3–5 m	10 complete heads	1981-1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site B, eastern corner	2–4 cm shards scattered on rubble and sand-floored depression on surface of small patch reef	3–5 m	200 shards	1981-1982	Survival	3.0% survival	No	Plucer-Rosario and Randall, 1987

Table 7. Literature Summary matrix for the leaving in place transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric Of Success	Quantitation of Success	Cost Data	Reference
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site C, northern corner	Complete 5–10 cm heads placed on upper surface of coral rubble mound	10–22 m	10 complete heads	1981. Table 7.	Survival, growth	73.3% survival, pooled size class data - no significant difference in survival between size classes; mean growth = 0.65 mm (s.d. = 0.32 mm)	No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site C, northern corner	Complete 10–15 cm heads placed on upper surface of coral rubble mound	10–22 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site C, northern corner	Complete 15–20 cm heads placed on upper surface of coral rubble mound	10–22 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site C, northern corner	2–4 cm shards scattered on upper surface of coral rubble mound	10–22 m	200 shards	1981–1982	Survival	21.5% survival	No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site A, reef slope along south side of bay	Complete 5–10 cm heads placed on rubble and sand substrate	1–2 m	10 complete heads	1981–1982	Survival, growth	10.0% survival, pooled size class data - no significant difference in survival between size classes; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site A, reef slope along south side of bay	Complete 10–15 cm heads placed on rubble and sand substrate	1–2 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site A, reef slope along south side of bay	Complete 15–20 cm heads placed on rubble and sand substrate	1–2 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987

Table 7. Literature Summary matrix for the leaving in place transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Ramets Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site A, reef slope along south side of bay	Table 7, 4 cm shards scattered on rubble and sand substrate	Table 7. 2 meters	200 shards	1981–1982	Survival	0.5% survival	No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site B, reef slope along south side of bay	Complete 5–10 cm heads placed on rubble and sand substrate	3–5 m	10 complete heads	1981–1982	Survival, growth	43.3% survival, pooled size class data - no significant difference in survival between size classes; mean growth = 0.75 mm (s.d. = 0.21 mm)	No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site B, reef slope along south side of bay	Complete 10–15 cm heads placed on rubble and sand substrate	3–5 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site B, reef slope along south side of bay	Complete 15-20 cm heads placed on rubble and sand substrate	3–5 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site B, reef slope along south side of bay	2-4 cm shards scattered on rubble and sand substrate	3–5 m	200 shards	1981–1982	Survival	4.5% survival	No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Cite C, reef slope along south side of bay	Complete 5-10 cm heads placed on coral rubble substrate	10–22 m	10 complete heads	1981–1982	Survival, growth	50.0% survival, pooled size class data - no significant difference in survival between size classes; mean growth = 0.55 mm (s.d. = 0.17 mm)	No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Cite C, reef slope along south side of bay	Complete 10-15 cm heads placed on coral rubble substrate	10–22 m	10 complete heads	1981-1982	survival, growth		No	Plucer-Rosario and Randall, 1987

Table 7. Literature Summary matrix for the leaving in place transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Cite C, reef slope along south side of bay	Complete 15-20 cm heads placed on coral rubble substrate	10-22 meters	10 complete heads	1981-1982	Survival, growth	50.0% survival, pooled size class data - no significant difference in survival between size classes; mean growth = 0.55 mm (s.d. = 0.17 mm)	No	Plucer-Rosario and Randall, 1987
Montipora pulcherrima	Very thin, contorted unifacial laminae with irregular coenosteum ridges	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Cite C, reef slope along south side of bay	2–4 cm shards scattered on coral rubble substrate	10–22 m	200 shards	1981–1982	Survival	1.5% survival	No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site A, western corner	Complete 5–10 cm heads placed on rubble and sand-veneered reef rock substrate	1–2 m	10 complete heads	1981–1982	Survival, growth	26.6% survival, pooled size class data - no significant difference in survival between size classes; mean growth = 0.66 mm (s.d. = 0.07 mm)	No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site A, western corner	Complete 10–15 cm heads placed on rubble and sand-veneered reef rock substrate	1–2 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site A, western corner	Complete 15–20 cm heads placed on rubble and sand-veneered reef rock substrate	1–2 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site A, western corner	2–4 cm shards scattered on rubble and sand-veneered reef rock substrate	1–2 m	200 shards	1981–1982	survival	6.0% survival	No	Plucer-Rosario and Randall, 1987

Table 7. Literature Summary matrix for the leaving in place transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site B, eastern corner	Complete 5–10 cm heads placed on rubble and sand-floored depression on surface of small patch reef	3–5 m	10 complete heads	1981–1982	Survival, growth	56.6% survival, pooled size class data - no significant difference in survival between size classes; mean growth = 0.84 mm (s.d. = 0.23 mm)	No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site B, eastern corner	Complete 10–15 cm heads placed on rubble and sand-floored depression on surface of small patch reef	3–5 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site B, eastern corner	Complete 15–20 cm heads placed on rubble and sand-floored depression on surface of small patch reef	3–5 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site B, eastern corner	2–4 cm shards scattered on rubble and sand-floored depression on surface of small patch reef	3–5 m	200 shards	1981–1982	Survival	33.5% survival	No	Plucer-Rosario and Randall, 1987

Table 7. Literature Summary matrix for the leaving in place transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site C, northern corner	Complete 5–10 cm heads placed on upper surface of coral rubble mound	10-22 m	10 complete heads	1981–1982	Survival, growth	86.6% survival, pooled size class data - no significant difference in survival between size classes; mean growth = 0.62 mm (s.d. = 0.31 mm)	No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site C, northern corner	Complete 10–15 cm heads placed on upper surface of coral rubble mound	10-22 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site C, northern corner	Complete 15–20 cm heads placed on upper surface of coral rubble mound	10-22 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site C, northern corner	3–6 cm nubbins glued to terra cotta bricks with epoxy and placed on upper surface of coral rubble mound	10–22 m	8 nubbins/brick, 7 bricks, 56 nubbins total	1981–1982	Survival, growth	98.2% survival; mean growth = 1.29 mm (s.d. = 0.40 mm)	No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cocos Lagoon, Site C, northern corner	2–4 cm shards scattered on upper surface of coral rubble mound	10–22 m	200 shards	1981–1982	Survival	15.0% survival	No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site A, reef slope along south side of bay	Complete 5–10 cm heads placed on rubble and sand substrate	1–2 m	10 complete heads	1981–1982	Survival, growth	40.0% survival, pooled size class data - no significant difference in survival between size classes; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site A, reef slope along south side of bay	Complete 10–15 cm heads placed on rubble and sand substrate	1–2 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987

Table 7. Literature Summary matrix for the leaving in place transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site A, reef slope along south side of bay	Complete 15–20 cm heads placed on rubble and sand substrate	1–2 m	10 complete heads	1981–1982	Survival, growth	40.0% survival, pooled size class data - no significant difference in survival between size classes; no samples with measurable growth (see text)	No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site A, reef slope along south side of bay	2–4 cm shards scattered on rubble and sand substrate	1–2 m	200 shards	1981–1982	Survival	15.0% survival	No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site B, reef slope along south side of bay	Complete 5–10 cm heads placed on rubble and sand substrate	3–5 m	10 complete heads	1981-1982	Survival, growth	20.0% survival, pooled size class data - no significant difference in survival between size classes; mean growth = 0.33 mm (s.d. = 0.09 mm)	No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site B, reef slope along south side of bay	Complete 10–15 cm heads placed on rubble and sand substrate	3–5 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site B, reef slope along south side of bay	Complete 15–20 cm heads placed on rubble and sand substrate	3–5 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Site B, reef slope along south side of bay	2–4 cm shards scattered on rubble and sand substrate	3–5 m	200 shards	1981–1982	Survival	3.0% survival	No	Plucer-Rosario and Randall, 1987

Table 7. Literature Summary matrix for the leaving in place transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Cite C, reef slope along south side of bay	Complete 5–10 cm heads placed on coral rubble substrate	10–22 m	10 complete heads	1981–1982	Survival, growth	83.3% survival, pooled size class data - no significant difference in survival between size classes; mean growth = 0.62 mm (s.d. = 0.31 mm)	No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Cite C, reef slope along south side of bay	Complete 10–15 cm heads placed on coral rubble substrate	10–22 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Cite C, reef slope along south side of bay	Complete 15–20 cm heads placed on coral rubble substrate	10–22 m	10 complete heads	1981–1982	Survival, growth		No	Plucer-Rosario and Randall, 1987
Pavona cactus	Small domed colonies composed of thin, undulating plates	N/A	Spawners	Guam, Marianas Islands	Cetti Bay, Cite C, reef slope along south side of bay	2–4 cm shards scattered on coral rubble substrate	10–22 m	200 shards	1981–1982	Survival	8.5% survival	No	Plucer-Rosario and Randall, 1987
Acropora hyacinthus	Plate-like or tabular	N/A	Spawners	North Reef, Lizard Island, Great Barrier Reef, Australia (12 degrees 40 min S, 145 degrees 28 min E)	Reef flat, 10–12 m inshore from the crest	Small (6–9 cm) fragments deployed on coral pavement and rubble	0.5–3 m (depending on tide)	5 quadrats, 10 fragments per quadrat, 50 fragments total	Not specified (1996–1997?)	Survival, reattachment, fecundity	9% survival after 17 months; see Figure 3 for combined reattachment results, Table 4 for combined fecundity results	No	Smith and Hughes, 1999
Acropora hyacinthus	Plate-like or tabular	N/A	Spawners	North Reef, Lizard Island, Great Barrier Reef, Australia (12 degrees 40 min S, 145 degrees 28 min E)	Reef flat, 10–12 m inshore from the crest	Large (18–20 cm) fragments deployed on coral pavement and rubble	0.5–3 m (depending on tide)	5 quadrats, 10 fragments per quadrat, 50 fragments total	Not specified (1996-1997?)	Survival, reattachment, fecundity	29% survival after 17 months; see Figure 3 for combined reattachment results, Table 4 for combined fecundity results	No	Smith and Hughes, 1999

Table 7. Literature Summary matrix for the leaving in place transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora hyacinthus	Plate-like or tabular	N/A	Spawners	North Reef, Lizard Island, Great Barrier Reef, Australia (12 degrees 40 min S, 145 degrees 28 min E)	Reef crest	Small (6–9 cm) fragments deployed among live coral dominated by tabular colonies of *Acropora hyacinthus* and live coral fragments	~ 30 cm shallower than reef flat	5 quadrats, 10 fragments per quadrat, 50 fragments total	Not specified (1996–1997?)	Survival, reattachment, fecundity	0% survival after 17 months; see Figure 3 for combined reattachment results, Table 4 for combined fecundity results	No	Smith and Hughes, 1999
Acropora hyacinthus	Plate-like or tabular	N/A	Spawners	North Reef, Lizard Island, Great Barrier Reef, Australia (12 degrees 40 min S, 145 degrees 28 min E)	Reef crest	Large (18–20 cm) fragments deployed among live coral dominated by tabular colonies of *Acropora hyacinthus* and live coral fragments	~ 30 cm shallower than reef flat	5 quadrats, 10 fragments per quadrat, 50 fragments total	Not specified (1996–1997?)	Survival, reattachment, fecundity	14% survival after 17 months; see Figure 3 for combined reattachment results, Table 4 for combined fecundity results	No	Smith and Hughes, 1999
Acropora hyacinthus	Plate-like or tabular	N/A	Spawners	North Reef, Lizard Island, Great Barrier Reef, Australia (12 degrees 40 min S, 145 degrees 28 min E)	Reef slope 5 m offshore from the crest	Small (6–9 cm) fragments deployed on sand with sparse coral cover	6–8 m deeper than reef crest	5 quadrats, 10 fragments per quadrat, 50 fragments total	Not specified (1996–1997?)	Survival, reattachment, fecundity	0% survival after 17 months; see Figure 3 for combined reattachment results, Table 4 for combined fecundity results	No	Smith and Hughes, 1999
Acropora hyacinthus	Plate-like or tabular	N/A	Spawners	North Reef, Lizard Island, Great Barrier Reef, Australia (12 degrees 40 min S, 145 degrees 28 min E)	Reef slope 5 m offshore from the crest	Large (18–20 cm) fragments deployed on sand with sparse coral cover	6–8 m deeper than reef crest	5 quadrats, 10 fragments per quadrat, 50 fragments total	Not specified (1996–1997?)	Survival, reattachment, fecundity	2% survival after 17 months; see Figure 3 for combined reattachment results, Table 4 for combined fecundity results	No	Smith and Hughes, 1999

Table 7. Literature Summary matrix for the leaving in place transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora millipora	Corymbose branching	N/A	Spawners	North Reef, Lizard Island, Great Barrier Reef, Australia (12 degrees 40 min S, 145 degrees 28 min E)	Reef flat, 10–12 m inshore from the crest	Small (6–9 cm) fragments deployed on coral pavement and rubble	0.5–3 m (depending on tide)	5 quadrats, 10 fragments per quadrat, 50 fragments total	Not specified (1996–1997?)	Survival, reattachment, fecundity	5% survival after 17 months; see Figure 3 for combined reattachment results, Table 4 for combined fecundity results	No	Smith and Hughes, 1999
Acropora millipora	Corymbose branching	N/A	Spawners	North Reef, Lizard Island, Great Barrier Reef, Australia (12 degrees 40 min S, 145 degrees 28 min E)	Reef flat, 10–12 m inshore from the crest	Large (18–20 cm) fragments deployed on coral pavement and rubble	0.5–3 m (depending on tide)	5 quadrats, 10 fragments per quadrat, 50 fragments total	Not specified (1996–1997?)	Survival, reattachment, fecundity	47% survival after 17 months; see Figure 3 for combined reattachment results, Table 4 for combined fecundity results	No	Smith and Hughes, 1999
Acropora millipora	Corymbose branching	N/A	Spawners	North Reef, Lizard Island, Great Barrier Reef, Australia (12 degrees 40 min S, 145 degrees 28 min E)	Reef crest	Small (6–9 cm) fragments deployed among live coral dominated by tabular colonies of *Acropora hyacinthus* and live coral fragments	~ 30 cm shallower than reef flat	5 quadrats, 10 fragments per quadrat, 50 fragments total	Not specified (1996–1997?)	Survival, reattachment, fecundity	8% survival after 17 months; see Figure 3 for combined reattachment results, Table 4 for combined fecundity results	No	Smith and Hughes, 1999
Acropora millipora	Corymbose branching	N/A	Spawners	North Reef, Lizard Island, Great Barrier Reef, Australia (12 degrees 40 min S, 145 degrees 28 min E)	Reef crest	Large (18–20 cm) fragments deployed among live coral dominated by tabular colonies of *Acropora hyacinthus* and live coral fragments	~30 cm shallower than reef flat	5 quadrats, 10 fragments per quadrat, 50 fragments total	Not specified (1996–1997?)	Survival, reattachment, fecundity	19% survival after 17 months; see Figure 3 for combined reattachment results, Table 4 for combined fecundity results	No	Smith and Hughes, 1999

Table 7. Literature Summary matrix for the leaving in place transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora millipora	Corymbose branching	N/A	Spawners	North Reef, Lizard Island, Great Barrier Reef, Australia (12 degrees 40 min S, 145 degrees 28 min E)	Reef slope 5 m offshore from the crest	Small (6–9 cm) fragments deployed on sand with sparse coral cover	6–8 m deeper than reef crest	5 quadrats, 10 fragments per quadrat, 50 fragments total	Not specified (1996–1997?)	Survival, reattachment, fecundity	4% survival after 17 months; see Figure 3 for combined reattachment results, Table 4 for combined fecundity results	No	Smith and Hughes, 1999
Acropora millipora	Corymbose branching	N/A	Spawners	North Reef, Lizard Island, Great Barrier Reef, Australia (12 degrees 40 min S, 145 degrees 28 min E)	Reef slope 5 m offshore from the crest	Large (18–20 cm) fragments deployed on sand with sparse coral cover	6–8 m deeper than reef crest	5 quadrats, 10 fragments per quadrat, 50 fragments total	Not specified (1996–1997?)	Survival, reattachment, fecundity	15% survival after 17 months; see Figure 3 for combined reattachment results, Table 4 for combined fecundity results	No	Smith and Hughes, 1999

Out of 61 experiments that used the leave-in-place method, only one experiment had a 100% success rate (Table 8). This method worked best on dome/lobate/massive corals and was least successful on branching corals. Size and morphology of the transplant and placement in deep water contributed to the 100% mortality of corals in five studies. In one study with a 100% success rate, whole coral heads were transplanted (not branching corals or coral nubbins), and corals were located in oceanographic conditions similar to their indigenous habitat (e.g., light intensity and water depth).

Table 8. Success and failure of the leave-in-place methodology based on coral morphology.

Success Rate (10 = 100%; 0 = 0%)	Branching Coral Studies	Massive with Branches Studies	Dome/lobate/ Massive Studies	Mound/ Plate Studies	Soft Coral Studies	Species Not Identified Studies
10	0	N/A	1	N/A	N/A	N/A
9	2	N/A	2	N/A	N/A	N/A
8	0	N/A	2	N/A	N/A	N/A
7	0	N/A	0	N/A	N/A	N/A
6	1	N/A	2	N/A	N/A	N/A
5	3	N/A	2	N/A	N/A	N/A
4	3	N/A	3	N/A	N/A	N/A
3	0	N/A	4	N/A	N/A	N/A
2	4	N/A	7	N/A	N/A	N/A
1	5	N/A	9	N/A	N/A	N/A
0	0	N/A	5	N/A	N/A	N/A

4.4. BIOLOGICAL RESTORATION - METHOD 1: REPRODUCTIVE METHODS

4.4.1 Introduction

Preservation of genetic diversity is essential for the maintenance of stable productivity in ecosystems (Tilman and Downing, 1994). The simple and rapid process of using asexual recruits (Figures 11 and 12) does not contribute to the genetic variability of a population. As a result, the use of sexual recruits is more favorable, although it is a longer and more complex process (Rinkevich, 2005).

Figure 11. Coral larvae collection (Photo provided by NOAA SEFSC).

Figure 12. Reproductive settling onto a plate-like device (Photo courtesy of Keys Marine Laboratory).

Two ways are recommended. The first is based on the suggestion for transplantation of coral colonies carrying eggs (Fucik, Bright, and Goodman, 1984; Richmond and Hunter, 1990). Gravid colonies may be carefully detached from their substrates by hammer and chisel and transplanted to denuded areas in containers of seawater or, if possible, carried under water over shorter distances during the peak of their reproductive season, just before shedding their planula-larvae. Through this method, planktonic coral larvae are introduced into new areas within the reefs that were previously inaccessible to them as a result of local water movement, currents, tides, and/or highly stressed areas. The approach is more applicable to brooding coral species that release highly developed planula larvae, such as in *Manicina areolata* and *Stylophora pistillata* (Rinkevich and Loya, 1979; Johnson, 1992), and to coral species in which planulae settle within a short period of release (reviewed in Harrison and Wallace,1990). In this case, dispersal of a majority of planulae is likely to be limited, promoting settlement near parent colonies or within the natal reef. The transplantation of the gravid colonies is done carefully to minimize any harm to the colonies, which consequently may reduce their reproductive output (Rinkevich and Loya, 1987, 1989). A group of several colonies is used as “reproductive seed” in a denuded area. A similar approach was successfully tested by Bouchon, Jaubert, and Bouchon-Navaaro (1981). They transported 42 coral colonies belonging to 21 genera into an underwater locality (Jordan coast, Red Sea) that was devoid of coral reefs. One year later, 16 newly settled colonies, belonging to six genera, were counted, showing the feasibility of this approach (in addition to the fact that 64 % of the colonies transplanted survived and contributed to this new, semi-artificial reef).

