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Cover Page Footnote

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CORAL REEF RESTORATION METHODS IN THE CARIBBEAN AND FLORIDA KEYS

By Melissa Wagner

ABSTRACT— There has been a massive decline in coral population worldwide, but the Caribbean Sea has been particularly impacted. The Caribbean was once the home to millions of branching coral, *Acropora*, but has seen severe degradation in the past few decades due to climate change, pollution, coral disease, bleaching events, overfishing, coastal development and other disturbances. Coral reef restoration has since expanded rapidly with thousands of coral nurseries in the Caribbean alone and has become an important process in maintaining coral reefs in our oceans today. Corals help protect our shorelines, maintain biodiversity in our oceans, provide jobs for fisheries and tourism, and bring money into the communities. The purpose of this review is to review the different types of coral reef restoration methods in the Caribbean and Florida Keys as well as some key complications with solutions to a successful coral restoration. The different methods of coral restoration include coral gardening, transplantation, micro-fragmentation, artificial reefs and genetic diversity in coral larvae. One of the most common and highly successful methods being coral gardening, while transplantation is also widely used. I describe each of these methods in this paper and identify core knowledge gaps and recent discoveries that may improve outplanted and nursery coral survivorship. Ecological processes and the density and arrangement of corals integrated with coral restoration could also impact coral survivorship in a positive way by possibly helping outplanted corals sustain a healthy environment without human intervention. Herbivory, corallivory, lack of nutrients, and diseases all are issues that must be addressed in coral restoration, but recent advances may provide solutions to these issues. Coral restoration is a relatively new process with not many long-term successful projects to learn from. Trial and error is still a big part of coral restoration today as researchers are still learning the best and most successful processes to aid coral survivorship.

Keywords: *Acropora*; coral gardening; fragmentation; growth; survivorship; transplantation

I. INTRODUCTION

Coral reefs cover a tiny portion of the Earth's surface, approximately 0.1% (Ladd et al., 2018). Despite their small size, they are highly important ecosystems, providing shoreline protection to millions of people living near the coast (Ladd et al., 2016), maintaining more than 30% of the total marine biodiversity (Ladd et al., 2016), serving as a key source in fisheries production (Ladd et al., 2016), and providing economic stability to local communities (Young et al., 2012). The reefs of the Caribbean Sea have been valued at approximately $3.1-$4.6 billion annually through food production from fisheries, tourism and recreation, and shoreline protection (Young et al., 2012). Since the mid 1970's, coral reefs in the Caribbean have lost over 50% of their coral coverage (Ladd et al., 2016) due to coral disease, bleaching events, overfishing, coastal development, pollution, raising ocean temperatures, and other disturbances (Ware et al., 2020; Ladd et al., 2019). Without human intervention, coral reefs might not be able to recover naturally (Young et al., 2012). In order to help protect coral reefs, coral restoration has been occurring worldwide (Bostrom-Einarsson et al., 2020). Coral restoration can be done in a number of different methods in land-based (*ex situ*) or ocean nurseries (*in situ*), including asexually or sexually derived corals, transplanting coral fragments, or moving entire coral colonies should they be slated for destruction due to development (SECORE International, 2020). The literature for this review was found using Google Scholar with the key word “coral restoration methods.” This search provided 72,300 results, and I skimmed through the top results and used the papers that included the Caribbean or Florida Keys. I also searched “coral restoration methods in the Caribbean and Florida Keys” and this search gave me 20,900 results and provided additional useful papers. Lastly, I searched specific methods to find more detailed papers about a single method of coral restoration.

The methods reviewed in this paper include reef gardening, direct transplantation, micro-fragmentation, artificial reefs and genetic diversity in coral larvae. The purpose of this review paper is to review the different methods of coral reef restoration found in the Florida Keys and the Caribbean as well as acknowledge core knowledge gaps found. In this paper there is more information about coral gardening and transplantation than any other method due to the extensive information known about these two most popular coral restoration methods.

II. Coral Restoration Methods

A. Reef Gardening

Reef gardening is the process of raising small fragments of corals, usually *Acropora* species, in nurseries before outplanting (the act of replanting the corals into another location in the ocean) them on degrading restoration sites (Bostrom-Einarsson et al., 2020). Coral gardening is the most commonly used method in

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the Caribbean (Young et al., 2012). When coral fragments are grown large enough in the nurseries, they can be broken into smaller pieces expanding the number of coral fragments available for outplantation without collecting more corals from wild reefs (Bostrom-Einarsson et al., 2020; Page et al., 2018). The corals live in coral reef nurseries until they have reached a higher survival rate which is when they can be outplanted onto damaged and degrading reefs (Bostrom-Einarsson et al., 2020). Most coral reef restoration nurseries are located *in situ* in Marine Protected Areas (MPAs). This is to keep corals protected from other stressors during their most vulnerable life stages (e.g., fishing, dredging snorkel/scuba activities, etc.) (Young et al., 2012). Coral garden nurseries can either be *in situ* (field-based) or *ex situ* (land-based) and, regardless of location, have a 68%-95% survivorship using this method (Young et al., 2012).

Site selection is very important in the succession of the coral gardens (Johnston et al., 2011). Nearby wild coral populations, depth, water motion, bottom type, size of the area, adjacent habitat, competitors, human activities/impacts, accessibility, number of nurseries, and permits all need to be considered when choosing a site for coral gardening (Johnston et al., 2011). In addition, when deciding on an outplanting site depth, water quality, bottom type, size of area, space competitors, predator abundance, wave exposure, origin of parent colonies, current/historical presence of coral gardening species (*Acropora*), human activities/impacts, number of outplanting sites, how much to outplant, and health/condition/size of outplanted corals need to be considered (Johnston et al., 2011). A study by Ware et al. (2020) found that corals on spur-and-groove habitats, distinct features on the front of reef slopes (Duce et al., 2016), were more successful than the corals on hard bottom habitats. The Coral Restoration Foundation in the Florida Keys have used spur and groove habitats during their outplantation (Ware et al., 2020). Rescue A Reef and Coral Restoration Foundation are two major restoration programs in the Caribbean (Lirman & Schopmeyer, 2016), and they use coral reef gardening as their preferred method.

Equipment needed for coral gardening is simple, inexpensive and relatively available. The coral gardening method can use metal frames, ropes, cinderblock platforms, Reef Balls (Fig. 2D), floating structures (Fig. 3B), ceramic EcoReefs (Fig. 2E) and electrified metal grids called BioRock (Fig 3A)

(Lirman & Schopmeyer, 2016; Young et al., 2012). Although Reef Balls and ceramic EcoReefs can be used in coral garden nurseries, they are more commonly used with artificial reefs during transplantation. Coral gardening nurseries in the Caribbean often use simple cement structures like large limestone boulders (Fig. 2A, B) (Jaap, 2000). Coral gardening is beneficial to coral growth and health, but it also provides secondary benefits including: habitat for fish and invertebrates on depleted reefs, increased genetic variations to enhance local diversity on the reef, a more sustainable source of coral for experimental research, aquarium specimens to showcase the benefits of coral restoration to millions of visitors, and unique volunteering opportunities (Johnston et al., 2011).

Reef gardening has many primary benefits such as high survivorship during the first year at the nursery (Young et al., 2012), it only requires a limited initial collection and has no sustained need for wild collections, high productivity while at the nursery, low cost, and simple technical requirements (Lirman & Schopmeyer, 2016). It also increases job opportunities with restoration and tourism (Lirman & Schopmeyer, 2016). Downsides of coral gardening are that its susceptible to storm damage, temperature variances, predation, poor water quality, and competition (Young et al., 2012). Researchers have found that coral survivorships are succeeding in the short term but decline after outplanting in the long term (Ware et al., 2020).