The second approach fits reef corals that reproduce either by broadcasting of gametes or by planulae brooding, the two most common strategies (Fadlallah, 1983; Harrison et al., 1984; Shlesinger and Loya, 1985; Szmant , 986; Harrison and Wallace, 1990; Soong, 1991; Gittings et al., 1992). Collection of the reproductive products is carried out in the field by plankton nets (Rinkevich & Loya, 1979) or in the laboratory (Yates & Carlson, 1993) by transferring gravid colonies into aquaria just before they spawn gametes or shed planula-larvae. The major benefit of this approach is based on the experience that under laboratory conditions many of the larvae settle and metamorphose (Harrigan, 1972; Rinkevich & Loya, 1979; Goreau, Goreau, and Hayes, 1981; Sato, 1985; Harrison and Wallace, 1990). Settlement under laboratory conditions are conducted on artificial objects (e.g., plastic substrates) or on natural substrates (e.g., pieces of coral skeletons or mollusk shells). The

type of substrate can influence both the number and type of recruits and the efficiency of data collection (Harriott and Fisk, 1987). New established colonies can transfer to the field and glue to the natural substrates by underwater epoxy cement. Several studies documented that larva settled in the laboratory and thereafter returned to the reef survived well and grew (Harrison & Wallace, 1990). These juvenile corals survived better in experimentally manipulated microhabitats not affected by direct sedimentation, not exposed to direct grazing activities, and not occupied by rapidly growing filamentous algae (Sato, 1985).

After a mass coral spawning event, Heyward, Smith, Reese, and Field (2002) collected the surface slick of eggs, sperm, and larvae and placed it in floating larval culture ponds. An estimated 4 million coral embryos of 18 Acropora species were captured. After a 7-day maturation period, larvae were delivered by gravity through a hose to settlement tents covering terracotta tiles. On control sites, beyond the tents, natural coral settlement was less than 1 recruit per tile over a 3-week period. In contrast, the number of recruits per tile within the nets ranged from 0.17 to 68 with a 20-minute input of larvae and 80 to 384 in tents with a 12-hour larval input. The experiment documented the mass larval seeding can enhance settlement significantly; however, this specific method is limited to areas with predictable mass spawning followed by large slicks of gametes and larvae.

Another method that can potentially enhance the rate of coral larval settlement is the use of settlement attractors, such as glycosaminoglycan (a sulfated polysaccharide). This is produced by a coralline alga (*Hydrolithon boergesenii*) and induces *Agaricia agaricites* and *Agaricia humilis* larvae to settle (Morse, 1994; Morse and Morse, 1996; Morse et al., 1996). Products similar to settlement attractors (which is equivalent to the coral flypaper) could be developed for other species and synthesized doe use in restoration projects; however, we are unaware of any restoration projects that have applied this method.

Recent artificial larval culturing for reef restoration has been focused on the genus Acropora, a few members of the family Faviidae, and on brooders such as the genus Pocillopora. The sexual propagation approach may result in genetically more diverse corals, but this approach is labor-intensive and more expensive than the asexual propagation method. Accurate timing of coral spawning is critical when obtaining coral gametes or fertilized eggs. Cultivation of corals from eggs are attempted either by using larvae collected from surface aggregates (slicks) after mass spawning or by laboratory fertilization. If spawn slicks are utilized, then natural levels of genetic variation can be attained without collecting sperm/egg bundles from donor colonies. The embryos and larvae are then bred in the laboratory or in floating ponds in situ until larvae (planulae) are able to settle to the bottom (Omori, 2011).

Cultured planulae can be used for restoration in two main ways: (1) they may be released directly onto the seabed of degraded reefs or artificial reefs at very high densities and allowed to settle naturally, or (2) they may be settled onto artificial substrata and reared in aquaria or in situ nurseries until they are ready to be transplanted to degraded reefs. A technique that combined floating larval rearing ponds with direct seeding has been tried in Western Australia and Okinawa (Heyward et al. 2002; Omori, Aota, Watanuk, Tanigughi, 2004). The results have shown that early recruitment can be significantly enhanced; however, the majority of these settled corals died due to natural processes. Therefore, at present, this method is not favored as a reef rehabilitation technique until positive evidence of a long-term effect has been demonstrated. The coral planulae may settle on materials such as concrete, ceramic or terracotta tiles. However, conditioning of the substrata is essential before attempting larval settlement because larvae follow special chemical signals emitted by certain bacteria and coralline algae on the substrata (Morse et al. 1996). They settle well onto

substrata that have been placed on the seabed a month or more beforehand, allowing coralline algae and bacterial films to grow on the surface. The larvae metamorphose into polyps (juvenile corals) after settlement. Juvenile corals are then cultured in aquaria or in situ nurseries until they are ready to be out-planted. Concurrently, algae-eating juvenile top-shell snails *Trochus niloticus* Linnaeus, 1767 are released into nurseries so that algae do not smother the corals on the substrata. In late 2006, 18 months after egg culture, colonies of *Acropora tenuis* (Dana, 1846) had grown to an average 5.8 cm in diameter in cages suspended in the sea; they were then transplanted experimentally onto the seabed near Akajima (Omori, Iwao, and Tamura, 2008). In June 2009, some of these 4-year-old colonies, as well as 5-year-old ones, had grown to 20–25 cm in diameter and spawned initially, showing the possibility of using this technique to assist coral reef restoration (Iwao, Omori, Taniguchi, and Tamura, 2010).

4.4.2 Literature Review

As seen in Table 9, we found 17 studies where this methodology was used.

Table 9. Literature Summary matrix for the Reproductive Settling transplant methodologies.

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms /Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Stylophora pistillata	Branching	N/A	Brooder	Gulf of Eliat, Red Sea	Nutrient-enriched mid-water floating nursery	N/A	10–12 m	11–14 colonies	2005–2006	Maximum # of released planulae per colony; % survival and % settled.	34–106 planulae; 6%0-68% survival; 27.1%–36.1% settlement	N/A	Amar & Rinkevich, 2007
Stylophora pistillata	Branching	N/A	Brooder	Coral Nature Preserve, Eliat, Israel, N. Red Sea	Not specified	Nursery consisting of iron rod and sandy bottom	5–10 m	400 polyps	1997–1999	Survival	41% after 3 months	N/A	Epstein et al., 2001
Stylophora pistillata	Branching	N/A	Brooder	Marine Biology Lab & Coral Nature Preserve, Eliat, Israel, N. Red Sea	Not specified	Settling of gametes onto cement tiles.	Experiment 1: 10–12 m	60 & 40 colonies	1997–1999	Survivorship	25% at MLB site and 82.5% at NR Site	N/A	Epstein et al., 2001
Stylophora pistillata	Branching	N/A	Brooder	Coral Nature Preserve, Eliat, Israel, N. Red Sea	Not specified	Settling of gametes onto crates with plastic net	Experiment 2: 5–10 m	310 branches	1997–1999	Growth & survivorship	Growth: 0.5%–45%: survivorship: 83% after 6 months and 61% after 18 months.	N/A	Epstein et al., 2001
Family *Acroporidae*	Branching	N/A	Spawners	Coral Bay, Western Australia	Spawning slicks found on the ocean surface skimmed off and put into settling ponds.	1.8 m in diameter pool made of food-grade, nylon reinforced vinyl fabric positioned into a PVC raft frame that measures 2 x 2 m. Frame is held in place by car tire inner tubes positioned under each corner of the PVC frame. Bilges pump in seawater and mesh windows allow for seawater exchange. The larval rearing ponds is placed over terra cotta tiles onto which settling occurs at 4 sites within Coral Bay.	Not specified	Not specified	1997	Survivorship & recruitment	5% of the original stock was surviving after 6 days; 6539 coral recruits were counted on the terra cotta tiles 4 weeks after seeding. 60% settled on the lower horizontal surfaces of the tiles; 33% settled on the vertical surfaces and 7% settled on the upper surfaces of the tiles. Range of 0.17-384 recruits per tile. Majority of recruits were from the family Acroporidae and only 18 were from pocilloporidae.	N/A	Heyward et al., 2002

Table 9. Literature Summary matrix for the Reproductive Settling transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms /Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Family *Pocillioporidae*	Branching	N/A	Brooders	Coral Bay, Western Australia	Spawning slicks found on the ocean surface skimmed off and put into settling ponds.	1.8 m in diameter pool made of food-grade, nylon reinforced vinyl fabric positioned into a PVC raft frame that measures 2 x 2 m. Frame is held in place by car tire inner tubes positioned under each corner of the PVC frame. Bilges pump in seawater and mesh windows allow for seawater exchange. The larval rearing ponds is placed over terra cotta tiles onto which settling occurs at 4 sites within Coral Bay.	Not specified	Not specified	1997	Survivorship & recruitment	5% of the original stock was surviving after 6 days; 6539 coral recruits were counted on the terra cotta tiles 4 weeks after seeding. 60% settled on the lower horizontal surfaces of the tiles; 33% settled on the vertical surfaces and 7% settled on the upper surfaces of the tiles. Range of 0.17–384 recruits per tile. majority of recruits were from the Family Acroporidae and only 18 were from Pocilloporidae.	N/A	Heyward et al., 2002
Acropora sp.	Branching	N/A	Spawners	Okinotorishima Island, Japan	Very strong waves & currents that wash away coral eggs and hinder larval settlement.	Corals were taken from Okinotorishima Island and moved to the Akajima Coral Hatchery where they were they were spawned in tanks and coral spawns allowed to grow on tiles. Tiles were then re-planted out at Okinotorishima Island.	Not specified	40 colonies	2006–2007	% survival	80% survival 3 months after spawning.	N/A	Miyaji et al., 2008

Table 9. Literature Summary matrix for the Reproductive Settling transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms /Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora tenuis	Branching	N/A	Spawner	Okinotorishima and Okinawa, Japan	Very strong waves & currents that wash away coral eggs and hinder larval settlement.	Corals were taken from Okinotorishima Island and moved to the akajima coral hatchery where they were they were spawned in tanks and coral spawns allowed to grow on unglazed ceramic tiles from Seto Ceramic Research Center. Tiles were then re-planted out at Okinotorishima Island. The substrate consisted of two substrates fixed 1 cm apart on a rod with corals on its top and protected by vinyl-coated wire cages with a mesh size of about 5 cm.	About 6 m	63000 juvenile corals	2007–2008	Increase in coral cover	A significant increase in coral cover was recorded only on the unshaded corals, or coral on the upper substrate, within cages and increased fourfold over the 14 months. This is due to the fact that the cages kept the corals free of predation and nibbling by fishes.	Yes	Nakamura et al., 2011

Table 9. Literature Summary matrix for the Reproductive Settling transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora tenuis	Branching	N/A	Spawner	Okinotorishima and Okinawa, Japan	Very strong waves & currents that wash away coral eggs and hinder larval settlement.	Corals were taken from Okinotorishima Island and moved to the Akajima Coral Hatchery where they were they were spawned in tanks and coral spawns allowed to grow on unglazed ceramic tiles from SETO Ceramic Research Center. Tiles were then re-planted out at Okinotorishima Island. The substrate consisted of two substrates fixed 1 cm apart on a rod with corals on its top without the vinyl-coated wire cages with a mesh size of about 5 cm.	About 6 m	63000 juvenile corals	2007–2008	Increase in coral cover	A significant decrease in coral cover on the shaded corals, or those on the lower substrate, occurred from 8 to 10 months after transplantation and then increased gradually over the last 4 month.	Yes	Nakamura et al., 2011

Table 9. Literature Summary matrix for the Reproductive Settling transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora tenuis	Branching	N/A	Spawner	Okinotorishima and Okinawa, Japan	Very strong waves & currents that wash away coral eggs and hinder larval settlement.	Corals were taken from Okinotorishima Island and moved to the Akajima Coral Hatchery where they were they were spawned in tanks and coral spawns allowed to grow on unglazed ceramic tiles from Seto Ceramic Research center. Tiles were then re-planted out at Okinotorishima Island. The substrate consisted of two substrates fixed 3 cm apart on a rod with corals facing each other without e vinyl-coated wire cages.	About 6 m	63000 juvenile corals	2007–2008	Increase in coral cover	A significant decrease in coral cover on the shaded corals, or those on the lower substrate, occurred from 8 to 10 months after transplantation and then increased gradually over the last 4 month.	Yes	Nakamura et al., 2011
Antipathes pennacea	Branching	N/A	Spawner	Jamaica	High water turbidity; secchi disc minimum 2 m.	Sunken ship from 1944	6.5 m	Natural settlement	1981–1982	Locational occurrence, basal stem lengths maximum tree height	Majority of occurrence restricted to the hull of the ship; max. Basal stem circumference was 101 mm (32.2 mmm in diameter); max height was 2 m although most found fell between 0.5 and 1 m in height.	No	Oakley, 1998

Table 9. Literature Summary matrix for the Reproductive Settling transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora sp.	Branching	N/A	Spawner	Manado, Indonesia	Small patch reefs on sandy bottom around the Likupang Marine Station of Sam Ratulangi University.	Marine blocks on sandy bottom	7–8 m	Corals were spawned, settled and raised on coral settlement devices for 1.5 years then transplanted onto marine blocks.	2009	Coral cover	Grew well; 4 of 7 colonies grew to >13 cm.	No	Okamoto et al., 2012
Pavona sp.	Leafy	N/A	Spawner	Manado, Indonesia	Small patch reefs on sandy bottom around the Likupang Marine Station of Sam Ratulangi University.	Marine Blocks on sandy bottom	7–8 m	Corals were spawned, settled and raised on coral settlement devices for 1.5 years then transplanted onto marine blocks.	2009	Coral cover	Did not grow well	No	Okamoto et al., 2012
Porites sp.	Branching	N/A	Spawner	Manado, Indonesia	Small patch reefs on sandy bottom around the Likupang Marine Station of Sam Ratulangi University.	Marine Blocks on sandy bottom	7–8 m	Corals were spawned, settled and raised on coral settlement devices for 1.5 years then transplanted onto marine blocks.	2009	Coral cover	Did not grow well	No	Okamoto et al., 2012
Acropora tenuis	Branching	N/A	Spawner	Miyako Island, Okinawa, Japan	Area of high grazing and sedimentation.	Plastic cages just below the surface of the water where polyps were attached to cement concrete plates.	3–4 m	Not specified	2004	Growth	10–39 polyps on each plate grew to colonies of about 40 mm in diameter.	No	Omori, 2005
Acropora spp.	Branching	N/A	Spawner	Akajima Marine Science Laboratory, Okinawa, Japan	Pond environment	Concrete or potter's clay tiles.	1.5–3.0 m	430,000 larvae settled out.	2006	Colony size	Average colony size of 5.8 cm in diameters	No	Omori, 2008
Dendronephthya hemprichi	Branching	N/A	Brooder	Coral Nature Preserve, Eliat, Israel, N. Red Sea	Oil contaminated waters	Steel wire with PVC plates	7 m	# of planulae not specified	1991	Survivorship	8%-110%	N/A	Oren and Benayahu, 1997
Dendronephthya hemprichi	Branching	N/A	brooder	Coral Nature Preserve, Eliat, Israel, N. Red Sea	Oil contaminated waters	Steel wire with PVC plates	11 m	# of planulae not specified	1991	Survivorship	15%-45%	N/A	Oren and Benayahu, 1997

Table 9. Literature Summary matrix for the Reproductive Settling transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Dendronephthya hemprichi	Branching	N/A	Brooder	Coral Nature Preserve, Eliat, Israel, N. Red Sea	Oil contaminated waters	Steel wire with PVC plates	15 m	# of planulae not specified	1991	Survivorship	8%-55%	N/A	Oren and Benayahu, 1997
Dendronephthya hemprichi	Branching	N/A	Brooder	Coral Nature Preserve, Eliat, Israel, N. Red Sea	Oil contaminated waters	Steel wire with PVC plates	17 m	# of planulae not specified	1991	Survivorship	25%-55%	N/A	Oren and Benayahu, 1997
Stylophora pistillata	Branching	N/A	Brooder	Coral Nature Preserve, Eliat, Israel, N. Red Sea	Oil and phosphate contaminated waters	Steel wire with PVC plates	6 m	# of planulae not specified	1991	Survivorship	10%-15%	N/A	Oren and Benayahu, 1997
Stylophora pistillata	Branching	N/A	Brooder	Coral Nature Preserve, Eliat, Israel, N. Red Sea	Oil and phosphate contaminated waters	Steel wire with PVC plates	14 m	# of planulae not specified	1991	Survivorship	75%-90%	N/A	Oren and Benayahu, 1997
Stylophora pistillata	Branching	N/A	Brooder	Coral Nature Preserve, Eliat, Israel, N. Red Sea	Oil and phosphate contaminated waters	Steel wire with PVC plates	7 m	# of planulae not specified	1991	Survivorship	15%-35%	N/A	Oren and Benayahu, 1997
Stylophora pistillata	Branching	N/A	Brooder	Coral Nature Preserve, Eliat, Israel, N. Red Sea	Oil and phosphate contaminated waters	Steel wire with PVC plates	11 m	# of planulae not specified	1991	Survivorship	25%-75%	N/A	Oren and Benayahu, 1997
Stylophora pistillata	Branching	N/A	Brooder	Coral Nature Preserve, Eliat, Israel, N. Red Sea	Oil and phosphate contaminated waters	Steel wire with PVC plates	15 m	# of planulae not specified	1991	Survivorship	15%-75%	N/A	Oren and Benayahu, 1997
Pocillopora damicornis	Bushy shape with branching	N/A	Brooder	Philippines	Laboratory aquaria	Laboratory aquaria	Not specified	# of planulae not specified	Not specified	Survivorship	47.5% survival for the 10-29 mm size class corals	N/A	Raymundo, 2003
Alveopora daedalea	Massive form (can grow in columns)	N/A	Brooder	Lab study	Lab study	Water with a low electrical current (0.75–1 volt)	Not specified	# of planulae not specified	1992	Settlement	>80% settled within 5 minutes	N/A	Goren, 1992

Table 9. Literature Summary matrix for the Reproductive Settling transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora hyacinthus	Plates with branchlets	N/A	Spawners	Lizard Island, Great Barrier Reef, Australia	Moderately exposed, off-shore reef area	26 racks	2 meters	Not specified	1994–1995	Location of maximum recruitment	Recruitment of Acroporaidae, Pocilloporidae and Poritidae species were 20 times lower for panels placed underneath *A. hyacinthus* than those in the open; bryzoans were four times higher under *A. hyacinthus* than in the open; rate of mortality of Pocillioprids was three times higher under the *A. hyacinthus* than on the open crest.	N/A	Baird and Hughes, 2000
None transplanted	N/A	N/A	N/A	Komodo National Park, Indonesia	Area of known blast fishing	Piles of quarried rock; 0.5 Table 9. 2.0 m^3 rock piles installed at each of 9 rubble sites.	Not specified	Not specified	1998–2001	Colonization	15.7 scleractinian recruits per m^2 per year and they were about 2–4 cm in diameter.	$5–10/$m^2$	Fox and Pet, 2001.
None transplanted	N/A	N/A	N/A	Komodo National Park, Indonesia (NK, BZ, NP, SS, KM, RS, BP, MI, MP)	Former fish blasting site	Rubble fields created by chronic blasting of variant currents.	6–10 m	1 m^2 plots of three different designs: (1) wide mesh fishing net attached to rubble with U-shaped rebar pins; (2) cement slabs pinned to rubble; (3) piles of rocks on top of the rubble (20-40 cm high and 20-30 cm in diameter).	1998	Coral recruitment	During the first 3 years, rock stabilization plots has the highest hard coral recruitment and cover, followed by cement and netting and lastly, untreated rubble.	Yes	Fox et al., 2005

Table 9. Literature Summary matrix for the Reproductive Settling transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
None transplanted	N/A	N/A	N/A	Komodo National Park, Indonesia (NK, BZ, NP, SS, KM, RS, BP, MI, MP)	Former fish blasting site	Rubble fields created by chronic blasting of variant currents.	6–10 m	100 m^2 plots of piles of rocks (limestone and lithic stone) on top of the rubble (70–90 cm high and spaced 2–4 m apart).	1998	Coral recruitment	Within a year, hard coral recruits showed up that were 2–4 cm in diameter and ranged from 1 recruit/m^2 to 40 recruits/m^2. After 2 years, the numbers of colonies had stopped increasing and started decreasing. Acropora and montipora were seen. Soft corals were seen at some sites and grew very quickly (*xenia* sp.).	Yes	Fox et al., 2005
None transplanted	N/A	N/A	N/A	Komodo National Park, Indonesia (NK, BZ, NP, SS, KM, RS, BP, MI, MP)	Former fish blasting site	Rubble fields created by chronic blasting of variant currents.	6–10 m	>1000 m^2 plots of 4 rock pile designs: (1) complete coverage (75 cm high); (2) 1–3 m^3 rock piles placed every 2–3 m; (3) spur & groove morphology parallel to the prevailing current; and (4) spur & groove perpendicularly to the current (75 cm high, 2 m wide, spaced every 2–3 m).	1998	Coral recruitment	After one year, mean of 7.3 recruits/m^2 at a mean size of 7.5 cm per recruit.	Yes	Fox et al., 2005
Acropora sp.	Not specified down to species level	N/A	Spawners	Sekisei Lagoon, Okinawa Island	Not specified	Ceramic coral settlement device on sandy bottom	10–15 meters	1803 coral settled	2002	Settlement	1803 coral settled	N/A	Okamoto, Nojima, Fujiwara, and Furushima, 2008

Table 9. Literature Summary matrix for the Reproductive Settling transplant methodologies (continued).

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Family Pocilloporidae	Not specified down to species level	N/A	Spawners	Sekisei Lagoon, Okinawa Island	Not specified	Ceramic coral settlement device on sandy bottom	10–15 m	88 corals settled	2002	Settlement	88 corals settled	N/A	Okamoto et al., 2008
unidentified species	Not specified down to species level	N/A	Spawners	Sekisei Lagoon, Okinawa Island	Not specified	Ceramic coral settlement device on sandy bottom	10–15 m	191 corals settled	2002	Settlement	191 corals settled	N/A	Okamoto et al., 2008
Stony & soft corals	N/A	N/A	N/A	Gulf of Eliat, Red Sea.	Underwater observatory; currents were 7–17 cm/s.	3 fixed (motionless) and 3 floating (motionful) arrays of vertical & horizontal-facing plastic plates.	13 m		2003	Size and number of coral spat	Coral recruits were mostly found at the fixed installations, mainly at the seabed and mid modules, where current velocities were lowest. Pooled march 2003 data (no differences between installations) showed total of 506 soft coral and 92 stony coral recruits after 6 months. Stony corals recruited only to shallow sites, mostly on the module nearest the seabed. The observatory site had higher coral recruitment of stony corals compared to the other 2 sites. The number of stony coral recruits increased from march to September 2003. The number of soft coral recruits significantly increased between march and September 2003, reaching an average of nearly 3 colonies per plate face (116 cm^2) at the observatory and south jetty.	No	Perkol-Finkel et al., 2006

Table 9. Literature Summary matrix for the Reproductive Settling transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Stony & soft corals	N/A	N/A	N/A	Gulf of Eliat, Red Sea	Underwater observatory; currents were 7–17 cm/s	3 fixed (motionless) and 3 floating (motionful) arrays of vertical & horizontal-facing plastic plates	13 m		2003	Size and number of coral spat	Coral recruits were mostly found at the fixed installations, mainly at the seabed and mid modules, where current velocities were lowest. Pooled march 2003 data (no differences between installations) showed total of 506 soft coral and 92 stony coral recruits after 6 months. Stony corals recruited only to shallow sites, mostly on the module nearest the seabed. The observatory site had higher coral recruitment of stony corals compared to the other 2 sites. The number of stony coral recruits increased from march to September 2003. The number of soft coral recruits significantly increased between march and September 2003, reaching an average of nearly 3 colonies per plate face (116 cm^2) at the observatory and south jetty.	No	Perkol-Finkel et al., 2006

Table 9. Literature Summary matrix for the Reproductive Settling transplant methodologies (continued).

Species	Morphology type	Biomarker	Reproduction Strategy	Geographic Location	Exposure conditions (temperature/storms/nutrient levels)	Substrate	Water depth	# of colonies transplanted/Rametes settled	Year	Study Metric of success	Quantitation of success	Cost data	Reference
Stony & soft corals	N/A	N/A	N/A	Gulf of Eliat, Red Sea.	North Oil Jetty currents were 7–17 cm/s.	3 fixed (motionless) and 3 floating (motionful) arrays of vertical & horizontal-facing plastic plates.	13 m		2003	Size and number of coral spat		No	Perkol-Finkel et al., 2006
Stony & soft corals	N/A	N/A	N/A	Gulf of Eliat, Red Sea.	South Oil Jetty; currents were 5–1 cm/s.	3 fixed (motionless) and 3 floating (motionful) arrays of vertical & horizontal-facing plastic plates.	28 m		2003	Size and number of coral spat		No	Perkol-Finkel et al., 2006

All 18 experiments were conducted on branching corals. Only one experiment resulted in 100% success, and no experiments had 100% mortality (Table 10). For the one study that a 100% success rate, success was attributed to low sedimentation rates, low coverage of turf-algae, minimal grazing by sea urchins and absence of the competitor tunicate *Didemnum sp*. Success was also attributed to the settlement apparatus deployed beforehand, allowing coralline algae and bacterial films to grow on the surface and the release of snails to curb algae growth for maintenance purposes. In general, mortality in these studies were due to predation by fish, high current conditions and small morphological sizes; high temperature and light intensity; and exposure of the corals to air.

Table 10. Success/failure of the reproductive settling methodology based on coral morphology.

Success Rate (10 = 100%; 0 = 0%)	Branching Coral Studies	Massive with Branches Studies	Dome/Lobate/ Massive Studies	Mound/ Plate Studies	Soft Coral Studies	Species Not Identified Studies
10	1	N/A	N/A	N/A	N/A	N/A
9	2	N/A	N/A	N/A	N/A	N/A
8	2	N/A	N/A	N/A	N/A	N/A
7	2	N/A	N/A	N/A	N/A	N/A
6	3	N/A	N/A	N/A	N/A	N/A
5	3	N/A	N/A	N/A	N/A	N/A
4	1	N/A	N/A	N/A	N/A	N/A
3	1	N/A	N/A	N/A	N/A	N/A
2	0	N/A	N/A	N/A	N/A	N/A
1	3	N/A	N/A	N/A	N/A	N/A
0	0	N/A	N/A	N/A	N/A	N/A

4.5. BIOLOGICAL RESTORATION METHOD 2: NURSERY

4.5.1 Introduction

This section discusses transplantation to a nursery (Figures 13 and 14) after an event such as a hurricane or ship grounding, or to protect the integrity of a species, like the endangered Acroporids. A coral nursery may be considered as a pool for local species that supplies reef-managers with unlimited coral colonies for sustainable management; however, recoverability depends on the stressor, the impacted species/community, and the temporal and spatial intensities of the stressor. The larger the transplanted fragment, the greater the probability of survival (Garrison and Ward, 2012).

Figure 13. Acropora nursery (Photo courtesy of the Coral Restoration Foundation).

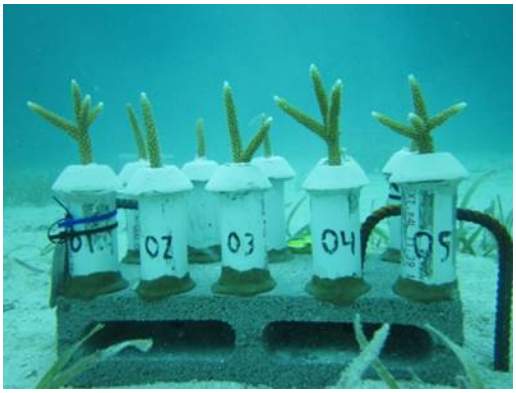

Figure 14. Fragments being reared for outplanting in a nursery (Photo courtesy of the University of Miami's Rosenstiel School of Marine & Atmospheric Sciences).

4.5.2 Literature Review

As seen in Table 11, we found 12 studies where this methodology was used.

Table 11. Literature Summary Matrix for nursery transplant methodologies.

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora palmata, Acropora cervicornis and Agaricia agaricites	Branching	N/A	Spawners	Isla Mujeres, Cancun National Park, Quintana Roo, Mexico	Area impacted by hurricanes and ship groundings; good current flow and good water quality	Block nursery	10–30 feet	900 fragments from healthy wild colonies; 60 were outplanted to a spot impacted by a ship grounding.	Not specified	Survivorship of outplants	The nursery itself had less than <70% survival.	N/A	Baca et al., in Johnson et al., 2011
Acropora sp.	Branching	N/A	Spawners	Guayanilla, Puerto Rico	Poor visibility area with good exposure to swells and currents.	Floating underwater coral apparatus nursery (PVC) on sand/rubble depressions of an existing reef and then outplanted to where the M/V Margara grounded in 2006.	40–50 feet	>1000 fragments from the grounding site were collected, planted on the nursery and then outplanted back to the ship scar area.	2006	Survivorship of outplants	90%	N/A	Griffin & Moore in Johnson et al., 2011

Table 11. Literature Summary matrix for nursery transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# Of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora cervicornis	Branching	6 different *Acropora cervicornis* genotypes were used.	Spawners	Puerto Rico, where the T/V Margara ran aground in 2006.	N/A	Damaged fragments from the ship grounding sites were transplanted onto line nurseries. Each line nursery had a 3 m tall by 3 m wide frame made of schedule 80 PVC pipe and 9 rows of monofilament line.	9–15 m	10 line nurseries were established and 712 fragments were hung, using rubber coated wire, line and cable ties, on the lines. The average size of each fragment was 4.4 cm.	2010–2011	Growth rate (linear and max diameter) and survival	5 genotypes of the 6 were unique. After 1 year, the average maximum diameter of the fragments was 21.7 cm and the average linear growth rate was 52.5 cm/year. 25% mortality was found at the 9 m depth site. 0.3 m increase in depth was associated with a 4.2 cm increase in growth rate and 1.0 cm increase in maximum diameter. Cable tie method was worst for linear growth and diameter.	No	Griffin et al., 2012
Acropora cervicornis	Branching	N/A	Spawners	Biscayne Bay National Park, Florida	Underwater nursery	Clippings cemented to cinder blocks with cement "pucks" in a nursery	6 m	88 fragments	2007	Growth & survivorship	Fragment mortality of 17.3% within the first 8 weeks after transplantation; >5 cm fragments grew faster than the <3 cm and 3–5 cm size classes.	N/A	Herlan and Lirman, 2008
Acropora cervicornis	Branching	N/A	Spawner	Biscayne Bay National Park, Miami, Florida	Staghorn coral nursery	Fragment tips glued to ceramic disks while with exposure to air within the nursery	5.5 m	15 donor colonies 2.5 cm in size	2009	Growth and survivorship of donor colonies	87% mortality; average growth rate of 5.4 cm/yr.; pruning of branching colonies maximizes coral productivity.	No	Lirman et al., 2010

Table 11. Literature Summary matrix for nursery transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# Of Colonies Transplanted/Rametes Settled	Year	Study Metric Of Success	Quantitation Of Success	Cost Data	Reference
Acropora cervicornis	Branching	N/A	Spawner	Biscayne Bay National Park, Miami, Florida	Staghorn coral nursery	Fragment tips glued to ceramic disks while with exposure to air within the nursery	5.5 m	15 donor colonies 3.5 cm in size	2009	Growth and survivorship of donor colonies	13% mortality; average growth rate of 7.6 cm/yr.; pruning of branching colonies maximizes coral productivity.	No	Lirman et al., 2010
Acropora cervicornis	Branching	N/A	Spawner	Biscayne Bay National Park, Miami, Florida	Staghorn coral nursery	Fragment tips glued to ceramic disks while with exposure to air within the nursery	5.5 m	12 donor colonies 2.5 cm in size	2009	Growth and survivorship of donor colonies	8 % mortality; average growth rate of 5.4 cm/yr.; pruning of branching colonies maximizes coral productivity.	No	Lirman et al., 2010
Acropora cervicornis	Branching	N/A	Spawner	Biscayne Bay National Park, Miami, Florida	Staghorn coral nursery	Fragment tips glued to ceramic disks while with exposure to air within the nursery	5.5 m	12 donor colonies 3.5 cm in size	2009	Growth and survivorship of donor colonies	0% mortality; average growth rate of 7.6 cm/yr.; pruning of branching colonies maximizes coral productivity.	No	Lirman et al., 2010
Acropora cervicornis	Branching	N/A	Spawners	University of Florida's Tropical Aquaculture Laboratory (TAL) in Rusking, Florida	Fiberglass tanks with synthetic salt water and RO/DI filtered freshwater	Corals sit on plastic grating	N/A	60 transplants taken were taken to TAL	Not specified	Outplanting	72 fragments have been outplanted to molassess reef, fl., in 25 feet of water, epoxied onto plastic pyramids and monitored. They have survived and are all growing well.	N/A	Marshall et al., in Johnson et al., 2011

Table 11. Literature Summary matrix for nursery transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora cervicornis	Branching	N/A	Spawners	Nova Southeastern University in Dania, Florida	Fiberglass tank with fresh seawater	Corals sit on plastic grating	N/A	60 were transplanted on an offshore nursery for growth comparison.	Not specified	Outplanting	72 fragments have been outplanted to molassess reef, fl., in 25 feet of water, epoxied onto plastic pyramids and monitored. They have survived and are all growing well.	N/A	Marshall et al., in Johnson et al., 2011
Acropora cervicornis	Branching	N/A	Spawners	Tavernier Key, Upper Florida Keys, Florida	Stressed environment with fine sand bottom	Block nursery, line nursery or coral tree nursery; corals grown on the block nurseries are outplanted on pucks epoxied to the substrate. Corals raised on line or tree nurseries are epoxied directly to the substrate.	30 feet	95 donor colonies collected to supplement the genetic diversity in the reef; more than 1500 corals have been successfully outplanted to 31 sites on 10 different reefs off the Upper Florida Keys.	Not specified	Survivorship and spawning of transplants to other sites	70% survival of outplants; spawning was observed in 2009, only 2 years after out-planting.	N/A	Nedimyer, in Johnson et al., 2011

Table 11. Literature Summary matrix for nursery transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora cervicornis and Acropora palmata	Branching	N/A	Spawners	Oracabessa Bay, St. Mary, Jamaica	Good wave and shore motion without sediment inputs	Nurseries made of PEET, plastic and sand screws was anchored into clean sand close to shore.	2–6 meters; 7 meters max depth	800–1000 from 4 nearby donor colonies; ouplantings: more than 200 40 to ›100 cm (total branching length) corals have been outplanted to three sites 500 m east of the nurseries in March, June, and July 2011.	2009–2011	No metrics because it was set-up to be a snorkeling garden	No metrics because it was set-up to be a snorkeling garden; permanent surgeon's knotDrop-loop attachment points, good for larger corals; however, tied drop-lines are preferable for very small corals.	N/A	Ross in Johnson et al., 2011
Acropora eurostoma	Branching	N/A	Spawners	Eilat, Israel, Red Sea	Nutrient-enriched fish farm	Floating nursery	6 meters	1 coral colony	2001	Growth	1.66%/day after 306 days	Yes	Shafir et al., 2006
Acropora eurostoma	Branching	N/A	Spawners	Eilat, Israel, Red Sea	Nutrient-enriched fish farm	Floating nursery	6 meters	687 fragments	2001	% Survival of rametes	52.1%-63.3%	Yes	Shafir et al., 2006
Acropora pharaonis	Branching	N/A	Spawners	Eilat, Israel, Red Sea	Nutrient-enriched fish farm	Floating nursery	6 meters	1 coral colony	2001	Growth	1.86%/day after 144 days	Yes	Shafir et al., 2006
Acropora pharaonis	Branching	N/A	Spawners	Eilat, Israel, Red Sea	Nutrient-enriched fish farm	Floating nursery	6 meters	527 fragments	2001	% Survival of rametes	48.60%	Yes	Shafir et al., 2006
Acropora valida	Branching	N/A	Spawners	Eilat, Israel, Red Sea	Nutrient-enriched fish farm	Floating nursery	6 meters	1 coral colony	2001	Growth	1.66%/day after 306 days	Yes	Shafir et al., 2006
Acropora valida	Branching	N/A	Spawners	Eilat, Israel, Red Sea	Nutrient-enriched fish farm	Floating nursery	6 meters	1054 fragments	2001	% Survival of rametes	74.50%	Yes	Shafir et al., 2006
Pocillopora damicornis	Branching	N/A	Spawners	Eilat, Israel, Red Sea	Nutrient-enriched fish farm	Floating nursery	6 meters	4 coral colonies	2001	Growth	1.56%/day after 144 days	Yes	Shafir et al., 2006
Pocillopora damicornis	Branching	N/A	Spawners	Eilat, Israel, Red Sea	Nutrient-enriched fish farm	Floating nursery	6 meters	3043 fragments	2001	% Survival of rametes	63.8%-73.1%	Yes	Shafir et al., 2006
Stylophora pistillata	Branching	N/A	Brooder	Eilat, Israel, Red Sea	Nutrient-enriched fish farm	Floating nursery	6 meters	3 coral colonies	2001	Growth	1.88%/day after 144 days	Yes	Shafir et al., 2006
Stylophora pistillata	Branching	N/A	Brooder	Eilat, Israel, Red Sea	Nutrient-enriched fish farm	Floating nursery	6 meters	1502 fragments	2001	% Survival of rametes	63%-76.9%	Yes	Shafir et al., 2006
Acropora formosa	Branching	N/A	Spawners	Boliano, Philippines	Typhoon-prominent area	Rock structures comprised of dead coral skeletons of massive corals	2- 4 meters	36	2005–2007	% Mortality, detachment, partial mortality and bleaching	Table 2	N/A	Shaish, Levy, Katzir, and Rinkevich, 2010

Table 11. Literature Summary matrix for nursery transplant methodologies (continued).