B. Direct Transplantation

Transplantation is the relocation of coral fragments from a donor to a recipient reef (Bostrom-Einarsson et al., 2020). This method is most commonly used for salvaging corals from planned construction activities that would destroy or disturb the colonies – for example, dredging, port and marina expansion, and beach renourishment (Bostrom-Einarsson et al., 2020; Young et al., 2012). The most common corals that get transplanted are branching corals with average rates of survival at 64% (Bostrom-Einarsson et al., 2020). Direct transplantation is less sustainable than reef gardening because reef gardening doesn’t have to continue harvesting coral fragments after the initial harvest (Bostrom-Einarsson et al., 2020) and effectively helps to save corals that would otherwise be lost. Equipment used in direct transplantation

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includes reef balls, cement pucks, concrete rosettes, cement, underwater epoxy, plastic cable ties, metal wire, nails, and bolts (Young et al., 2012). Cable ties and underwater epoxy has been known to be the most successful and increase the survival of transplanted corals (Young et al., 2012). Reef gardening and direct transplantation have relatively low costs compared to other restoration methods (Young et al., 2012) which is one reason why they are the most used methods.

C. Micro-Fragmentation

Micro-fragmentation is the same as coral gardening but with 1cm^2 fragments of massive and encrusting corals (Bostrom-Einarsson et al., 2020; Page et al., 2018). It requires cutting a small piece out of a massive coral and attaching it to disks to place into nurseries (Bostrom-Einarsson et al., 2020). Although coral restoration teams have been using fast-growing branching corals like *Acroporas*, recent work has included massive and encrusting coral species due to modern developments of micro-fragmentation (Lirman & Schopmeyer, 2016). Techniques to extract coral fragments from massive and encrusting corals has been difficult in the past but recently, advancements in techniques have made fragmenting massive and encrusting corals possible (Page et al., 2018). Massive coral fragments take approximately 12 months until they have grown large enough to outplant or split into smaller fragments for regrowth (Bostrom-Einarsson et al., 2020), but they have a high survivability and rapid growth of fragments once outplanted (Bostrom-Einarsson et al., 2020). Massive corals are more resilient to stressors compared to the commonly used *Acropora cervicornis* (Page et al., 2018). Massive coral species used for micro-fragmentation in the Florida Keys are *Obicella faveolate* and *Montastrea cavernosa* (Page et al., 2018). In order to extract a micro-fragment from a massive coral, a diamond blade saw must be used to cut into the donor coral (Bostrom-Einarsson et al., 2020). Otherwise, micro-fragmentation uses the same equipment and process as coral gardening. The micro-fragments are then attached onto flat platforms where they will grow. Once they grow large enough (~6cm^2), they are outplanted and each family species is arranged close together. Overtime, they fuse together creating a larger colony which is known as re-skinning (Bostrom-Einarsson et al., 2020).

D. Artificial Reefs

Artificial reefs are structures placed on the seabed to create a potential habitat for corals. The structures may include Reef Balls (Fig. 2D), EcoReefs (Fig. 2, E), and Biorock. Artificial reefs are typically used as the base for coral transplantations (Bostrom-Einarsson et al., 2020). This method has a 66% survival rate (Bostrom-Einarsson et al. 2020).

Reef Balls (Fig. 2D) are round, hollow structures made out of textured concrete with multiple holes (Barber & Barber, 1996). This shape and texture encourages the growth of corals and provides shelter for marine life (Barber & Barber, 1996). Barber & Barber (1996) conducted a simple test on how Reef Balls can create a diverse ecosystem. Bare Reef Balls left for 4 months were covered in sponges, algae, tunicates, feather dusters, barnacles, and provided habitat for a variety of fishes (Barber & Barber, 1996).

EcoReefs (Fig. 2E) are snowflake-shaped ceramic pieces made to imitate the branching corals commonly used in coral restoration: *Acroporas* (Moore & Erdmann, 2008). The EcoReefs are made to reestablish a degrading reef while allowing the reef to look more natural than other artificial reef structures (Moore & Erdmann, 2008). Sometimes concrete structures can reduce tourism and react with chemicals in the seawater interfering with coral growth or coral settlement (Moore & Erdmann, 2008). EcoReefs are touted for their simplicity and material, unglazed ceramic stoneware, which doesn't contain chemicals or toxins (Moore & Erdmann, 2008). The design is simple, but effective, with many features built into it allowing for multiple settling locations. Its multiple branching arms maximize the surface area for coral recruitment, its vertical arrangement keeps corals from getting buried in sand and suffocated by algae, and its spatial complexity effectively houses reef and juvenile fishes (Moore & Erdmann, 2008). The structure only requires a cable to tie down coral fragments, reducing equipment costs and foreign objects in the ocean (Moore & Erdmann, 2008). Because of the EcoReef's design, it rapidly results in a reef community which is essential for long-term, successful coral reefs (Moore & Erdmann, 2008).