Species	Morphology type	Biomarker	Reproduction Strategy	Geographic Location	Exposure conditions (temperature/storms/nutrient levels)	Substrate	Water depth	# of colonies transplanted/ Rametes settled	Year	Study Metric of success	Quantitation of success	Cost data	Reference
Montipora digitata	Branching	N/A	Spawners	Boliano, Philippines	Typhoon-prominent area	Rock structures comprised of dead coral skeletons of massive corals	2–4 m	360	2005-2007	% Mortality, detachment, partial mortality and bleaching	Table 2	N/A	Shaish et al., 2010
Pocillopora damicornis	Branching	N/A	Spawners	Boliano, Philippines	Typhoon-prominent area	Rock structures comprised of dead coral skeletons of massive corals	2–4 m	360	2005-2007	% Mortality, detachment, partial mortality and bleaching	Table 2	N/A	Shaish et al., 2010
Acropora pulchra	Branching	N/A	Spawners	Behind the breakwater of Henchun Power Plant in southern Taiwan	Protected from waves, with ample sunlight penetration and more or less constant flow rate of water	Nursery made of iron and plastic rods with coral attached by fishing line; entire structure was attached to the sandy bottom	6 m	20 branches of 1cm fragment size	2003	New branch development	3 new branches after 3 months; 8 new branches after 4 months	N/A	Soong & Chen, 2003
Acropora pulchra	Branching	N/A	Spawners	Behind the breakwater of Henchun Power Plant in southern Taiwan	Protected from waves, with ample sunlight penetration and more or less constant flow rate of water	Nursery made of iron and plastic rods with coral attached by fishing line; entire structure was attached to the sandy bottom	6 m	20 branches of 4 cm fragment size	2003	New branch development	6 new branches after 3 months; 17 new branches after 4 months	N/A	Soong & Chen, 2003
Acropora pulchra	Branching	N/A	Spawners	Behind the breakwater of Henchun Power Plant in southern Taiwan	Protected from waves, with ample sunlight penetration and more or less constant flow rate of water	Nursery made of iron and plastic rods with coral attached by fishing line; entire structure was attached to the sandy bottom	6 meters	20 branches of 7 cm fragment size	2003	New branch development	8 new branches after 3 month and 18 new branches after 4 months.	N/A	Soong & Chen, 2003

Table 11. Literature Summary matrix for nursery transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora pulchra	Branching	N/A	Spawners	Behind the breakwater of Henchun Power Plant in southern Taiwan	Protected from waves, with ample sunlight penetration and more or less constant flow rate of water	Nursery made of iron and plastic rods with coral attached by fishing line; entire structure was attached to the sandy bottom	6 m	40 branches of 4-cm fragment size	2003	New branch development under different orientations above the distal bifurcation	6 new branches after 3 months and 17 new branches after 4 months	N/A	Soong & Chen, 2003
Acropora pulchra	Branching	N/A	Spawners	Behind the breakwater of Henchun Power Plant in southern Taiwan	Protected from waves, with ample sunlight penetration and more or less constant flow rate of water	Nursery made of iron and plastic rods with coral attached by fishing line; entire structure was attached to the sandy bottom	6 m	40 branches of 4-cm fragment size	2003	New branch development under different orientations below the distal bifurcation	16 new branches after 3 months and 18 new branches after 4 months.	N/A	Soong & Chen, 2003
Acropora pulchra	Branching	N/A	Spawners	Behind the breakwater of Henchun Power Plant in southern Taiwan	Protected from waves, with ample sunlight penetration and more or less constant flow rate of water	Nursery made of iron and plastic rods with coral attached by fishing line; entire structure was attached to the sandy bottom	6 m	20 branches of 6-cm fragment size	2003	New branch development on fragments hung at distal end up	8 new branches after 4 months	N/A	Soong & Chen, 2003
Acropora pulchra	Branching	N/A	Spawners	Behind the breakwater of Henchun Power Plant In southern Taiwan	Protected from waves, with ample sunlight penetration and more or less constant flow rate of water	Nursery made of iron and plastic rods with coral attached by fishing line; entire structure was attached to the sandy bottom	6 m	20 branches of 6-cm fragment size	2003	New branch development on fragments hung distal end down	2 new branches after 4 months	N/A	Soong & Chen, 2003

Table 11. Literature Summary matrix for nursery transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora pulchra	Branching	N/A	Spawners	Behind the breakwater of Henchun Power Plant in southern Taiwan	Protected from waves, with ample sunlight penetration and more or less constant flow rate of water	Nursery made of iron and plastic rods with coral attached by fishing line; entire structure was attached to the sandy bottom	6 m	15 branches of 6-cm fragment size	2003	New branch development on injured and non-injured corals	After 2 months, there were 9 new branches on the non-injured corals. After 3 months, there were 9 new branches on the non-injured corals and 4 new branches on the injured coral.	N/A	Soong & Chen, 2003
Acropora pulchra	Branching	N/A	Spawners	Behind the breakwater of Henchun Power Plant in southern Taiwan	Protected from waves, with ample sunlight penetration and more or less constant flow rate of water	Nursery made of iron and plastic rods with coral attached by fishing line; entire structure was attached to the sandy bottom	5 m	40 branches of 4-cm fragment size	2003	New branch development at 5-m depth	After 3 months, there were 9 new branches and after 4 months there were 18 new branches	N/A	Soong & Chen, 2003
Acropora pulchra	Branching	N/A	Spawners	Behind the breakwater of Henchun Power Plant in Southern Taiwan	Protected from waves, with ample sunlight penetration and more or less constant flow rate of water	Nursery made of iron and plastic rods with coral attached by fishing line; entire structure was attached to the sandy bottom	10 m	40 branches of 4-cm fragment size	2003	New branch development at 10-m depth	After 3 months there were 3 new branches and after 4 months there were 8 new branches.	N/A	Soong & Chen, 2003

Table 11. Literature Summary matrix for nursery transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora tenuis	Corymbose plates with neat, evenly spaced branches	N/A	Spawners	Akajima Coral Hatchery, Okinawa (nursery)	BROODSTOCK: 2.16 m^3 fiberglass (outdoor), 0.39 m^3 PC (indoor) tanks, 50% SW exchange per hr., light intensity 622 to 1566 µmol per m2 per sec, V = ~ 10 cm per sec, T = 21.8–29.0 °C; LARVAE: reared in var. 30–500 L PC tanks, 75% SW exchange per day for 4–5 days, then moved to 0.544 m^3 tanks for settling; JUVENILES: moved after settling to 1.664 m^3 outdoor tanks, 50% SW exchange per hour, light intensity = 554–1059 µmol per m^2 per sec, temperature = 20.9–29.0 °C	JUVENILES: 12 x 12 x 2.5 cm unglazed ceramic tiles with 1.5 x 1.5 cm openings	BROODSTOCK: 0.8–0.9 m; JUVENILES: ≤0.4 m	110848 larvae settled	2006–2008	Survival, growth	Subset of 116 juvenile colonies tracked; total survival after 10 months = 65622 colonies	Yes	Nakamura et al., 2011
Acropora tenuis	Corymbose plates with neat, evenly spaced branches	N/A	Spawners	Okinotorishima Island (outplant site)	24.7–29.7 °C monthly avg. surface water temperature (May 2007–April 2008); light intensity at 5 m around noon in fair weather = ~ 1000 µmol per m^2 per sec (May 2007)	Treatment A: two ceramic tiles fixed 1 cm apart on steel rod with corals on upper surfaces; rod anchored to substrate w/ epoxy and protected by ~5 cm mesh vinyl-coated wire cage	~ 6 m; 50, 100 or 150 cm above sea floor	564 (total) ceramic tiles outplanted	2008–2010	Survival, growth	43 ceramic tile/juvenile colony pairs selected for tracking; only upper tile of pair showed significant increase (nearly 4x) in % coverage over 22 mos.	Yes	Nakamura et al., 2011

Table 11. Literature Summary matrix for nursery transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Acropora tenuis	Corymbose plates with neat, evenly spaced branches	N/A	Spawners	Okinotorishima Island (outplant site)	24.7–29.7 °C monthly avg. surface water temperature (May 2007–April 2008); light intensity at 5 m around noon in fair weather = ~ 1000 µmol per m^2 per sec (May 2007)	Treatment B: as in A, but w/o cage	~6 m; 50, 100 or 150 cm above sea floor	564 (total) ceramic tiles outplanted	2008-2010	Survival, growth	33 ceramic tile/juvenile colony pairs selected for tracking; no significant increase in % coverage for either tile over 22 mos.	Yes	Nakamura et al., 2011
Acropora tenuis	Corymbose plates with neat, evenly spaced branches	N/A	Spawners	Okinotorishima Island (outplant site)	24.7–29.7 °C monthly avg. surface water temperature (May 2007–April 2008); light intensity at 5 m around noon in fair weather = ~1000 µmol per m^2 per sec (May 2007)	Treatment C: two ceramic tiles fixed 3 cm apart on steel rod with corals opposing each other; rod anchored to reef w/ epoxy (no cage)	~6 m; 50, 100 or 150 cm above sea floor	564 (total) ceramic tiles outplanted	2008–2010	Survival, growth	32 ceramic tile/juvenile colony pairs selected for tracking; no significant increase in % coverage for either tile over 22 mos.	Yes	Nakamura et al., 2011
Echinopora lamellosa	Encrusting/ submassive/ leaf-like	N/A	Spawners	Boliano, Philippines	Typhoon-prominent area	Rock structures comprised of dead coral skeletons of massive corals.	2–4 m	360	2005–2007	% mortality, detachment, partial mortality and bleaching	Table 2	N/A	Shaish et al., 2010
Merulina aequituberculata	Encrusting/ submassive/ leaf-like	N/A	Brooder	Boliano, Philippines	Typhoon-prominent area	Rock structures comprised of dead coral skeletons of massive corals.	2–4 m	0	2005–2007	% mortality, detachment, partial mortality and bleaching	Table 2	N/A	Shaish et al., 2010
Merulina scabricula	Encrusting/ submassive/ leaf-like	N/A		Boliano, Philippines	Typhoon-prominent area	Rock structures comprised of dead coral skeletons of massive corals.	2–4 m	36	2005–2007	% mortality, detachment, partial mortality and bleaching	Table 2	N/A	Shaish et al., 2010

Table 11. Literature Summary matrix for nursery transplant methodologies (continued).

Species	Morphology Type	Biomarker	Reproduction Strategy	Geographic Location	Exposure Conditions (Temperature/Storms/ Nutrient Levels)	Substrate	Water Depth	# Of Colonies Transplanted/ Rametes Settled	Year	Study Metric of Success	Quantitation of Success	Cost Data	Reference
Porites rus	Encrusting/ submassive/ leaf-like	N/A	Spawners	Boliano, Philippines	Typhoon-prominent area	Rock structures comprised of dead coral skeletons of massive corals.	2–4 m	36	2005–2007	% mortality, detachment, partial mortality and bleaching	Table 2	N/A	Shaish et al., 2010

All 16 experiments were conducted on branching corals. No experiments resulted in a 100% success mortality rate (Table 12). Successes found among nursery studies were credited to the location of corals in an unshaded and upward-facing direction; the use of corals nubbins instead of adult corals; and the ability to locate the nursery in a shallow-water area with limited wave action, easy accessibility, and nearby donor populations (without predation or tourism pressures). Low success rates were caused by storm impacts, high irradiation, elevated seawater temperatures, and predation.

Table 12. Success/failure of the nursery methodology based on coral morphology.

Success Rate (10 =100%; 0 = 0%)	Branching Coral Studies	Massive with Branches Studies	Dome/ Lobate/ Massive Studies	Mound/ Plate Studies	Soft Coral Studies	Species Not Identified Studies
10	0	N/A	N/A	N/A	N/A	N/A
9	1	N/A	N/A	N/A	N/A	N/A
8	8	N/A	N/A	N/A	N/A	N/A
7	1	N/A	N/A	N/A	N/A	N/A
6	0	N/A	N/A	N/A	N/A	N/A
5	1	N/A	N/A	N/A	N/A	N/A
4	0	N/A	N/A	N/A	N/A	N/A
3	0	N/A	N/A	N/A	N/A	N/A
2	0	N/A	N/A	N/A	N/A	N/A
1	5	N/A	N/A	N/A	N/A	N/A
0	0	N/A	N/A	N/A	N/A	N/A

4.6. RESEARCH NEEDS

As stated by Ken Nedimyer from the Coral Restoration Foundation in Key Largo, FL., "Scientists are probably five years away from really being able to answer questions concerning the optimal design for coral restoration and transplant work while maintain genetic diversity" (Byrne, 2013). During our review of relevant literature, we identified the following data gaps that require further research:

- We must determine if localized restoration at scales of hectares can cascade benefits to down-current areas at scales of tens of hectares or square kilometers.
- We must discover if small, community-based reef restoration projects can produce viable and sustainable functioning reef areas and whether there is a minimum size needed for sustainability (relevant to the wider issue of the minimum size needed for marine protected areas to be effective).
- Further research is needed in a number of areas, including optimum laboratory conditions for culture, species-specific responses to culture (based on the work of Richmond, 1995), the efficacy of adding an ocean nursery period to the grow-out phase, an economic evaluation of culture, long-term impacts of fusion on colony stability, length of time to reproductive maturity in transplants, attributes in corals that underpin inter- and intra-specific differences in their sensitivity to thermal stress, ocean acidification and pollutants and coral responses transplantation stress.
- We must use studies that analyze growth rates in different genera of natural coral colonies and how transplants reflect the actual significance of their contribution to the overall recovery of the reef (as growth rates and recovery are dependent on a number of factors).

- We must use validation studies of “coral flypaper.” Morse (1994) and Morse and Morse (1996) isolated the chemical glycosaminoglycan (a sulfated polysaccharide) from a coralline algae (*Hydrolithon boergesenii*) that signals *Agaricia agaricites hummlis* larvae to settle. The synthesized material called “coral flypaper,” has proved effective for attracting larvae. Presumably, scientists can isolate and synthesize chemical signals for other species to develop other larval settlement stimulators.
- We must use studies that analyze the efficacy of using other invertebrates to make sites more appealing for coral settlement. For example, using *Diadema antillarum*, the spiny sea urchin (Lessios et al., 1984; Sammarco, 1982), or *Choneplax lata*, the chiton (Littler and Littler, 1995), to graze on algae at damaged reef sites stimulate coralline algae growth and enhance coral settlement.
- We must analyze both effectiveness and efficiency of the DNA fingerprinting method of corals to propagate clones of a particular species that fill in diversity gaps in colonial structure within a reefscape (based on the work of Coffroth et al, 1992).
- We must research the implications of epigenetics, which involves taking the genes of resilient coral strains and passing them onto offspring, as a selecctive breeding to create “super corals” (Putnam, 2012).

5. COST INFORMATION

Overall, cost information was very scarce in the peer-reviewed literature. Most information was disseminated through teleconferences conducted by project team members. In published literature, nine studies included detailed costs estimates. When detailed cost information was available, costs were associated with restoration activities instead of restoration goals. Costs varied depending on the methodology used and whether travel and transportation were included as variables in the eight detailed studies we found. Costs varied from $0.02/colony, which included maintenance (not travel) in the Red Sea at a nursery site, to $26/transplant, which included travel and salaries in the U.S. Virgin Islands using cable ties. Studies did not provide costs to achieve overall restoration goals for the project, which made it extremely difficult to estimate an efficiency and cost ratio.

5.1. COST INFORMATION FOR PHYSICAL TRANSPLANTATION METHODS

Kaly (1995) conducted a study to determine which transplantation technique is best for moderate scale rehabilitation projects on the Great Barrier Reef off the coast of Australia by testing rapid and inexpensive reintroductions of corals into a damaged area. Corals were transplanted to the area where they were found Lizard Island in Queensland, Australia. They were also taken from two bommies at the island. Corals were transplanted using cement and cable ties either exposed to air during transport or not exposed to air during transport. Based on the study's results, attachment by cement and reduced air exposure during coral transport are best ways to handle corals during relocation. No quantitative metrics were tracked and documented for this study (see Table 3). The expected cost to transplant 245,000 fragments per hectare is approximately $580 K (plus shipping costs). Due to high costs, it was determined that restoring 10% of the density (at $58 K) is more realistic for moderate scale projects.

In an effort to combat coral losses due to mass bleaching and mortality, a 2002 study by the Mobosa Marine National Reserve in Kenya, Africa, explored the idea of using low-cost transplantation techniques and tested it to how these techniques compared to natural recovery for coral restoration projects. The success rate for massive corals and massive corals with branches were 60% (see Table 3). The elimination of stress to the corals (sedimentation, algal competition, and abrasion) was the best way to have high success rates. Using epoxy to adhere the transplanted fragment cost approximately $0.71 per transplant (not including salary) (Edwards, 2010).

In a Fiji experiment (Job et al., 2005), coral rested on the reefscape using different methods to approximately transplant 2000m^2 of reef and increasing coral cover by 10% to 15%, which cost approximately $11,400.00 (material costs US $1,300; salary costs $10,100). Costs incurred were for a team of 2 scientists, 2 field assistants, 1 boat driver, 1 boat (free-diving skills, no scuba used), and fieldwork period of 10 days (60% of the time allocated for restoration activities, 40% of the time allocated for scientific input site selection, and baseline monitoring). No quantitative metrics were documented for this study.

Survival of transplants attached to bamboo substrates was investigated by Ferse (2010). Disintegration of the bamboo structures, sedimentation, and post-transplantation stress all led to higher fragment mortality. The total cost of the project was $298.33, which included 100 bamboo frames ($66.11); 5,000 cable ties ($77.78); 6.67 gallons of Epoxy glue ($21.11); and 5,000 concrete bases ($133.33) for a total of 5,000 transplants/100 m^2. At greater than 80% mortality at most sites, the study concluded that in places where currents or waves threaten to

dislocate transplants, a higher effort needs to be directed towards strong and durable attachment of transplant corals. No quantitative metrics were documented for this study.

In the 2012 study by Garrison and Ward, storm-generated coral fragments were transplanted within the Virgin Islands National Park area. The cost of materials, use of a boat and scuba, and scientist salary totaled US $21 per transplant. Costs were expected to decrease further (to a fraction of US $1 per transplant for nylon cable ties) if all work was conducted by volunteers on snorkel. Collection, transportation, and attachment of each fragment to a reef 1- to 5-km distance required 0.6 hour per fragment. This study revealed 0% success rate for branching corals tested (see Table 5).

5.2. COST INFORMATION FOR BIOLOGICAL TRANSPLANTATION METHODS

A coral reef rehabilitation study was conducted at a former fish blasting site in Komodo National Park in Indonesia (Fox et al., 2003). Coral recruitment onto three different structures was measured;1 m^2 plots of three different designs included (1) wide mesh fishing net attached to rubble with U-shaped rebar pins, (2) cement slabs pinned to rubble, and (3) piles of rocks on top of the rubble (20 to 40 cm high and 20 to 30 cm in diameter). During the first 3 years, rock stabilization plots had the highest hard coral recruitment and cover, followed by cement and netting, and lastly, untreated rubble. After 1 year, there was a mean of 7.3 recruits/m^2 at a mean size of 7.5 cm per recruit. Success rate for branching corals in this study were 70% (see Table 3). In this study, rocks were the least expensive treatment at an approximate cost of $5/$m^2$, including materials, transportation, boat rental, and labor.

In the 2006 study by Schrimm et al., both biological and physical restoration techniques were used in an area plagued by coral quarrying for the past 50 years in Bora Bora, French Polynesia. The physical restoration component consisted of filling in extraction pits and the establishment of a breakwater structure composed of artificial concrete blocks. The biological restoration piece consisted of the creation of a coral garden by transplanting corals onto artificial blocks or onto the seabed directly. After 2 years, the coral garden flourished with natural colonization of corals and other reef organisms to the concrete blocks (reef diversity similar to nearby reefs) and only had a 3% mortality rate. After 30 months, however, a phytoplankton bloom and a mass bleaching event lead to mortality among both physical and biologically restored areas. The overall success rate varied from 90% to 100% for tested branching and plate coral species (see Table 3). The estimated cost for the physical restoration (20,000 m^2 of sand fill, concrete “boulders”) was approximately $763 K. The estimated cost for the biological restoration (3,500 $m^2$of coral transplantation) was approximately $166 K.

In a 2006 study by Shafir, Rijn, and Rinkevich, a nursery was established next to a protected fish farm in the nutrient-rich waters of Eliat Bay in the Red Sea. The nursery consisted of coral fragments growing on artificial substrates in the Port of Eliat and transplanted onto a mid-water (6 m) floating nursery. Success rates for branching corals in this study varied from 10% to 80% (see Table 11). The “coral gardening concept” of pruning and monthly maintenance has fostered mass production of coral colonies at low costs, high survivorship, fast growth, and short nursery phases.

Estimates from *in situ* midwater and benthic nursery culture suggest that an order of 5 to 10 transplants can be reared per US dollar. At a spacing of 0.5 m on a degraded reef, this would suggest culture costs alone of US $4,000 to 8,000 per hectare (for the 40,000 transplants that would be needed) (Edwards and Gomez, 2007). No quantitative metrics were documented for this study.

Adult corals were transported from an island to a hatchery in Japan (Nakamura et al., 2011). These cultured corals were then substrates with new corals that were transplanted onto a native reef. The native reef had a problem with outflow of eggs and large from the reefs (due to currents/turbidity) as well as low recruitments from neighboring reefs. Recruits grew better on unshaded parts of the native reef or substrate and nibbling by filefish and puffer fish impeded growth. Reproductive settling in this study cost approximately $1.48/juvenile settled (including depreciation costs on the tanks and nettings). No quantitative metrics were documented for this study (see Table 9).

Costs vary according many different site-specific field parameters and depend on the overall goal of the project (Harriot and Fisk, 1987).

6. STRATEGY RECOMMENDATIONS

Coral transplantation is complex, requires investment, expertise, and long-term planning. With these requirements, the transplantation may fail due to unforeseen and unpredictable events not controlled by managers. Transplantations will only work if there are similar conditions at the both transplant and coral source sites.

Before any transplantation or restoration project begins, goals should be outlined and experts should consider each one. Once stakeholders agree on project goals, then a set of objectively verifiable and measurable indicators (or targets) should be established. These indicators will help determine the success (or failure) of an evaluated project. Targets should match goals, accurate, easily accessible, and include a timeframe. A timeframe with milestones can help a project manager monitor progress and help determine corrective actions (adaptive management) when indicators fail to perform within the predicted timeframe. Indicators may be endpoints (e.g., percentage of live coral cover, evidence of restoration of key ecosystem processes, coral recruitment or fish grazing) (Edwards and Gomez, 2007). Coral transplantation will not be effective in conserving coral species or in assisting reef recovery over time until underlying factors causing degradation of reefs and mortality of corals are understood, addressed, and eliminated or mitigated (Shokry et al., 2013).

We recommend including the local population of the proposed coral transplantation site in the planning process, for example, many universities have marine science programs housing local expertise. Those who live in the area can develop an interest in a transplantation project and its outcomes. Coral transplantation should be carried out by people with relevant experience. Volunteers from various types of organizations like the Reef Check Foundation can assist with transplantations, thus saving costs on labor and travel. Organizations such as the Combat Wounded Veteran's Challenge use opportunities like coral transplanting to rehabilitate their soldier's physiological, biomedical, and pathological injuries (see Figure 15).

Figure 15. Combat Wounded Veteran's Challenge volunteers help transplant corals in Florida as part of their rehabilitation process. (Photos courtesy of the Combat Wounded Veteran's Challenge).

6.1. PLANNING/MONITORING RECOMMENDATIONS

6.2. SITE SELECTION CONSIDERATIONS

Prior to considering coral transplantation, ensure that the transplant site is not subject to ongoing impacting processes, such as strong waves, shallow water snorkel areas, crown-of-thorns (COTs) infestation, or shading by structures or vessels. Ensure donor areas have a sufficient healthy and diverse coral cover. Total coral collection impacts must be within the natural variability of the area and cannot reduce the donor area coral cover or species composition. For the transplant site, identify and record the proposed species, numbers, sizes and placement of the individual colonies to be transplanted. Document a methodology, addressing careful removal, fragmentation, handling and attachment of corals, and describing how impacts to live tissue will be minimized (Shokry et al., 2013). Here is a list of important survey information for coral transplantation (before and after):

1. Clear benthic maps that characterize the habitat(s) to be impacted, preferably broken down by habitat type and quantified by area. Record GPS points of all transplanted corals.
2. Feature a species list, which includes hard and soft corals, anemones, sponges, algae and other major sessile organisms that has a measure of abundance by species or group (e.g., sponges). (Visual observations, photography and video are highly recommended.)
3. Transplanted organisms should have metrics that include color, bleaching, competition with benthic algae, disease, and percentage of cover by functional groups for both the study site and an adjacent non-impacted area. This will provide a reference sample for vitality.
4. Feature a measure of live coral cover and other sessile organism cover (sponges in particular). Usually this is reported as a percentage cover of the overall area.
5. Report some measure of colony density and size distribution (e.g., size frequency, median and range of colony diameters) to determine reef age and disturbance.
6. Provide a measure of reef rugosity to help determine reef complexity.
7. Feature fish surveys using standard and repeatable methods.
8. Feature measures of critical water quality and site parameters within short spatial ranges, including turbidity (Rodgers et al., 1994, 2001).
9. List cause(s) of local coral reef degradation and the synergistic impacts of stressors. List the removal of cause(s) and stressors.
10. List of natural and socio-economic factors that obstruct recovery.
11. Algal assembly type and height should be estimated and reported (McCook, Jompa, and Diaz-Pulido, 2001)
    a. Closely adhering creeping mats (0.2- to 1-cm thick)
    b. Tough, interwoven turf mats (2- to 10-cm thick)
    c. Thick tangles of more delicate ephemerals (20- to 50-cm thick)
    d. Distinct algal canopies (10- to 200-cm high)
12. Multivariate analysis and Bray-Curtis similarity coefficient and multidimensional scaling (MDS) are useful tools to compare reference and restored sites (Clarke and Warwick, 2001). If the restoration is progressing, then Bray-Curtis similarity coefficient values will converge to reach a higher degree of similarity (>85%). The MDS plot will document spatial convergence of the restoration and reference sites. Vector of habitat equivalence analysis (HEA) points over time provides an indication of direction of change the reference and restored plots will be moving in the same general direction toward convergence.

Project site visits and project construction monitoring can improve compliance; a site can meet avoidance and minimization measures as conditioned in the permit or project plans. If a site is expected to recover in 10 years, monitoring should be done for that time span with more intensive sampling at the onset and reduced effort. Trends and status must be monitored in restoration projects. Monitoring is the only method to determine the success of the restoration, document trends, find solutions to problems (Gomez and Yap, 1984; Likens, 1988; Rogers, 1988; Swanson and Sparks, 1990; Rogers, McLain, and Zullo, 1988; Done, 1997; Connell, Hughes, and Wallace, 1997).

Successful coral transplantation is both site- and species-specific (Dizon and Yap, 2006; Bruno, 1998). Microhabitat features and localized interactions in a site can determine the difference between overall survivorship and mortality (Raymundo, 2001). Choosing a site to transplant corals into is as important as selecting what species to relocate within the site. Transplant all corals to the same depth, aspect, habitat, water flow, proximity to adjacent colonies, and orientation as the site from which they were removed. Consider interactive impacts between adjacent colonies. Tag, photograph, and accurately identify each transplanted colony for the duration of the transplantation at least 12 months following the project's completion. Carefully maintain transplants. Revisit and reattach corals weekly in the first month and at least every two weeks within the next three months (Shokry et al., 2013).

Some echinoderms (e.g. the crown-of-thorns starfish [*Acanthaster planci*]), gastropod mollusks (e.g., coralliophila, drupella, phestilla), and fish feed on live corals. There is some anecdotal evidence that transplants (if stressed) may actually attract some predators (e.g., the cushion star, Culcita). There is little one can easily do about mobile fish grazers (many of which are beneficial due to its key role in grazing down competing algae and creating space for invertebrate larval settlement), but slower-moving starfish, cushion star, and gastropod predators can be removed from the vicinity of transplants and deposited away from the restoration sites. This routine husbandry can extend to removing excess algae (e.g., with a wire brush) that appears to threaten transplants and reattach any detached transplants. If there is excessive algal growth, then other management measures need to be considered, too. If there is a significant outbreak of crown-of-thorns, then more drastic measures are required (Edwards and Gomez, 2007).

Many studies discover the best way to increase survival and growth rates of transplanted corals (Epstein, Bak, and Rinkevich, 2001; Soong and Chen, 2003; Okubo, 2004; Rinkevich, 2005; Okubo, Taniguichi, Motokawa, 2007). These studies revealed that (1) pruning more than 10% of the branches increases mortality of the donor colony; (2) large fragments have much higher probability of survival; (3) very small fragments are unsuitable for transplantation because they are smothered by algae or lost (due to nibbling by fish); (4) the most suitable fragment size of Acropora for transplantation is 4 to 6 cm in diameter; (5) sexual reproduction varies depending on size of the fragment; (6) fragments are best kept underwater while being transported from sampling site to nursery and from nursery to transplantation site; (7) firm fixation of the fragments onto raised substrate is critical for survival and growth if corals are transplanted on unstabilized substrate or flat seabed they may be buried or damaged by material moved by storm-driven waves; and (8) after transplantation, personnel should check colonies regularly and eliminate macroalgae and the coral-eating gastropods *Drupella spp.* for an extended period of time (minimum 3 years).

Sleeman, Boggs, Radford, and Kendrick (2005) showed that modeling the recovery of reefs from different transplanting arrangements can lead to insights on how to optimize restoration efforts. These modeling approaches are useful to understand the origin and formation of reefs.

Differences of topographic complexity of actual reefs with model simulations of large temporal scales (Blakeway, 2000) can be analyzed. Alternately, they can be used to investigate how organisms with different life histories (Sleeman et al., 2005) or different spatial planting regimes (Oborny and Cain, 1997) influence the emerging landscape structure. By simulating 30 years of coral growth and recruitment, corals with r-selected life history strategies were found to experience a faster increase in cover and topographic complexity (as measured from both the hypsometric integral and rugosity) compared with the K-selected strategist. These models provide information that can be used to assess the site-specific life histories of the coral at a transplantation site and model its recovery before doing any field work.

6.3. CONSIDERATIONS ABOUT THE COST OF TRANSPLANTATIONS

Core items that should be considered for any coral transplant projects:

- Transportation costs to get and from the site from where you are now
- Boat charter (cost/day x number of days)
- Labor costs (costs/day x number of days)
- Costs of diving equipment and air fills
- Equipment costs (e.g., stakes, drills, cable ties, bins, and hammers)
- Electricity, fuel, water, and other utility expenses
- Repair/maintenance costs
- Depreciation costs

The time required for transplantation depends on the following:

- Initial coral cover surviving
- Projected final cover of coral
- Coral attachment
- Distance required to source of transplantable corals
- Weather conditions
- Worker skillset

The rate at which divers can collect and deposit corals will depend on the skillset and experience of divers, a body of water's depth, and the amount of suitable coral at the collection site. Cost of permits and the monitoring/reporting are factors to consider for proposed transplants in the United States. We did not find any published literature that contained these data types. Local experts and community groups can help keep costs low.

6.4. SCHEDULING OF TRANPLANTATION EVENT CONSIDERATIONS

Warm months cause stress of corals due to bleaching. Coral disease is also more prevalent during this period. If transplantation occurs during this period, the coral mortality rate will increase. Project teams should examine the annual sea surface temperature records for the proposed transplantation area and move forward with process at least a couple of months before or after the annual peak in temperature. Bad weather during this period may also be another challenge for translation.

Another factor to consider is the reproductive state of the corals. Corals, which are channeling energy into egg production and are just about to spawn, are more susceptible to the additional stress of transplantation (as either donors or transplants) than colonies in between spawning

seasons. For species with seasonal broadcast spawning, transplantation should not occur during spawning (Edwards and Gomez, 2007).

6.5. RECOMMENDATIONS FOR CHOSING SOURCE CORALS FOR TRANSPLANTATION

Candidate species for coral transplantation persist at undergraded (or less degraded) sites in the same environmental setting. They should be transplanted only if any chronic adverse anthropogenic impacts (likely to cause their death) are being addressed by management measures. Otherwise, transplantation is likely futile.

6.5.1 Morphological Considerations

Branching species similar to those in families Acroporidae and Pocilloporidae are fast growing and easy to fragment (Karlson and Hurd, 1993; Bouchon, Jaubert, and Bouchon-Navaro, 1981; Alcala, Gomez, and Aleala, 1982; Auberson, 1982; Plucer-Rosario and Randall,1987; Harriott and Fisk, 1987. They are favored in transplantation as they produce a rapid increase in percentage of live coral cover in a short period. Conversely, these species are (1) more sensitive to transplantation than slower growing submassive and massive corals (survival rates can lower); (2) more susceptible to warming associated with El Niño Southern Oscillation events, and thus more likely to experience mass bleaching and subsequent mass mortality (if the warming event is prolonged); and (3) more susceptible to disease than some other families. There are significant risks associated with restoration projects that rely on such species (Edwards and Gomez, 2007; Harriott and Fisk, 1987).

A fragment with many branches can also extend in various directions, which raises its potential for high total growth. Fragments collected from basal or the more proximal part of donor colonies had thicker diameters and, as a consequence, more surface area and live tissues per unit length of fragments. Their ability to acquire energy, either by capturing food particles or by photosynthesis, is potentially higher than thin fragments that have much less surface area (Soong et al., 2003). Skeleton porosity also increases toward the distal ends of acroporid branches (Gladfelter, 1982), perhaps allowing more energy being spent in local calcification in distal branches. Fragments collected from the proximal part of *Acropora* colonies are better from the perspective of fragment growth and branching. However, removing basal parts (at the same time) suggests destabilizing more distal branches in the donor colonies. Nevertheless, under certain conditions, it is possible to remove proximal branches without destroying distal branches, especially from the periphery of large *Acropora* colonies. In some habitats proximal branches in the basal part of donor colonies are likely to be encrusted and suffocated by sea anemones. However, these branches do extend and branch after being transplanted to a well-lit and less crowded environment. In light of this, it is possible to attain higher total growth if proximal branches are removed from the original environment and transplanted to a new location. Comparisons of fragment length indicate that very small fragments (e.g., 1 cm) were too small to use for coral generation in nurseries, because they tend to be smothered by algae or simply get lost, perhaps on account of predation. Moreover, in this study their branching frequencies were low, implying that their potential for propagation purposes is low. Small fragments, nevertheless, may be considered if labor is not a limiting factor and if algae can be cleared frequently (e.g., in a land-based laboratory). If this is the case, we suggest that branches of intermediate diameters be used (Soong et al., 2003). Thick branches of *Acropora* tend to have cores without live tissues; fouling organisms, such as algae, once growing and establishing themselves on the exposed ends of these surfaces, are likely to inhibit further growth of the corals. Additionally, from the perspective of the donor colonies, removal of long branches may render the original colonies infertile or result in low fecundities for some years (Lirman, 2000).

The location of new axial polyps may be affected by two factors. The first is developmental constraint. Axial polyps could be newly formed only in *A. pulchra* and not by the transformation of existing radial polyps (Soong et al., 2003). An axial polyp may become degenerated and resembles a radial polyp in the colonies of the branching *Acropora Formosa* (Oliver, 1984). Such a branch (i.e., without an axial polyp) had lower skeletal extension rates than others with an axial polyp at the branch tips. Investigations into the transformation from a radial to an axial polyp have yet to be reported in the available literature (Soong et al., 2003).

Resources allotted to regeneration are limited (Meesters and Bak, 1995; Hall, 1997; Rinkevich, 1997); this may well be the second factor influencing where to develop new axial polyps. The finding that only certain new tissues generate new axial polyps in a fragment supports the notion of a resource limitation. In short, not all parts of a fragment have the ability to develop new axial polyps. Moreover, the results also suggest that the direction of nutrient translocation in an acroporid branch can be flexible and reversed (Gladfelter, 1983). Axial polyps may be generated near the cut edges, if not for the presence of tissue wound in the center portions of fragments. Thus, the original direction of translocation (i.e., toward the branch tip) had to be reversed in half of the branches when the new axial polyps were generated in the center portion of the fragments. Branching acroporids are known to translocate nutrients directionally, which leads to faster extension rates of axial polyps (Gladfelter, 1983; Fang, Chen, and Chen, 1989). Likewise, the ability of corals to regenerate was found to be dependent on the position of the injuries in the colonies. In Acropora palmate, the regenerative capability decreases away from the growing edge (Meesters and Bak, 1995). In a multispecies comparison, however, no position effect was found in the regenerative ability in six of seven species (Hall, 1997). Results of our orientation experiments on fragments without axial polyps indicate the distal or proximal ends in the original colony did not have any inherent advantage in generating new axial polyps. Instead, the local environment determined the end at which new axial polyps were produced. It is possible that all the branches we used in the experiment were distal branches of the colonies and that the two ends of the 6-cm fragments posed little difference in ontogenic gradients along the branches. Coral fragments, like whole colonies, extend faster in shallow water than in deeper waters (Huston, 1985; Custodio and Yap, 1997; Nagelkerken et al., 1999). On the other hand, fragments on racks in shallow waters (5 meters) were more easily destroyed by waves than those in deeper waters (10 meters). Similar results have been observed in non-branching species where deep (10-meter) transplants survived better than shallow ones at 1.5 meters (Plucer-Rosario and Randall, 1987). The structure of the racks must be reinforced to sustain wave actions in shallow waters of an exposed environment, or, alternatively, a compromise has to be made between potential growth rates and the risk of survival (Soong et al., 2003).

There is less research on other growth forms (e.g., massive, submassivee) and branching species in other families such as the (slow growing) Poritidae and Merulinidae regarding restoration potential. Although there is considerable variation between genera and even species within these other families, it is clear that at least some of these less favored species (e.g., *Porites lutea*, *P. lobata*, and some Pavona species) are less sensitive both to transplantation and to warming anomalies and are likely to survive long term despite slow growth. The drawback for these slower growers is that the desired topographic complexity (which provides shelter and tends to attract fish and other fauna) is achieved slower with these species. Massive corals also work for transplantations due to their low damage and mortality and may ultimately produce the habitat required for fish and other coral morphologies (Shokry et al., 2013). A sensible compromise is to transplant a good mix of species and not to put all your eggs into one high-risk basket by concentrating on acroporids and pocilloporids (Edwards and Gomez, 2007).

6.5.2 Reproductive Style Considerations

Culturing coral may provide a feasible means of providing coral transplants for reef restoration if laboratory rearing facilities are available. Corals can be cultured in an easy and cost-effective way from larvae obtained from brooding species (most of which produce larvae either monthly or several times per year). Culturing corals from fragments is suitable for easily fragmenting species, providing only a small amount is removed from donor colonies (current literature suggests <10%), and stress to donor reefs is minimized (Raymundo, 2003).

Corals raised on land from fertilized eggs and larvae collected from slicks on the sea surface after mass spawning should be used for reproductive settling techniques in areas where bleaching, predation by crown of thorns starfish, heavy typhoons, and terrestrial runoff are prevalent (Okamoto et al., 2008).

International Union for Conservative of Nature (IUCN) guidelines (IUCN, 2002) suggest that the ramets and genets used in transplantation efforts be tracked in order to further assess performance of genets and the consequences of transplantation on survival of coral communities. This data is fairly easy to collect (Baums, 2008) and will improve our ability to design successful restoration projects. Selected coral should be minimized to preserve the genetic viability of the species (though it is not clear to achieve this). Maximizing the genetic variability in the brood stock is important to prevent inbreeding and bottleneck effects and to maintain the genetic integrity of the species.

6.5.3 Ecological Considerations

Corals should be selected from similar habitats to those into which they will be moved, with respect to depth, turbidity, wave action, tidal currents, and degree of exposure to freshwater runoff. Many corals are known to have relatively narrow tolerances for variations in these factors, and selecting the corals from closely matched habitats should increase survival. The most significant consideration is depth, as coral that moved to shallower depths are frequently bleach, and corals that moved to greater depths have slow growth rates due to the reduced light (Harriot and Fisk, 1987).

6.5.4 Colony Size Considerations

The selection of colony size will depend largely on the resources available to the transplanter (e.g., size of boat and size of display area) and consider that smaller colonies are able to spread over a large area but are unable to produce as impressive a display as larger colonies. Below a particular size, survival rate drops sharply for colony fragments. In our experiments, we had good survival for colonies with a longest dimension greater than 30 cm. Survival rates dropped sharply for pieces 10-cm to 25-cm long, and rates were extremely low for fragments less than 10-cm long. Similar results were found for fragments of a pocilloporid species (Harriot and Fisk, 1987). Work with very small coral transplants suggests a marked improvement in survival above about 10 mm (1 cm) in diameter, whereas some experiments working with larger transplants have shown better survival of transplants over a size of about 10 cm compared to smaller ones. Acropora fragments about 4-cm long are considered the most appropriate for use in coral generation. It is recommended that longer branches be broken into 4-cm fragments to prouce more cut edges per until length of fragments (Soon et al., 2003). Critical sizes may vary with both species and site and depend on both the amount and type of algae (and other organisms) competing for space and the abundance and size of potential coral grazers like parrotfish. If a transplant is just one mouthful, then a grazer may destroy it in one bite. If there are several mouthfuls, then a transplant may survive. If there is a lot of macroalgae, then a small

coral may easily be shaded and overgrown, whereas a larger one may be able to persist (Edwards and Gomez, 2007).

However, it seems likely that transplanting asexually derived fragments at a minimum size of 5 to10 cm will promote better survival and do more to enhance topographic diversity. If size–frequency distributions were available from surveys of the reference ecosystem, then densities of corals at the average transplant size or larger would be a more justifiable target. Determining what transplant density to attempt will depend on the aim of the target–if it's an immediate aim of the transplantation or an ultimate aim after approximately 5 to10 years of natural recovery assisted by some initial transplantation. An alternative approach would set a goal within approximately 5 to10 years for the restored site and should aim for approximately 75% of the coral cover (or better) of the reference ecosystem. Knowing existing coral cover, starting sizes of transplants, and average growth rates, one could then estimate the number of transplants needed to achieve the goal. (Edwards and Gomez, 2007).

To minimize damage to colonies during collection, it is best to select colonies with thin or dead bases in preference to those attached by a large base. Massive corals are difficult to collect due to their broad base. We collected colonies using a hammer and masonry chisel. For collecting thinner branches of staghorn species, a single sharp hit with a chisel was often sufficient. When branches of Acropora corals are collected, the tips of the branches will almost always break, but if the coral survives, the tissue will grow over the broken branch tip quickly (often within a month) and new branches will grow from the tip. In some experiments, transplanted corals can easily be distinguished from non-transplants because the ends of branches generally showed a rosette type structure where many branches had formed at the regenerating branch tip (Harriot and Fisk, 1987). Until more research is done and we have a better understanding of the impact of pruning coral colonies, we suggest applying the precautionary principle and not excise more than 10% of donor colonies. For massive coral colonies, remove fragments from the edge of the colony (Edwards and Gomez, 2007).