Finally, Biorock can also be used for coral restoration growth as a structure that utilizes

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electrolytic technology to maintain healthy corals under the stressful conditions of both high temperature and reduced water quality (Goreau & Hilbertz, 2005). Low voltage is used to create an electrical current to cause electrolysis of seawater to metal racks that coral fragments are fixated on. This creates a calcareous substrate for corals to settle upon and provides the coral with some extra energy to grow allowing them to focus the rest of their energy on reproduction and resisting environmental stressors (Goreau & Hilbertz, 2005). This method has shown great results with corals growing at accelerated rates (Goreau & Hilbertz, 2005). Biorock reefs have had success not only in the Caribbean but also around the world (Goreau & Hilbertz, 2005).

E. Coral Larvae

Collecting coral larvae for nursery stock is an important method in keeping genetic diversity in the coral reefs. As *Acroporids* are commonly used in coral restoration, they naturally reproduce asexually through fragmentation (cloning), thus collecting coral larvae is a crucial aspect in restoration goals for increasing the genetic diversity with increasing environment stressors (Bostrom-Einarsson et al. 2020). A new restoration effort called coral larvae cradle has been created by Suzuki et al., (2020) which is made to improve larval supply and post-settlement in sexually assisted coral restoration efforts (Suzuki et al., 2020). It is designed in a funnel shape positioned vertically in the water column, covered by nylon mesh with a wide opening at the seabed over the corals that narrows and enters a $9m^2$ cylinder area that is closed at the surface (Fig 4 & 5) (Suzuki et al., 2020). This process “reduces initial mortality in corals by ensuring high fertilization rates, larval survival, and settlement on artificial substrates” (Suzuki et al., 2020). The coral larvae cradle is usually done on Scleractinians (stony corals) because they are broadcast spawners (Suzuki et al., 2020). They focus more on the *Acropora* species because of the high number of *Acropora* used in coral restoration (Suzuki et al., 2020). This process is solely *in situ* with no land facilities needed (Suzuki et al., 2020). The larval cradle can ensure direct larval seeding of damaged reefs as the cradle can move to targeted areas and coral larvae can be easily released from the cradle (Suzuki et al., 2020). Artificial reefs can be used to enhance post-settlement survival of corals because the

Acroporids are known to have very high mortality during the first 6 months of settlement (Suzuki et al., 2020). Suzuki et al., (2020) has shown high success rates of survival (99.1% after 4 days) and fertilization using the larval cradle. This method allows several million coral larvae to be procured without land facilities and can be used for large-scale coral restoration (Suzuki et al., 2020).

A recently developed method using larvae is larval seeding. Gametes with embryos are harvested and then placed onto natural or artificial reefs (Bostrom-Einarsson et al. 2020). This method has only been used a small number of times and is expensive, time consuming, and has seen limited success (Young et al., 2012).

III. Corals Used in Restoration

The most common corals used in coral restoration in the Caribbean are *Acropora cervicornis* (staghorn coral) and *Acropora palmata* (elkhorn coral) (Fig. 6). They are important species for reef growth, island formation, fisheries habitats, and coastal buffering in the Caribbean (Young et al., 2012). *Acropora cervicornis* and *A. palmata* have high growth rates, naturally use fragmentation for asexual reproduction, maintain the ability to heal rapidly from wounds, and high survivorship of fragmentation compared to other corals (Young et al., 2012; Ladd et al., 2016). They have been the key reef building corals in the Caribbean for over thousands of years (Garrison & Ward, 2012) and provide essential habitat for a multitude of reef-associated organisms (Ladd et al., 2016). *Acropora cervicornis* and *A. palmata* have been listed as “threatened” under the US Endangered Species Act (Ladd et al., 2016) as they have declined up to 95% in some areas of the Caribbean (Young et al., 2012). Most restoration efforts focus on *A. cervicornis* and *A. palmata* for these reasons (Ladd et al., 2016). *Porites porites* (finger coral) have also been used in coral restoration efforts due to their fast growing and natural reproduction by fragmentation, but they are less commonly used compared to the *Acropora*. Although, branching corals are used most for coral restoration, massive corals are also becoming more popular for coral restoration. *Orbicella faveolate* and *Montastrea faveolate* have been used in the Florida Keys for experiments on the success of massive

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corals fragmentation and the feasibility of "coral reskinning" (Page & Vaughan, 2014). Massive corals such as *O. faveolate* and *M. faveolate* are appearing in coral nurseries more often due to their increased outplant survivorship and growth (Page et al., 2014).

IV. Complications and Solutions

Coral restoration isn't perfect and there is a variety of potential issues that may reduce coral survivorship. Herbivory, corallivory, lack of nutrients, and diseases are all common issues with coral restoration (Ladd et al., 2018; Ladd et al., 2020; Lirman & Schopmeyer, 2016). Unfortunately, these potential threats are not always a priority or recognized when choosing a nursery location (Ladd et al., 2018).

A. Herbivory

Herbivory is an essential part of successful coral restoration sites. Introducing algal herbivores to restoration sites will increase the survivorship of corals by assisting coral settlement, growth, and survival by consuming the algae that competes with corals for space on the reefs and may transmits coral diseases and poison coral tissues (Ladd & Shantz, 2020). Corals need herbivores after major disturbances to allow corals to recolonize instead of macroalgae taking over preferred substrates (Ladd & Shantz, 2020). A study done by Henry et al. (2019) found that restoration tanks with herbivorous snails and herbivorous tuxedo urchins have had a positive impact in the growth and survivorship of *Acropora cervicornis*. Herbivores are "a simple and cost-effective method for increasing nursery production" (Ladd & Shantz, 2020). Finding an MPA that has a large population of herbivorous animals to be a coral nursery can be beneficial for coral restoration (Ladd & Shantz, 2020). In cases where MPA's and/or large population of herbivorous animals are not possible, creating or placing nurseries near vertical structures has been shown to bring in herbivorous fishes to keep the algae off the corals (Shantz et al., 2015). Growing a couple corals to large sizes can be done in place of adding artificial structures to create a more natural environment for herbivorous fish in coral nurseries (Ladd & Shantz, 2020). Most restorations use staff and volunteers to hand pick algae off of coral fragments initially, but that can be very time consuming and algae regrowth is inevitable (Ladd & Shantz, 2020). By providing restoration sites with herbivores, coral success is far more likely and far more cost effective in mitigating macroalgae growth (Chiappone et al., 2006). Outplanting corals in areas with high population of herbivorous organisms or introducing herbivory on outplanted reefs should be a priority in restoration projects (Ladd et al., 2018).

B. Corallivory

Corallivory is the predation on corals (Ladd & Shantz, 2020) and may be a significant threat to successful coral restorations. Mitigation of corallivory often relies on using mesh with openings for small herbivores, but maintains protection from larger corallivorous parrotfish, especially while coral fragments are small and fragile (Ladd & Shantz, 2020). Although the mesh cages keep larger corallivores out, small corallivorous invertebrates (e.g., fireworms and coral snails) may still be highly destructive. Arrangement of corals, such as *Acropora cervicornis* in a mixed-species orientation versus conspecific strands, has shown to reduce the predation of corals by coral snails (Brucker, 2013; Johnston & Miller, 2014; Ladd & Shantz, 2020). Additional protection may be achieved by the introduction of predators to minimize corallivory (Ladd & Shantz, 2020).

C. Lack of Nutrients

Some corals are more heterotrophic than others and have the ability to filter feed for nutrients without the photosynthetic help of the endosymbionts (Ladd & Shantz, 2020). Depending on the species, heterotrophy is responsible for 15% - 35% of the daily metabolic requirements of healthy coral colonies as well as 100% in bleached corals (Houlbrèque & Ferrier-Pagès, 2009). Supplemental feeding has shown increased coral growth in most cases (Ladd & Shantz, 2020). Although this idea has not been tested extensively, with Ladd and Shantz (2020) only finding 8 such studies, it may serve as a potential new method to improve coral restoration.