6.5.5 Species-specific Considerations

A. micropthalma and *E. lamellosa* show high growth rates accompanied by low survivorship as a result of their being more selective in terms of location with a narrower range of adaptability (Dizon and Yap, 2006). Certain species of Acropora (Tanner, Hughes, and Connell, 1996; Yap, Alino, and Gomez, 1992) are characterized as short-lived and fast growing. For example, *A. micropthalma* appears to belong to this group (Dizon and Yap, 2006). Others species like *P. cylindrica* are a more stable component of reef communities with intermediate performance in both growth and survivorship; they also have a ubiquitous distribution. In addition, *A. micropthalma* has a fragile, branching growth form; species such as this perform the role of fillers in the reef matrix, similar to the fungiids or mushroom corals, which can have an ephemeral life history (Wood, 1995). *A. palifera*, P. cylindrical, and *P. lobata* act as framework builders (Scott and Risk, 1988), with more sturdy growth forms and high survivorship rates after transplantation. A similar result was obtained in a Caribbean experiment using *P. astreoides* (Gleason, Brazeau, and Munfus, 2001). Massive corals in Puerto Rico experienced as much as 90% survival 1 year after transplantation (Ortiz-Prosper et al., 2001). Massive forms may be slower growing, but they have a higher survivorship rate than the fast growing (yet short lived) branching forms (Dizon and Yap, 2006; Clark and Edwards,1995).

P. cylindrical is known to tolerate a wide range of environmental conditions (Seebauer, 2001). In a tank experiment, the growth of *P. cylindrical* from the Great Barrier Reef was not affected by suspended particle load within the ranges tested (Anthony, 1999). This might provide further evidence that ubiquitous species, such as *P. cylindrica*, have wider ranges of

distribution because of superior abilities to adapt to a variety of environmental conditions. Thus, they may be more suitable candidates for transplantation. Furthermore, some studies have suggested that the development trajectory of a community depends on whether it is dominated by broadcast spawning or by brooding species (Preece and Johnson, 1993; Ayre and Hughes, 2000; Nishikawa, Katoh, and Sakai, 2003; Edmunds et al., 2004).

A suitable species for restoration in the target site with a capability of resisting extreme environmental changes (e.g., temperature and radiation) should be considered. The seasonality of transplantation is also significant as it provides new transplants an optimal duration for establishment. For example, the most favorable season for transplantation in Bolinao would be January to February, at the end of the Northeast monsoon season and before the beginning of the summer (Shaish et al., 2010). The present bleak situation of coral reefs does not leave much room for an optimistic future, a view supported by the Wakeford and his associate's conclusion in 2008 that disturbance intervals shorter than 8 years could reduce the present of dominance of hard coral groups. Furthermore, even commonly occurring natural events such as rainfall and storms may develop to natural catastrophes when their frequency and intensity enhanced (Thibault and Brown, 2008).

6.5.6 Collection and Transportation Recommendations

As little damage as possible should be done to the coral colonies during collection to minimize the areas of dead tissue that might be susceptible to infections, such as 'white and black band disease' reported overseas. Corals should be collected over as wide an area as possible. This would reduce the impact at any one site, and depending on the number of corals collected, the change would probably be undetectable. It is certainly possible that in areas of high coral cover, growth of some colonies is limited by competition for space with neighboring colonies. In such flourishing communities, release from competition by removing some branches or colonies would allow a more rapid growth of other colonies and the space would be quickly occupied. It is also recommend about 50% of each colony of branching coral be left intact at the collection site. The most hazardous life history stage is the recruitment and early growth phase, and if a substantial part of a colony remains, the chances of its surviving and re-growing are much greater than that of a coral planulae attempting to settle on the vacated space (Harriot and Fisk, 1987).

Porites lobata has been shown to recover slower from tissue damage than was *Favia specioisa* and *Goniastrea aspera*. Tissue damage and lesion repair was best in unexposed areas (minimal wave action areas). For hooked and roped transplants, colonies generated 22% of the tissue in the damaged area and then died after four weeks. For cemented transplants, colonies generated about 80% tissue regeneration, but by week 16, colonies achieved only 40% damage recovery overall (Clark, 1997). This study showed that transplanting from areas of anthropogenic disturbance to more protected areas, like marine parks or preserves, is a viable option.

While transplanting, corals should avoid air for long periods. However, our experiments have indicated that the survival rate of all groups of corals exposed to air (but out of the sun on the deck of the boat for up to 60 minutes) were not significantly different from corals carried in large water containers. Once corals were exposed to air for periods of two hours or more, survival rates dropped. The method selected would depend on the distance between the collection site and the transplant site and the mode of transport. If corals are transported between sites in approximately 30 minutes or less, the easiest method is to place colonies on the shaded boat deck. If exposure period will last more than an hour, corals can submerge in water containers, or undergo gentle splashing water during transport to reduce dehydration. It is

recommended that loading of the boat should commence immediately before departure. Establish a collection area under or adjacent to the boat and load when enough is collected (Harriot and Fisk, 1987).

Corals transplanted that were exposed to air should be protected from direct sunlight with a tarpaulin or another cover. Given that corals can be damaged by high temperatures, it may be preferable to avoid exposing corals at the hottest time of the day during summer (Harriot and Fisk, 1987).

Collection and transportation of corals are much easier when weather conditions are calm. In small boats and in wind conditions over 15 knots, there is an increased chance that corals transported on deck will bounce and abrade each other, and possibly break. Most boats can travel faster in calm weather and this would reduce the period of exposure for transplanted corals (Harriot and Fisk, 1987). This is possible, but the method shows it is impractical in practice. The boat has to move extremely slowly to prevent loss of colonies and a long journey between reefs could take hours. If weather conditions are not absolutely calm, the corals bounce on each other and are broken. If nets are used, any branching corals become entwined in the nets, are easily damaged, and take a very long time to remove (Harriot and Fisk, 1987).

6.6. TRANSPLANTATION METHOD RECOMMENDATIONS

6.6.1 Physical Restoration–Glue/Epoxy

For this method, it is vital to keep in mind the placement involved orientation of the coral fragments in their previous growth positions and wedging the fragments as tightly as possible in the substrate. The correct orientation is easily determined by the upward facing polyps and lighter colored surfaces facing upwards. Careful placement takes very little time and results in a more natural display (Harriot and Fisk, 1987). As you may recall, the results of our literature review were presented in Section 4.1.2. For the purposes of this document, each study was sorted by the morphological type of coral it assessed in that study. Some studies assessed more than one type of coral morphology and some did not. The morphological type categories were branching and massive/lobate/dome/mound/plate. Each study then was ranked on a scale of 0 to 10 based on the success criteria used by each author, with 0 signifying that the study was not successful and 10 signifying that the study was 100% successful. These data were then analyzed using the Wilcoxon Signed-Rank test to determine if the epoxy/glue technique was more or less successful for branching corals verses other morphological types. The results of that analysis show that cement/epoxy/glue are equally as successful or branching corals as for massive, lobate, dome, mound, and plate corals for the studies analyzed.

6.6.2 Physical Restoration–Ties/Rods/Cables

For this method, it is vital to keep in mind the placement involved orientation of the coral fragments in their previous growth positions and wedging the fragments as tightly as possible in the substrate. The correct orientation is easily determined by the upward facing polyps and lighter colored surfaces facing upwards. Careful placement takes very little time and results in a more natural display (Harriot and Fisk, 1987). As you may recall, the results of our literature review were presented in Section 4.2.2. In this technical report, each study was sorted by the morphological type of coral it assessed in that study. Some studies assessed more than one type of coral morphology and some did not. The morphological type categories were branching and massive/lobate/dome/mound/plate. Each study was then ranked on a scale of 0 to 10 based on the success criteria used by each author, with 0 signifying that the study was not successful and 10 signifying that the study was 100% successful. These data were then analyzed using the

Wilcoxon Signed-Rank test to determine if the ties/nails/rods technique was more or less successful for branching corals verses other morphological types. The results of that analysis show that ties/nails/rods are work better for branching corals than for massive, lobate, dome, mound and plate corals for the studies analyzed.

6.6.3 Physical Restoration–Leave in Place

For this method, it is vital to keep in mind the placement involved orientation of the coral fragments in their previous growth positions and wedging the fragments as tightly as possible in the substrate. The correct orientation is easily determined by the upward facing polyps and lighter colored surfaces facing upwards. Careful placement takes very little time and results in a more natural display (Harriot and Fisk, 1987). As you may recall, the results of our literature review were presented in Section 4.1.3. For the purposes of this document, each study was sorted by the morphological type of coral it assessed in that study. Some studies assessed more than one type of coral morphology and some did not. The morphological type categories were branching and massive/lobate/dome/mound/plate. Each study then was ranked on a scale of 0 to 10 based on the success criteria used by each author, with 0 signifying that the study was not successful and 10 signifying that the study was 100% successful. These data were then analyzed using the Wilcoxon Signed-Rank test to determine if the leaving in place technique was more or less successful for branching corals verses other morphological types. The results of that analysis show that leaving in place was equally as successful or branching corals as for massive, lobate, dome, mound, and plate corals for the studies analyzed.

6.6.4 Biological Restoration–Reproductive Settling

As you may recall, the results of our literature review were presented in Section 4.4.2. In this technical report, each study was sorted by the morphological type of coral it assessed in that study. Some studies assessed more than one type of coral morphology and some did not. The morphological type categories were branching and massive/lobate/dome/mound/plate. Each study then was ranked on a scale of 0 to 10 based on the success criteria used by each author, with 0 signifying that the study was not successful and 10 signifying that the study was 100% successful. The majority of the literature found for this technique was conducted on branching corals and, as such, the analysis was not able to be run to determine if reproductive settling is more effective on branching corals than any other morphological type of coral.

6.6.5 Biological Restoration–Nurseries

As you may recall, the results of our literature review were presented in Section 4.5.2. In this technical report, each study was sorted by the morphological type of coral it assessed in that study. Some studies assessed more than one type of coral morphology and some did not. The morphological type categories were branching and massive/lobate/dome/mound/plate. Each study then was ranked on a scale of 0 to 10 based on the success criteria used by each author, with 0 signifying that the study was not successful and 10 signifying that the study was 100% successful. The majority of the literature found for this technique was conducted on branching corals and, as such, the analysis was not able to be run to determine if reproductive settling is more effective on branching corals than any other morphological type of coral.

6.7. MANAGEMENT RECOMMENDATIONS

In transplantation projects where the area is considered for Marine Protected Area classification, it is sometimes unclear if the area will benefit from the classification. MPAs are unlikely effective if located in areas that are subject to numerous and uncontrollable external stressors from atmospheric, terrestrial, and oceanic sources (which can degrade the environment and compromise protection). These critical calculations are determined before designation and periodically re-evaluated after designation. Top priority is given to designating MPAs in minimally impaired locations that can act as reference sites for monitoring and assessment programs (Jameson et al., 2002). The success of MPAs as a management tool is successful when communities collectively support the MPA and government agencies (or in some cases, nongovernmental organizations,), provide the necessary financing, monitoring, enforcement, and technical expertise to ensure that MPAs reach their management objectives. The most important factors when considering MPA status include the following:

1. Level of competition (i.e., impacts of uncontrollable stressors entering the MPA)
2. Ability to compete (i.e., what control do we have over these stressors)
3. Level of community and institutional capacity to manage MPAs; and
4. MPA size considerations (managing a large area) (Jameson et al., 2002)

When approved as an effective management tool, the floating "larval dispersion hub" (See Section 4.4.) may also have a dramatic influence on the design and implementation of regional network of MPAs (Amar and Rinkevich, 2007).

Marine Reserves/No-Use Zones/Controlled General Use area designations are other options for coral reef protection and conservation. The establishment of a marine reserve or enforcement of conservation-related legislation does not preclude continuing destruction caused by recreational activities. Proclaiming an area a coral reef preserve often increases accessibility and usually attracts the attention of additional divers, fishermen, boaters, and other wishing to visit the area for recreation (Rinkevich, 2005). Effects of recreational activities include the effects of runoff and sewage discharges from tourist resorts (Bell, Greenfield, Hawker, and Connell, 1989), recreational fishing and boating (Davis, 1977; Jaap and Morelock, 1997; Tilmant, 1987; Rogers, McLain, and Zullo,1988), SCUBA and skin diving (Hawkins and Roberts, 1992, 1993; Talge, 1993), and human trampling on coral reefs and sediment resuspension (Woodland and Hooper, 1977; Liddle and Kay,1987; Kay and Liddle, 1989; Neil, 1990; Ward, 1990; Liddle, 1991; Riegl and Velimirov, 1991; Hawkins and Roberts 1993). A five-year study designed to evaluate the effects of human recreational activities at Biscayne National Park, Florida, failed to detect significant differences in the functioning of any of the parameters monitored between more heavily used and lesser used reefs (Tilmant, 1987).

6.8. NURSERY RECOMMENDATIONS

- Preferably, the nursery should be situated in a protected area since mechanical forces may significantly reduce operational success. A shallow location for the nursery (here at 6-m depth) in midwater (here 14 m above the sea bottom) and in a nutrient–enriched site are recommended for obtaining faster growth rates of shallow coral species.
- Within a specific timeframe, working with nubbins will generate smaller colonies amenable for transplantation (the optimal size for coral transplantation was not tested here). This will reduce the stress inflicted on the donor colonies, which could increase colony production. Under the set of conditions tested, the main cause for coral loss was detachment from the substrate of larger coral fragments.

- Monthly maintenance of the nursery (observations, replacement of plastic frames, and relocation of crowded coral colonies within plastic frames, removing dead corals fragments and detached samples) requires about ten diving hours per month (Shafir et al., 2006).
- Presence of crowded pins prevented herbivorous fish and grazing invertebrates from naturally cleaning the nets and pins from settled organisms. Spacing the pins proved to increase the efficiency of this ‘‘natural’’ cleaning. Moreover, the use of plastic pins enabled the manual cleaning of each colony in a fast and easy way without harming the developing coral. The pins could also act as an efficient attachment device during transplantation (Shafir et al., 2006).
- Short nursery time reduces nursery costs and increases restoration efficiency. It also reduces the threats of predation and competition caused by corallivorous snails and settling organisms. However, in an established nursery, where stocks of farmed coral colonies are continuously cultured, the invasion of new organisms originating from the plankton should be considered.
- Part of the success of a nursery is due to the location of the nurser. The midwater nursery examined in a 2006 study (Shafir et al., 2006) was located in an isolated, nutrient–enriched area at a distance of 6 to 8 km from the natural reef. The area is protected from the impacts of tourists (e.g., skin and scuba divers) and the site was not subjected to predation by corallivorous fish, common in southern Eilat reef (Shafir et al., 2006).
- In addition to seawater temperature, light and water current are two very important factors to regulate and maintain at optimum conditions for maintaining corals in tanks as brood stock.

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APPENDIX A
ACRONYMS AND SYMBOLS

ACRONYM	DEFINITION
ACH	Akajima Coral Hatchery
ACOE	Army Corps of Engineers
ANOVA	Analysis of Variance
ARRA	American Recovery and Reinvestment Act
BAS	Best Available Science
C	Celsius
Ca	Cadmium
Cb	Columbium
CBD	Consortium for Biological Diversity
CBRA	Coastal Barriers Resources Act
CECW	Corps of Engineers Civilian Works
CEERD	US Army Engineer Research and Development Center
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
CITES	Convention on International Trade in Endangered Species
cm	Centimeter
cm^2/mo	Centimeter Squared Per Month
CNMI	Commander Northern Marianas Islands
COCs	Chemicals of Concerns
CORIS	Coral Reef Information System
COTs	Commercial-off-the-shelf
CRCA	Coral Reef Conservation Act
CRTMIS	Coral Reef Transplant Methods Implementation Strategy

CSD	coral settling device
CWA	Clean Water Act
CZMA	Coastal Zone Management Act
d	Day
DAR	Division of Aquatic Resources
df	degrees of freedom
DGGE	denaturing gradient gel electrophoresis
DI	dissolved ion
DLNR	Department of Land and Natural Resources
DNA	deoxyribonucleic acid
DoD	Department of Defense
EBSCO	Elton B. Stephens Company
EEZ	Economic Exclusive Zone
EFH	Essential Fish Habitat
EIS	Environmental Impact Statement
EO	Executive Order
EPA	Environmental Protection Agency
ER	Environmental Readiness
ESC	Engineering Service Center
ESTCP	Environmental Security and Technology Certification Program
et. Al.	Et Alia (and others)
etc.	Etcetera
F.A.C.	Florida Administrative Code
FDEP	Florida Department of Environmental Protection
FDIC	Federal

FedReg	Federal Register
FKNMS	Florida Keys National Marine Sanctuary
ft	Feet
FUCA	Floating Underwater Coral Nursery
FWS	Fish and Wildlife Service
gal	Gallon
h	Hour
H_a	Hypothesis
HAPC	Habitat of particular concern
H_o	Hypothesis
HQ	Headquarters
in	Inch
K	Thousand
km^2	Kilometers squared
KW	Key West
LTD	Limited
m	Meter
m^2	Meters Squared
MBL	Marine Biological Laboratory
mg/d	Milligrams
mg/d	Milligrams Per Day
MILCON	Military Construction
mm	millimeter
mmol	Millimol
MMPA	Marine Mammal Protection Act

mo(s)	Month(s)
MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
MPA	Marine Protected Area
MSA	Magnuson Stevenson Act
n	Sample Number
NAVFAC	Naval Facilities
NEPA	National Environmental Policy Act
NESDI	Navy's Environmental Sustainability Development to Integration
NGC	Nursery-Grown Corals
NGO	Non-Governmental Organization
NMSA	National Marine Sanctuary Act
NO2-	Nitrite
NO3-	Nitrate
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NPDES	National Pollutant Discharge Elimination System
NPS	National Park Service
NR	Nature Reserve
NSEU	Nova South Eastern University
NWHICRER	Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve
ORD	Office of Research & Development
OPA	Oil Pollution Act
p	Probability
PAC	Pacific

PEET	Polyethylene Terephthalate
pH	Potential Hydrogen
PKMRC	Pigeon Key Marine Research Center
PVC	Poly Vinyl Chloride
r^2	Regression Analysis
RDM	Relative Dominance Model
RHA	River and Harbors Act
RO	Reverse Osmosis
RPAs	Reservation Preservation Areas
RTC	Resolution Trust Corporation
RTE	Reciprocal Transplant Experiment
RTS	Restoration Test Sites
Sb	Antimony
SD	Standard Deviation
SE	Standard Error
SERDP	Strategic Environmental Research and Development Program
SFA	Sustainable Fisheries Act
sp	Species
SPAs	Special Permit Areas
SS	Source Sites
SSC	Space and Naval Warfare Systems Center
SUML	Silliman University Marine Laboratory
TAL	Tropical Aquaculture Laboratory
TS	Transplantation site
US $	U.S. Currency

US EPA	United States Environmental Protection Agency
USC	United States Code
USCRTF	United States Coral Reef Task Force
USFWS	United Stated Fish & Wildlife Service
USGS	United States Geological Service
USVI	United States Virgin Islands
vs	Versus
WHOAS	Woods Hole Open Access Server
X^2	Chi-squared Analysis
yr	Year

SYMBOLS

"	Inches
	Number
%	Percentage
&	And
~	About
<	Less Than
=	Equal To
>	Greater Than
±	Plus/Minus
≤	Less Than or Equal To
≥	greater than or equal To
©	Copyright
®	Registered
□d	Degree

APPENDIX B
FEDERAL, STATE AND LOCAL REGULATIONS

Legal and administrative responsibilities change frequently to comply with updated federal, state, and local laws. These, tied into specific facility/area agreements, MOAs, MOUs etc. and are very complex and will not be discussed in detail due these complexities of the processes themselves and the fact that they are highly dependent upon the specific action taken and the specific area the action is taken within. Contact the authors, your environmental planners and/or your Legal Counsel for assistance.

B1. OVERALL REGULATORY SUMMARY

B1.1 Corals should not be collected, either alive or dead. The United States federal government prohibits the removal or destruction of corals from all areas of the continental shelf within a three-mile limit.

B1.2 The Florida Fish and Wildlife Conservation Commission prohibits the collection of living or dead stony corals (Order Scleractinia) or fire corals (Millepora spp.) within Florida waters.

B1.3 Collection of hard corals is also banned in Hawaii, Guam, and Puerto Rico.