Corals may also acquire nutrients from fish excretion according to Ladd and Shantz (2020):

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"Corals utilize the inorganic ammonium and phosphorus excreted by fishes to fuel photosynthesis" and "naturally occurring enrichment from fish excretion increase coral growth, while human-mediated enrichment tended to decrease coral growth" (Shantz & Burkepile, 2014). Shantz et al., (2015) suggests that the condition and growth rates of *Acropora cervicornis* transplanted to locations with high fish biomass is greater than at locations with low biomass. Studies show a positive relationship between fish and coral densities with *A. cervicornis* (Ladd & Shantz, 2020). This benefit may also see greater herbivory and further promote coral growth (Ladd et al., 2018).

D. Diseases

Diseases are a major source of mortality to corals in Florida (Lirman & Schopmeyer, 2016). Corals such as *Acropora*, are widely used in coral restoration because of their natural asexual reproduction of fragmentation which decreases their genetic variability and increases their susceptibility for diseases. Dense coral plantings also make them more susceptible to diseases (e.g., white band disease) and allow for rapid transmission (Sheridan et al., 2013; Kojis & Quinn, 2001). The best way found to deal with this issue in coral nurseries is to remove corals at the first sign of disease and place them into a quarantined area/tank away from the nursery to be treated. There haven't been any successful treatments for diseased corals and because of this, corals that have had an outbreak in a disease are not outplanted (Lirman & Schopmeyer, 2016). Little is known about the origins of coral diseases and how they affect corals (Sheridan et al., 2013), but it is believed that diseases develop when corals become stressed which can include environmental/anthropogenic factors, biological factors, or a combination of both (Sheridan et al., 2013). This also means that corals can get a disease *in situ* or *ex situ* but how they contact the disease can be different (Sheridan et al., 2013). Sheridan et al. (2013) believes the best option to deal with diseases in coral restorations is through prevention (Sheridan et al., 2013).

V. KNOWLEDGE GAPS

Coral restoration is a relatively new process so there are a lot of unknowns and knowledge gaps within this topic. Several core knowledge gaps that could assist coral reef restoration are evident in the current state of the field: Trophic Ecology and Density/Arrangement.

The usage of trophic ecology in coral restoration (Ladd et al., 2019) have been new drivers of restoration success. According to Ladd et al. (2009), "Coral restoration studies focus on the survival and growth of outplanted corals, few have investigated if and how restoration has impacted the reef community or important ecological processes." Diversity on a reef is important and can be an indicator of the ecosystem's wellbeing (Ladd et al., 2019). Diverse assemblages of fishes on a reef are critical for sustaining a healthy reef community (Ladd et al., 2019). For example, herbivores consume algae that compete with corals, invertivores feed on coral predators, and predators shape the behavior of lower trophic groups (Ladd et al., 2019). Coral restoration practitioners may overlook the necessity of ecological processes in coral nurseries when they are determining sites for coral nurseries (Ladd et al., 2018). While successful coral nursery locations focus on existing coral cover, available clean substrate, and water depth (Ladd et al. 2018), the ecological processes that provide a functional and sustainable coral reef should also be considered.

The density and arrangement of corals used for restoration can significantly affect the survival, growth, and recruitment of the coral reefs (Ladd et al., 2019). A study done by Ladd et al., (2016) in the Florida Keys showed that corals in a colony of 12 grow two times faster than corals in a colony of 24 (Ladd et al., 2019). Although coral survivorship increases as colony density decreases, Ladd et al., (2016) found that increasing the density to 3 corals m^2 resulted in more growth than they expected but adding more corals (6 or 12 corals m^2) gave a negative result with decreased growth rates (Ladd et al., 2016). Coral restoration needs to include both expansion of coral populations as well as promoting ecological processes for the most successful survivorship of coral reefs (Ladd et al., 2019).