B1.4 The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) regulates international trade of certain animals and plants. More specifically, the Convention regulates the import, export, re-export, and introduction from the sea of certain plants and animals. Species for which CITES controls trade are included in one of three appendices. These appendices classify animals in terms of their vulnerability. Many corals are classified by CITES as Appendix II species. These species are not necessarily threatened with extinction but may become so unless their trade is strictly controlled. Appendix II includes the following corals: Indo-Pacific blue coral (Heliopora coerulea; Family Helioporidae, Order Helioporacea); Organ-pipe coral (Tubipora musica; Family Tubiporidae, Order Stolonifera); All corals in the Order Scleractinia (1634 species of reef- building, stony corals); and All corals in the order Antipatharia (245 species of black corals)

B2. FEDERAL ACTS

Coral Reef Conservation Act

Reference: 16 U.S.C. §§6401-6409.

http://coris.noaa.gov/activities/actionstrategy/08 cons act.pdf

Lead Agency: National Oceanic and Atmospheric Administration (NOAA)

Application: The CRCA is the primary federal legislative tool used for coral reef conservation. Though the CRCA promotes the research, conservation, and management of U.S. coral reef ecosystems and provides funding for projects consistent with those goals, it does not establish a regulatory framework for preventing activities that may harm coral reefs. The legislation requires the Administrator of NOAA to report to Congress every two years.

National Marine Sanctuaries Act

Reference: 16 U.S.C. §§ 1431-1445.

http://sanctuaries.noaa.gov/librarv/National/NMSA.pdf

Lead Agency: National Oceanic and Atmospheric Administration (NOAA), although the U.S. Coast Guard may help enforce the Act.

Application: The areas designated as National Marine Sanctuaries under the Act contain many coral reef ecosystems, which receive protection under the Act as a "sanctuary resource." Destruction and injury to coral reefs located within designated national marine sanctuaries is prohibited by NMSA. Furthermore, the individual regulations for some national marine sanctuaries specifically prohibit the destruction or injury of coral. The Act provides criminal and civil consequences for violations of the Act and holds violators strictly liable for their actions.

Ocean Dumping Act

Reference: 33 U.S.C. §§ 1401-1430.

http://epw.senate.gov/mprsa72.pdf

Lead Agency: The Environmental Protection Agency. U.S. Army Corps of Engineers may issue permits for the dumping of dredged material. The U.S. Coast Guard is responsible for assisting EPA by monitoring the seas for violations of the ODA. NOAA provides research support and guidance regarding the issuance of permits

Application: The ODA bans the dumping and associated transport of materials into the territorial sea and contiguous zone of the U.S. The Act's policy of protecting marine ecosystems protects coral reefs. Though not explicitly stated in the Act, those individuals found dumping unauthorized materials over or near coral reefs could be criminally or civilly liable for their actions, just as they would be for other unauthorized dumping in U.S. waters. Each violation carries up to a $50,000 civil penalty and may reach $125,000 for the dumping of medical waste. Further, violation of the ODA may result in up to five years in prison and the seizure of any property associated with the violation. For example, a district court found a permit authorizing the dumping of dredged material near a coral community to be in violation of the ODA. The U.S. Army Corps of Engineers had deposited approximately 4.4 million cubic yards of dredged material and was forced to stop dumping at that location. Though not a case regarding coral reefs, but hard and soft corals attached to exposed limestone, the case offers an example of how the ODA might be used to protect coral reefs.

Antiquities Act of 1906

Reference: 16 U.S.C. §§ 431-433
http://www.nps.gov/history/local-law/antil906.htm

Lead Agency: The President of the United States designates monuments and delegates management duties to various federal agencies. The Act authorizes the Secretaries of the Interior, Agriculture, and the Army to issue permits for excavation, examination, or gathering of objects at the site of any monument designated under the Act. Other agencies may be delegated management authority, such as the National Oceanic and Atmosphere Administration, National Park Service, Fish and Wildlife Service,

Department of Interior's Bureau of Land Management, the U.S. National Forest Service, and other agencies within the Department of the Army.

Application: National monument designations are an effective way to preserve and protect coral reef ecosystems. Activities harmful to coral reefs within national monuments are limited by specific regulations. Additionally, the regulations for each monument may provide for criminal and/or civil punishment. For example, violation of regulations in the Virgin Island Coral Reef National Monument or the Buck Island Reef National Monument may result in up to three months in prison, a "fine as provided by law," or both. Regulations for the Northwestern Hawaiian Islands Marine National Monument prohibit many actions regarding coral reefs, but provide no penalties for such violations.

It appears that national monuments may be eliminated only through the legislative process. The Act does not specify whether the President has the power to remove or modify a monument that has been proclaimed by a previous president.

Endangered Species Act

Reference: 16 U.S.C. §§ 1531-1534; 50 CFR Section 17.3.

http://www.mnfs.noaa.gov/pr/laws/esa/

Lead Agency: National Oceanic and Atmospheric Administration (NOAA)/U.S. Fish and Wildlife Service (FWS).

Application: The ESA provides for the protection of endangered and threatened species, including corals. Currently, there are only two species of corals listed. Both elkhorn and staghorn coral are listed as "threatened." However, the prohibitions on take an commercial trade do not apply to the species and no critical habitat was established. In addition to protecting specific species, entire coral reef ecosystems may be protected through designation as a “critical habitat.”

50 CFR 17.3 Section 9 prohibits the “take” of Acropora corals; take for threatened corals includes “to harass, harm, … wound, kill…or collect, or to attempt to engage in any such conduct”. “Take” also includes any “significant habitat modification or degradation where it actually kills or injures wildlife by significantly impairing essential behavioral patterns, including breeding, feeding, sheltering”.

Abandoned Shipwreck Act

Reference: 43 U.S.C. §§ 2101-2106.

http://www.cr.nps.gov/local-law/FHPL AbndShipwreck.pdf

Lead Agency: National Park Service (NPS)

Application: The ASA's primary goals are to protect and preserve abandoned shipwrecks of historical value. In order to do so, however, the surrounding environment may also require protection, such as when disturbing the site would damage the abandoned vessel. Should a wreck be on or sufficiently near a coral reef, the reef may receive protection under the ASA. Violators of a state's regulations concerning an abandoned shipwreck detrimentally affecting coral reefs may be subject to civil or criminal punishment, but that determination is left to the respective state.

The NPS Guidelines recommend that states coordinate and cooperate with federal agencies during the formation and application of abandoned shipwreck management policies and regulations. States may consult with the following agencies: U.S. Army Corps of Engineers; U.S. Coast Guard; Advisory Council on Historic Preservation; National Oceanic and Atmospheric Administration; Office of the Judge Advocate General, U.S. Department of the Navy; General Services Administration; Bureau of Oceans and International Environmental and Scientific Affairs, U.S. Department of State; and others.

Each state is responsible for the management and care of abandoned shipwrecks and their sites located in state waters. Furthermore, the NPS Guidelines recommend that states coordinate and cooperate with federal agencies during the formation and application of abandoned shipwreck management policies and regulations.

Magnuson Stevens Act

Reference: 16 U.S.C. §§1801-1891.

http://www.nmfs.noaa.gov/msa2005/docs/MSA amended msa%20 20070112 FINAL.p df

Lead Agency: National Marine Fisheries Service (NMFS)

Application: The Act directly protects deep-sea corals through the Deep-Sea Coral Research and Technology Program, as well as the Act's authorization to designate zones to protect deep-sea corals. Coral reefs designated as essential fish habitat in fishery management plans will receive additional protection. Furthermore, with goals to reduce bycatch and overfishing, fishery management plans may indirectly prohibit or limit fishing practices that are harmful to coral reefs. Under Magnuson Stevens, NOAA has amended five fishery management plans to prohibit trawling in a 370,000 square mile area in Alaska to protect cold water corals as essential fish habitat and habitat areas of particular concern.

The Act directs the Secretary to coordinate with Fishery Management Councils and other federal agencies, such as NOAA, and educational institutions in the development of the Deep-Sea Coral Research and Technology Program. The services of the Department of Defense and the U.S. Coast Guard may be utilized to enforce the Act. The Magnuson-Stevens Act claims exclusive jurisdiction over all fishery-related activities within the EEZ. However, the Act preserves state jurisdiction within state waters. The Act also recognizes state jurisdiction over fisheries in other circumstances, such as when the state's laws and regulations are consistent with the federal fishery management plans and regulations.

Marine Mammal Protection Act

Reference: 16 U.S.C. §§ 1361-1423.

http://www.nmfs.noaa.gov/pr/pdfs/laws/mmpa.pdf

Lead Agency: National Oceanic and Atmospheric Administration (NOAA); Fish and

Wildlife Service (FWS)

Application: NOAA is responsible for the protection of whales, dolphins, porpoises, seals, and sea lions. FWS enforces the MMPA with respect to polar bears, sea otters, walruses, dugongs, and manatees. The Secretary of Commerce has the authority to protect the habitat of marine mammals, which potentially includes coral reefs. Individuals in violation of the MMPA may face civil penalties up to $10,000 per infraction or criminal charges with the potential for one year in prison, a fine up to $20,000, or both for each

conviction. JOJ Additionally, each vessel found in violation of the MMPA may face civil penalties up to $25,000 per violation and the forfeiture of its entire cargo.

The Commission may coordinate its efforts with those of "any federal agency." NOAA and FWS remain the primary agencies, dividing the responsibilities for marine mammal protection. NOAA and FWS may designate state officials and employees to assist in enforcing the MMPA. The Act preempts state laws regarding the take of marine mammals unless there is "a transfer of management authority by the Secretary."

Coastal Zone Management Act

Reference: 16 U.S.C. §§ 1451-1466.

http://coastalmanagement.noaa.gov/about/media!CZMA_I 0_II_06.pdf

Lead Agency: National Oceanic and Atmospheric Administration (NOAA)

Application: The CZMA specifically calls for the federal government to encourage and assist states with the protection of coral reefs and their habitat within the coastal zone. Coral reef ecosystems may receive protection under state CMPs. Furthermore, any proposed federal, private, or resource development action that would harm coral reefs in violation of state CMP could be blocked under the CZMA's consistency provision. Consequently, any coral reef falling within the state's coastal zone areas receive state and federal protection under the CZMA.

In approving state CMPs or amendments, the CZMA requires NOAA to consult with “other interested federal agencies.” Additionally, federal agency actions, including permitting, must be consistent with the state CMPs.

States have broad authority in developing and enforcing CMPs. States may object to federal actions in the coastal zone if such actions would be inconsistent with the state's coastal zone management plan.

National Environmental Policy Act

Reference: 42 U.S.C §§ 4321-4370.

http://www.nepa.gov/nepa/regs/nepa/nepaeqia.htrn

Lead Agency: Council on Environmental Quality (CEQ)

Application: Proposed federal actions that would threaten coral reefs, either directly or indirectly, would require an EIS or an EA to assess the impact and to propose alternatives or mitigation measures, if necessary. Though neither NEPA nor CEQ regulations specifically address coral reef protection, the Act could encompass a coral reef as part of the affected “human environment.”

All federal agencies proposing actions that may significantly affect the environment are subject to NEPA. Additionally, NEPA compels the appropriate federal agencies to cooperate when preparing an EIS.

Federal, state, and local agencies and the public may comment on an EIS or an EA before it becomes final.

Clean Water Act

Reference: 33 U.S.C. §§ 1251-1387.

http://www.epa.gov/npdes/pubs/cwatxt.txt

Lead Agency: Environmental Protection Agency (EPA)

Application: The CWA protects coral reefs by regulating the discharge of pollutants from point and nonpoint sources. Though the CWA does not specifically protect coral reefs, they benefit from the water quality protections necessary for healthy coral reef ecosystems.

U.S. Army Corps of Engineers issues permits regarding the deposit of dredge material (Section 4040(b); 33 C.F.R. 323.2(e).

NPDES permitting may be carried out by states with authority from the EPA or the Corps. The CWA requires states to monitor and report water pollution levels. Additionally, the Act encourages states to develop water quality standards and programs.

River and Harbors Act

Reference: 33 U.S.C. §§ 401-426.

http://www.usace.army.mil/CECW/Pages/reg materials.aspx

Lead Agency: U.S. Army Corps of Engineers

Application: The regulation of construction and the prohibition of discharge into navigable waters without a permit positively affect water quality necessary for healthy coral reef ecosystems.

The Department of Justice is responsible for conducting the legal proceedings needed to enforce this statute. The RHA requires United States attorneys to "vigorously prosecute" offenders and report to the Attorney General of the United States the action taken against those offenders.

Although the Corps has primary permitting authority for obstructions to navigation and the discharge of material into navigable waters, the U.S. Department of Transportation has approval authority over construction plans for bridges and causeways.

Many Corps of Engineer's permits are authorized under the Rivers and Harbors Act, not under Section 404 of the Clean Water Act (CWA) for projects that consist of dredging where no subsequent fill is involved, although few would argue that the impacts of dredging, as well as increased sedimentation, and turbidity should be considered to meet NEPA requirements. The 1990 MOA between the Corps and EPA, determining mitigation guidelines, was also specific to Section 404 of the CWA. The 2002 Regulatory Guidance Letter (RGL-02-2), extended consideration for compensatory mitigation guidance for aquatic resource impacts to the Rivers and Harbors Act of 1899. Therefore, this report includes activities from civil works projects or Corps Section 10 permitted projects with impacts to coral reefs.

The Fish and Wildlife Coordination Act provides authority for the U.S. Fish and Wildlife Service to review and comment on the effects on fish and wildlife of activities permitted or undertaken by the Corps of Engineers.

States do not have a significant role under the Act.

Oil Pollution Act

Reference: 33 U.S.C. §§ 2701-2762.

http://frwebgate.access.gpo.gov/cgi-bin/usc.cgi?ACTION=BROWSE&TITLE=33USCC40

Lead Agency: U.S. Coast Guard

Application: The Act helps reduce damage caused by oil spills by requiring double hulled vessels. Additionally, the Act facilitates the clean-up of spills. The Act mandates the establishment of the Interagency Coordinating Committee on Oil Pollution Research (Interagency Committee). The Interagency Committee must coordinate a program for oil pollution research and technology development. The Interagency Committee is to assess the current technologies and knowledge regarding oil pollution prevention, response and mitigation. They must also identify oil pollution research gaps and establish goals for the development of oil pollution technology.

The members of the Interagency Committee must be representatives from various departments and agencies. Interagency Committee representatives: Coast Guard, Department of Commerce, Department of Energy, Department of the Interior, Department of Transportation, Department of Defense, Department of Homeland Security, Environmental Protection Agency, National Aeronautics and Space Administration, and any other Federal agencies that the President may designate States may enforce requirements for financial responsibility in navigable waters of the state.

Coastal Barriers Resources Act

Reference: 16 U.S.C. 3501-3510.

http://www.usda.gov/rus/water/ees/pdflcbra.pdf

Lead Agency: United States Fish and Wildlife Service

Application: While the CBRA does not specifically regulate coral reef ecosystems, the prohibition of federal funds for hazardous coastal development on barrier islands helps to protect water quality, which is essential to the viability coral reefs.

Federal agencies affected by the Act are required to promulgate regulations to assure compliance with the act and to provide annual reports and certifications of compliance with the Act.

The Task Force Co-chairs are the United States Fish and Wildlife Service, National Park Service and the Geological Survey make up the Coastal Barriers Task Force, which works to implement the statute's funding prohibitions.

However, the law has established a process for the RTC and FDIC to transfer interests in land to public or nonprofit conservation organizations.

Fish and Wildlife Coordination Act

Reference: 16 U.S.C. §§ 661-667e.

http://www.usbr.gov/power/legislation/fwca.pdf

Lead Agency: Fish and Wildlife Service

Application: Under the Act, coral reef ecosystems are protected when federal actions seek to control or modify a natural water body in proximity to a coral reef. For example, before issuing a permit, the U.S. Army Corps of Engineers is required to consult with the FWS to determine the impact on fish and wildlife. The Act also authorizes the FWS to conduct studies and surveys on wildlife, which helps determine potential effects a project may have on coral reefs. Additionally, FWS is able to provide technical expertise and recommendations to agencies toward protecting coral reefs that serve as fish habitat.

The Act authorizes the U.S. Bureau of Mines, in addition to the FWS, to make investigations into activities involving sewage, mines, industrial wastes, erosion, and other polluting substances to determine its effect on wildlife. The Act also requires any agency constructing a new dam to consult with the Bureau of Fisheries for fish migration.

Additionally, the Act directs any federal agencies involved with a project that may modify or have an effect on wildlife resource to consult with the Service and State Fish and Wildlife agencies regarding possible impact.

Any department or agency of the U.S. engaged in an activity that may result in the control or modification of a body of water must be in accordance with plans approved jointly by: the head of the department or agency exercising primary administration; the Secretary; the head of the state agency exercising administration of the wildlife resources.

National Park Service Organic Act

Reference: 16 U.S.C. §§ 1-4.

http://www.nps.gov/legacy/organic-act.htrn

Lead Agency: National Park Service (NPS)

Application: By establishing NPS and requiring it to regulate the National Park System, the Act indirectly provided for the protection of coral reefs located within national parks, monuments, and reservations. The Act itself does not specifically protect coral reefs, but they could be included in the undefined “natural, [sic] curiosities, wonders, or objects of interest. ”

The U.S. Forest Service may be consulted regarding the “supervision, management, and control of national monuments contiguous to national forests.”

Lacey Act

Reference: 16 U.S.C. §§ 3371-3378.

www.fws.gov/le/LawsTreaties/Lacey.pdf

Lead Agency: National Oceanic and Atmospheric Administration (NOAA)/Fish and

Wildlife Service (FWS)

Application: The Lacey Act protects coral reefs by prohibiting the unauthorized taking of fish, wildlife, and plants from U.S. waters. Coral species, fish, and plants receiving protection under other laws benefit from the Act's additional protection. Furthermore, coral reefs under the jurisdiction of foreign laws receive protection via the Act's importation ban if obtained illegally.

Secretaries of the Interior and Commerce must consult with the Secretary of the Treasury in carrying out their duties under the Act. The National Oceanic and Atmospheric

Administration has the authority to "assess civil penalties, impose permit sanctions, issue written warnings, and/or seize and forfeit property" for violations of the Act. The Animal and Plant Health Inspection Service may initiate forfeiture proceedings against all equipment used in the transportation of plants in violation of the Act.

The Act prohibits the import, export or movement of interstate commerce of any protected species under the Act in violation of state law. The Act also makes it illegal to import, export, or move in interstate commerce, any protected species under the Act unless the package meets labeling requirements.

Sustainable Fisheries Act

Reference: Public Law 104-297

http://www.gpo.gov/fdsys/pkg/PLAW-104publ297/pdf/PLAW-104publ297.pdf

Lead Agency: NMFS

Application: The SFA amends the Magnuson Fishery Conservation and Management Act to authorize appropriations, to provide for sustainable fisheries, and for other purposes. requires that each regional fishery management council identify the habitats used by all the life history stages of their managed species. The habitats that are necessary to the species for spawning, breeding, feeding, or growth to maturity are designated as Essential Fish Habitat (EFH). These habitats must be described in narratives and identified geographically in a fishery management plan (FMP).

A subset of EFH is Habitat Area of Particular Concern (HAPC). An area can be designated as an HAPC based on one or more of the following: the importance of the ecological function provided by the habitat, its sensitivity to human-induced environmental degradation, the extent of threats posed by development to the habitat, or the rarity of the habitat type

The HAPC designation does not confer additional protections or restrictions, but can help prioritize conservation effort

B.3 EXECUTIVE ORDERS

Executive orders are weaker forms of law. They have force of law when they have expressed or implied authority from Congress or when Congress is silent, as long as they do not impede the powers of another branch of government.

Executive Order 13089, Coral Reef Protection

Reference: 63 Fed. Reg. 32701 dated June 11, 1998.

http://www.coralreef.gov/about/executive_order13089.pdf

Lead Agency: U.S. Coral Reef Task Force (USCRTF)

Application: In 2000, the Task Force published a National Action Plan that outlines conservation strategies under two themes: understanding coral reef ecosystems and reducing the adverse impacts of human activities. The Plan is meant to provide the framework for the priorities, strategies, and implementation plans of the Task Force and its members. The CRCA also requires NOAA and the Task Force to develop a National Action Strategy. The Strategy uses short-term goals to implement the National Action Plan. The Strategy has thirteen goals for protecting coral reef ecosystems. NOAA must report on the implementation of the strategy to Congress every two years.

The Coastal Development and Shoreline Modification section of the Action Plan lists seven recommendations with specific actions including:

"Assess the effectiveness of recent coral reef mitigation projects for Section 404 projects in Puerto Rico, USVI (U.S. Virgin Islands), and Hawaii and provide technical guidance for future mitigation activities related to permitting actions."

Executive Order 13158, Marine Protected Areas

Reference: 65 Fed. Reg. 34909 dated May 31, 2000

http://map.gov/executive_order/execordermpa.pdf

Lead Agency: Department of Commerce/Department of Interior

Application: The Order established a network for Marine Protected Areas and the National Marine Protected Areas Center Additionally, the MPA Federal Advisory committee has worked to advise the Secretaries of Commerce and the Interior on implementing the Order. The establishment of the network of MPAs, the Center, and the Committee provides greater protection to coral reefs located within MPAs. The expansion or identification of new MPAs could protect more coral reef ecosystems. Furthermore, the monitoring and reporting requirements in the Order could identify gaps in protection of MPA resources, like coral reefs, as well as to identify emerging threats to coral reefs within MPAs.

B4. DEPARTMENT OF DEFENSE (DoD)

DoD Directive 6050.16, DoD Policy for Establishing and Implementing Environmental Standards at Overseas Installations Marine Protected Areas (20 Sept. 1991

Reference: http://www.zianet.com/tedmorris/dg/dodd6050.16.pdf

DoD Directive 4715.5, Overseas Environmental Baseline Guidance Document (15 March 2000)

Reference: http://www.dtic.mil/whs/directives/corres/pdf/471505p.pdf

Application: These directives, both issued by DUSD(ES) clarifies how DoD addresses environmental standards outside the United States. DoD operations, activities, and installation activities in and around foreign nations shall be consistent with international agreements, status of forces agreements, final governing standards (FGS) issued for host nations, or where no FGS have been issued, the criteria under the Overseas Environmental Baseline Guidance Document (OEBGD). Many of the countries in which the military operates have invoked similar coral reef protection policies, laws, or initiatives as apply in the United States. Military operating overseas should be aware of and comply with these mandates.

DoD Instruction 4715.3, Environmental Conservation Program (3 May 96).

Reference: http://www.dtic.mil/whs/directives/corres/pdf/471503p.pdf

Application: Assigns responsibilities and prescribes policy and procedures for general conservation management, natural resources management, and cultural resources management on DoD property.

Memorandum on Implementation of Ecosystem Management in the DoD, Office of the Under Secretary of Defense (August, 8, 1994).

Reference: N/A

Application: Assigns ecosystem management as the basis of future management of DoD lands and waters and provides guidelines for ecosystem management implementation.

OPNAVINST 5090.1C, Change 1, Environmental and Natural Resources Program Manual (18 July 2011).

Reference:http://doni.daps.dla.mil/Directives/05000%20General%20Management%20Security%20and%20Safety%20Services/05-00%20General%20Admin%20and%20Management%20Support/5090.1C%20CH-1.pdf

Application: Provides requirements, assigns responsibilities and issues policy for the management of the environment and natural resources for all Navy ships and shore activities.

NAVFAC Natural Resources Management Procedural Manual, P-73, Vol II.

Reference: N/A

Application: Provides guidance and procedures for implementation of natural resources regulations on Navy property.

Marine Corps Order P5090.2A, Environmental Compliance and Protection Manual (10 Jul 98).

Reference:http://www.miramar.marines.mil/Portals/60/Docs/MEMS/MCO%20P5090.2A%20W%20CH%201-2.pdf

Application: Describes the requirements of federal environmental regulations and implements DoD environmental policies.

B5. STATE/LOCAL

B5.1 Florida

In state waters, the Florida Department of Environmental Protection (FDEP) is the designated trustee. Southwest of Miami, jurisdiction is complicated by federal parks, wildlife refuges, state parks, aquatic preserves and the Florida Keys National Marine Sanctuary. In most cases, jurisdiction in these areas falls under both federal and state.

Under the Submerged Lands Act, Congress gave States title to submerged lands within 3 miles (3 marine leagues along Gulf Coast of Florida and Texas). When a National Marine Sanctuary includes state waters, states may have a more active role in the management of the sanctuary. NOAA, in conjunction with the appropriate state and local government agencies, is required to develop a comprehensive management plan and regulations for individual sanctuaries. The role of state and local authorities may be specified in the sanctuary designation process and the sanctuary management plan.

South Florida's Coral Regulations:

Florida Coral Reef Protection Act, Florida Statute 403.93345

Reference:http://www.leg.state.fl.us/statutes/index.cfm?App_mode=Display_Statute&Search_String=&URL=0400-0499/0403/Sections/0403.93345.html

Lead Agencies: FDEP, FDEP Coral Reef Conservation Program & FDEP South East District.

Application: Florida's Coral Reef Protection Act went into effect on July 1, 2009. The law increases protection of Florida's endangered coral reefs by raising awareness of the damages associated with vessel groundings and anchoring on coral reefs. The law affects all vessels (commercial and recreational) that transit state waters within Monroe, Miami-Dade, Broward, Palm Beach, and Martin counties, and holds those that injure reefs responsible for causing damage to, or destruction of, coral reefs.

The Florida Department of Environmental Protection runs the Reef Injury Prevention and Response Program (http://www.dep.state.fl.us/coastal/programs/coral/ripr.htm). This program is responsible for leading response to, and management of, coral reef and hard bottom injuries resulting from vessel impacts such as grounding, anchoring, and cable drag events.

Environmental Resource Permitting, Florida Statute 373.129, .413 & .414

Reference:http://www.leg.state.fl.us/Statutes/index.cfm?Mode=View%20Statutes&Submenu=1&Tab=statutes&CFID=318982721&CFTOKEN=22758160

Lead Agency: Florida Department of Environmental Protection (FDEP), FDEP South East District & FDEP Bureau of Beaches & Coastal Systems.

Application: This regulations look sat impacts to corals from turbidity, sedimentation, toxicity and physical disturbances.

Surface Water Quality Standards, Florida Administrative Code 62-500 & 530

Reference:http://www.leg.state.fl.us/Statutes/index.cfm?Mode=View%20Statutes&Submenu=1&Tab=statutes&CFID=318982721&CFTOKEN=22758160

Lead Agency: Florida Department of Environmental Protection (FDEP), FDEP South East District & FDEP Bureau of Beaches & Coastal Systems.

Application: This regulations look sat impacts to corals from turbidity, sedimentation, toxicity and physical disturbances.

Protection of Sovereign Submerged Lands, Florida Statute 253.04

Reference:http://www.leg.state.fl.us/Statutes/index.cfm?Mode=View%20Statutes&Submenu=1&Tab=statutes&CFID=318982721&CFTOKEN=22758160

Lead Agency: Florida Department of Environmental Protection (FDEP), FDEP South East District & FDEP Bureau of Beaches & Coastal Systems.

Application: This regulations look sat impacts to corals from turbidity, sedimentation, toxicity and physical disturbances.

Pollution Control, Florida Statute 403.121 & .201

Reference:http://www.leg.state.fl.us/Statutes/index.cfm?Mode=View%20Statutes&Submenu=1&Tab=statutes&CFID=318982721&CFTOKEN=22758160

Lead Agency: Florida Department of Environmental Protection (FDEP), FDEP South East District & FDEP Bureau of Beaches & Coastal Systems.

Application: This regulations look sat impacts to corals from turbidity, sedimentation, toxicity and physical disturbances.

Joint Coastal Permit, Florida Statute 161.054 & .055

Reference:http://www.leg.state.fl.us/Statutes/index.cfm?Mode=View%20Statutes&Submenu=1&Tab=statutes&CFID=318982721&CFTOKEN=22758160

Lead Agency: Florida Department of Environmental Protection (FDEP) & FDEP Bureau of Beaches & Coastal Systems.

Application: This regulations look sat impacts to corals from turbidity, sedimentation, toxicity and physical disturbances.

Marine Life Rule, Florida Administrative Code 68B-42.009

Reference: https://www.flrules.org/gateway/RuleNo.asp?ID=68B-42.009

Lead Agency: Fish & Wildlife Conservation Commission (FWC)

Application: Regulates physical contact with the reef environment.

Special Activity License, Florida Administrative Code 68B-8

Reference: https://www.flrules.org/gateway/ChapterHome.asp?Chapter=68B-8

Lead Agency: FWC

Application: Regulates physical contact with the reef environment. The Marine Special Activity License (SAL) Program issues licenses for activities that require a waiver of marine fisheries regulations. Activities that we license include (but are not limited to): scientific research, education, exhibition, aquaculture, the use of non-conforming gear (for research purposes only), the testing of innovative gear, the use of marine chemicals, the release of marine organisms, and the use of dredges for harvesting marine organisms.

Specific information regarding how Special Activity Licenses are issued and the program is managed may be found in FWC rule 68B-8, Florida Administrative Code. Program policies and a flow chart that are incorporated into the rule by reference are as follows:

- FWC Policy on the Release of Marine Organisms (192KB) referenced in 68B-8.003(7), F.A.C.
- FWC Marine Prohibited Species Policy (214KB) referenced in 68B-8.009(4)(b)10., F.A.C.
- Decision Process for the Genetic Risk Assessment of Release Activities Involving Marine Organisms referenced in 68B-8.010(4), F.A.C.

Special Activity Licenses issued by the FWC do not authorize any activities in:

- State parks, unless a research/collecting permit has been obtained from the Florida Dept. of Environmental Protection, Division of Recreation and Parks.
- National parks.
- Federal Waters - the federal Exclusive Economic Zone (EEZ), which is any area seaward of 3 nautical miles on the Atlantic and 9 nautical miles on the Gulf. The exceptions being species that are managed solely by the State of Florida and state regulations are extended into federal waters.

- Zoned areas of the Florida Keys National Marine Sanctuary (FKNMS) in Monroe County. Zoned areas include Ecological Reserves (ERs), Sanctuary Preservation Areas (SPAs), and Special Use Areas (including Research Only (RO) areas) (Figure).

Some activities conducted within any area of the FKNMS may need to be licensed by the Sanctuary such as coral collection, live rock/live sand collection, placement of equipment on the sea floor, and use of prohibited gear. For information on whether or not your activities may need to be licensed by the Sanctuary, please contact Joanne Delaney, Permit Coordinator, NOAA/Florida Keys National Marine Sanctuary at joanne.delaney@noaa.gov.

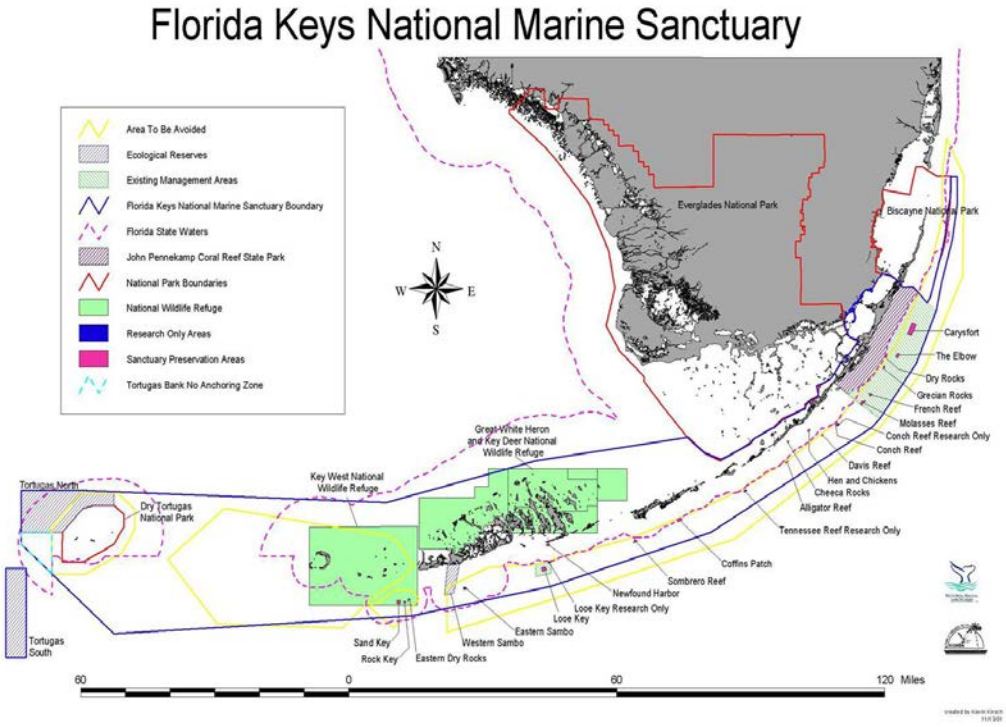

Figure B-1. Map of the Florida Keys National Marine Sanctuary.

Coral Protection in State Parks, Florida Statute 258.008(3)(a)

Reference:http://www.leg.state.fl.us/Statutes/index.cfm?Mode=View%20Statutes&Submenu=1&Tab=statutes&CFID=318982721&CFTOKEN=22758160

Lead Agency: Florida Department of Environmental Protection (FDEP), FDEP South East District & FDEP Division of Recreation and Parks.

Application: Regulates physical contact with the reef environment.

State Endangered Species, Florida Administrative Code 62A-27.003(1)(a)

Reference: https://www.flrules.org/gateway/department.asp?deptid=62

Lead Agency: FWC

Application: Regulates physical contact with the Pillar coral, Dendrogyra cylindricus, which is a state-listed endangered species.

An excellent reference that details coral reef oversight and mitigation efforts in South Florida and the Caribbean is presented by the United States Fish and Wildlife Service Southeast (USF&WS, 2004).

B5.2 Hawaii

Corals are regulated under the federal fishing regulations applicable to the Hawaii Archipelago can be found in the Code of Federal Regulations, Title 50: Wildlife & Fisheries, Chapter 7, Part 665, and can be accessed at http://ecfr.gpoaccess.gov.

Aquatic Resources, Hawai‘i Revised Statute, Chapter 187A.6

Reference: http://www.capitol.hawaii.gov/hrscurrent/Vol03_Ch0121-0200D/HRS0187A/

Lead Agency: Hawaii Division of Aquatic Resources (DAR) within the Department of Land and Natural Resources (DLNR).

Application: Regulates physical contact with the reef environment.

Requirements for Hawaii Precious Corals Management Unit Species

- Federal permit and logbook reporting
- Use of only selective gear that can discriminate or differentiate between type, size, quality or characteristics of living or dead corals
- Bed specific quotas
- Closed areas
- Minimum height 10 inches for live pink coral
- Minimum stem diameter 1 inch or minimum height 48 inches for live black coral
- Moratorium on gold coral 2008 to 2013

Table B-1. Hawaii Archipelago Fisheries Ecosystem Plan Management Unit Species.

Hawaii Precious Corals Management Unit Species		
Scientific Name	English Common Name	Local Name
Corallium secundum	pink coral (also called red coral)	NA
Corallium regale	pink coral (also called red coral)	NA
Corallium laauense	pink coral (also called red coral)	NA
Gerardia spp.	gold coral	NA
Narella spp.	gold coral	NA
Lepidisis olapa	bamboo coral	NA
Antipathes dichotoma	black coral	NA
Antipathes grandis	black coral	NA
Antipathes ulex	black coral	NA
Hawaii Coral reef Ecosystem Management Unit Species (Potentially Harvested Reef Taxa)		
Scientific Name	English Common Name	Local Name
Azooxanthellates	ahermatypic corals	ko`a
Fungiidae	Mushroom corals	ko`a
N/A	Small and large coral polyps	ko`a
N/A	Soft corals and gorgonians	NA
Actinaria	Anemones	NA
Zoanthinaria	soft zoanthid corals	NA
Solanderidae	hydroid corals	NA
Stylasteridae	lace corals	ko`a

B5.2.1Requirements for Hawaii coral reef ecosystem Management Unit Species

- Special permit, reporting and pre-landing and notification for any directed fishery harvesting potentially harvested coral reef taxa
- Ban on harvest of live rock and living corals except for indigenous people for traditional uses and aquaculture operations for seed stock under special permit, reporting and pre-landing notification requirement.

NOAA's Ocean Service co-manages, along with the State of Hawaii, the Hawaiian Islands Humpback Whale National Marine Sanctuary and administers the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve. This was created by Executive Order 13178 issued on December 4, 2000.

Work conducted in this area requires special permitting either from the Co-trustees of the Papahānaumokuākea Marine National Monument or from the National Oceanic and Atmospheric Administration's (NOAA) National Ocean Service (NOS) for working within the fifteen Reservation Preservation Areas (RPAs) (B-2), which are part of the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve (NWHICRER) (see http://www.papahanaumokuakea.gov/permit/).

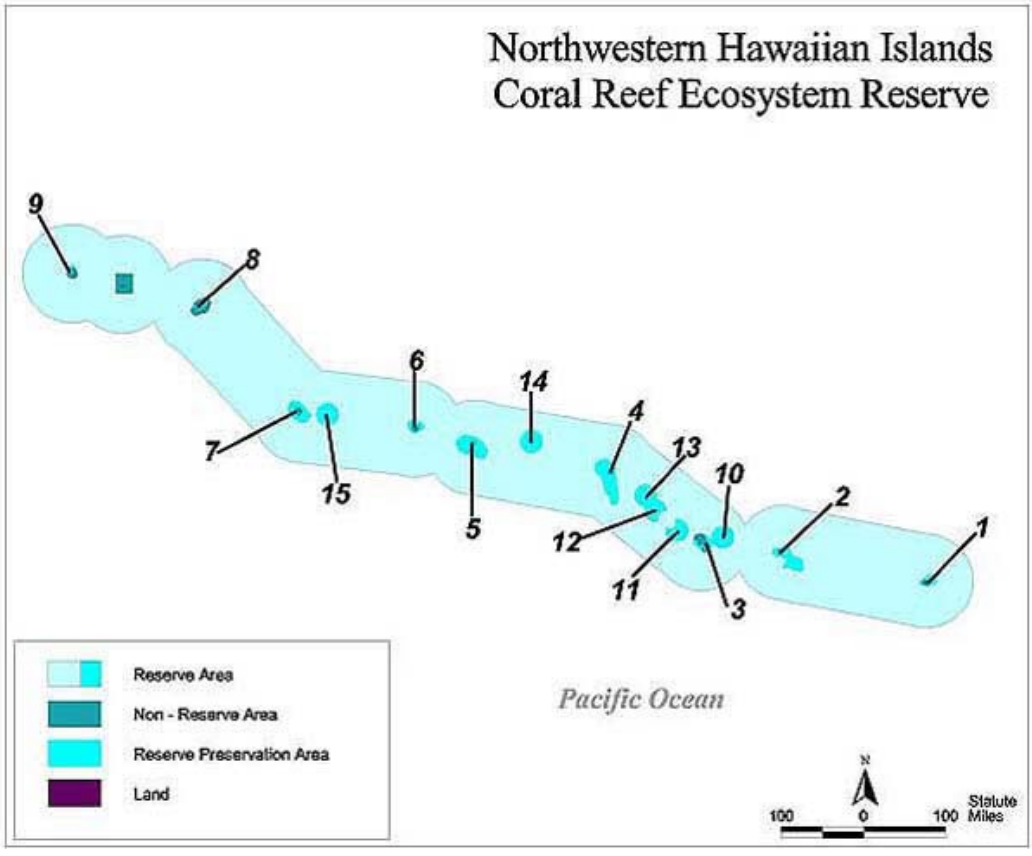

Figure B-2. Reservation preservation areas within the Northwestern Hawaiian Islands (NWHI) Coral Reef Ecosystem Reserve.

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14. ABSTRACT

This study provides a roadmap for making decisions when formulating mitigation packages presented to regulatory agencies. Natural resource planners, range managers, and other environmental team members can refer to the Coral Reef Transplant Method Implementation Strategy (CRTMIS) for scientific evidence to determine coral reef transplant and mitigation methods. Conversely, CRTMIS provides information that would argue against the transplantation option under certain conditions. Overall, CRTMIS will serve as a tool to help meet the following Navy goals: keep submerged training lands available for use by the Navy, lower mitigation costs, provide scientifically defensible data to be used in National Environmental Policy Act (NEPA) consultations/agreements, and help select transplantation methods that will lead to an increase of genetic diversity among coral reefs and stronger, resilient ecosystems.

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coral reefs, transplantation and mitigation methods, strategy methodology, coral morphology

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