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VI. CONCLUSION

Coral restoration has grown to be so popular that there are nurseries in every tropical ocean basin (Ladd & Shantz, 2020). The most common coral restoration methods performed are coral gardening or transplantation (Bostrum-Einarsson et al., 2020). These methods account for 68% of all restoration projects in the Caribbean (Bostrum-Einarsson et al., 2020). Coral transplantation is in combination with coral gardening as part of the outplanting process. Coral gardening is the preferred method for coral reproduction and coral reef restoration in the Caribbean (Lirman & Schopmeyer, 2016). More than 10,000 corals are being grown in nurseries and outplanted onto degrading reefs each year in the Caribbean (Lirman & Schopmeyer, 2016). Because coral gardening is a relatively new process in the Caribbean, data of long-term survivorship on outplanted corals are slim. Yet, the oldest known gardening program in the Caribbean is Puerto Rico. They have had long lasting success with the survivorship of their corals for over 7 years now (Lirman & Schopmeyer, 2016). In Florida, staghorn corals have also survived outplantation of 5 plus years and continue to grow and create new colonies. Additionally, elkhorn colonies that were raised from larvae have proven successful after outplanting and spawned 4 years after. Corals grown in nurseries that reproduce as wild corals do prove that coral gardening is in fact lending support to corals so they can recover naturally (Lirman & Schopmeyer, 2016). The knowledge gaps found during this review are the use of trophic ecology and nutrient cycling at coral restoration sites and outplanted sites (Ladd et al., 2016; Ladd et al., 2018). If restoration and conservation efforts of threatened coral species and threatened reefs are going to succeed, factors causing the decline will need to be addressed (Garrison & Ward, 2012) as well as trophic ecology and nutrient cycling (Ladd et al., 2016; Ladd et al., 2018). While a "catch all" coral restoration method might be ideal for practitioners, this work highlights that there is no perfect or best method and requires restoration projects to account for multiple components. Coral restoration is still growing, and new techniques and information are improving every day in the field, but human interaction is needed at this point to save and protect the coral reefs.

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FIGURES AND TABLES:

BOX 4: COMPARISON OF NURSERY TYPES

There are multiple parameters to consider when choosing a nursery design. Below is a comparison of three types of nurseries.

Comparison of Nursery Types	**Line**	**Block**	**Frame**
Use of vertical space	Better	None	None
Predation	Lower Rates	Higher Rates	Higher Rates
Water flow and circulation	Better	Reduced	Reduced
Can be raised or lowered in the water column to respond to weather events	Yes	No	No
Can be relocated prior to storms	Yes	Yes (but more difficult)	Yes (but more difficult)
Cheap and easy to set up (all materials are readily available)	Yes	Yes	Yes
Maintenance	Low	High	High
Growth rates	Higher	Lower	Lower
Hazard to marine life	Higher Potential	Low Potential	Low Potential
Suitable for shallow areas	No	Yes	Yes
Can be deployed in sand or rubble	Yes	Yes	Yes
Long-lasting	No	Yes	Yes
Ease of anchoring	Yes	Yes	Yes
Provides immediate habitat for fish and invertebrates	No	Yes	Yes
Macroalgae accumulation	No	Yes	Yes

Figure 1- Nursery type pros and cons for three coral garden nursery types (Source: Johnson et al., 2011)

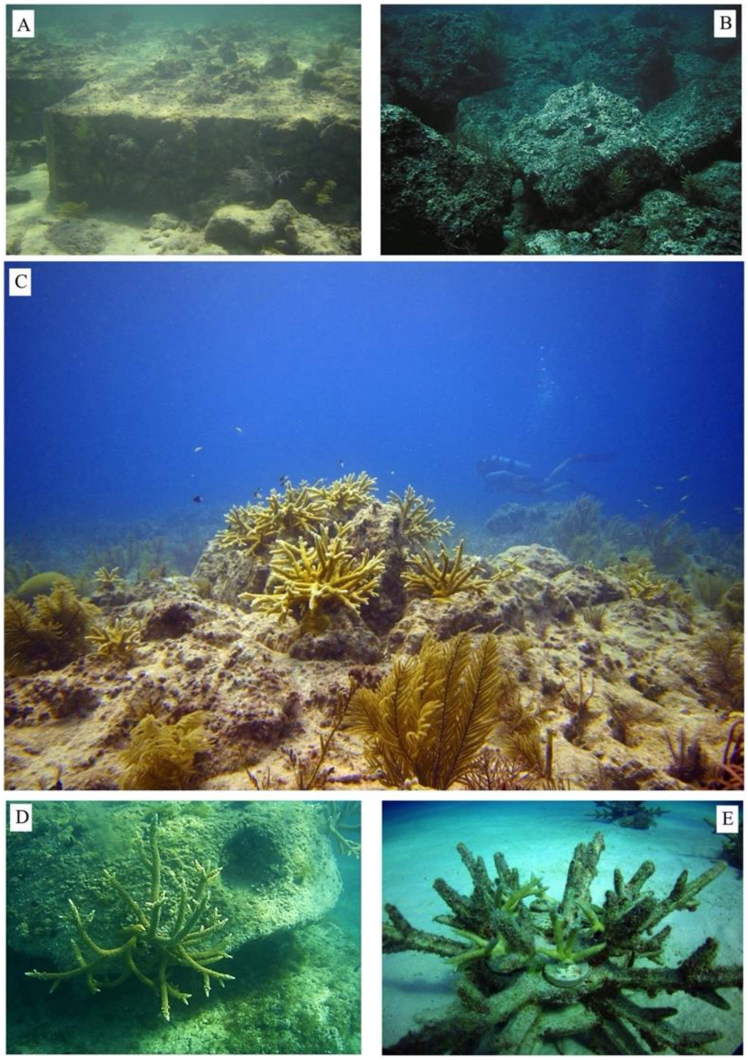

Figure 2 - "Reef restoration structures. (A) Cement modules used to restore the Maitland grounding site in Florida, (B) limestone boulders used to restore the Elpis grounding site in Florida, (C) nursery-grown *A. cervicornis* colonies attached to the modules used to restore the Wellwood grounding site in Florida (Photo credit: K. Nedimyer; Coral Restoration Foundation; http://www.coralrestoration.org/), (D) *A. cervicornis* colonies attached to ReefBalls in Antigua (http://www.reefball.org/), (E) *A. cervicornis* colonies attached to EcoReefs in Florida (http://www.ecoreefs.com/) (Photo credit: M. Johnson, The Nature Conservancy)." (Source: Lirman & Schopmeyer, 2016)

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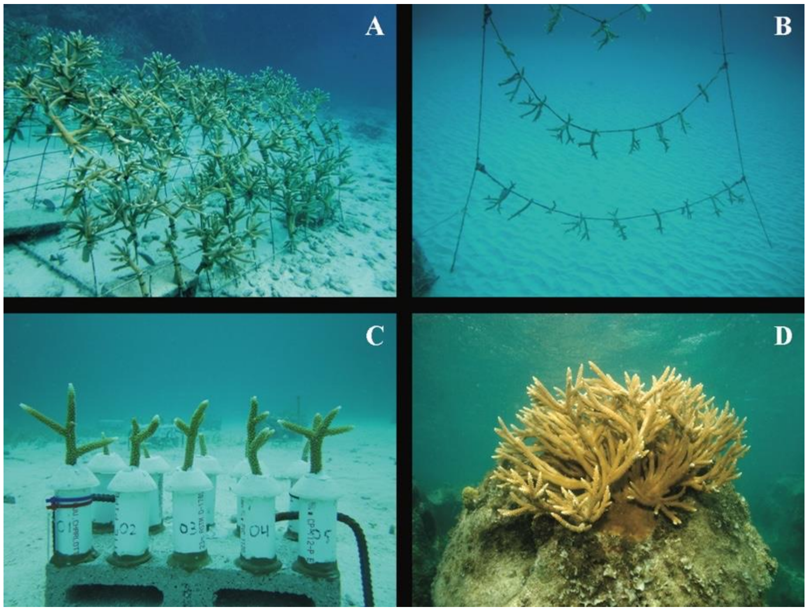

Figure 3 - Coral gardening and/or artificial reef structures (A) Wire frames, (B) ropes (more for coral gardening), (C) cinder-block platforms (more for coral gardening), and (D) Reef Balls (more for artificial reefs) used as artificial structures for propagating coral fragments within coral nurseries. Photos courtesy of (A) T Thyberg, (B) V Galvan, and (D) E D’Alessandro. (Source: Young et al., 2012)

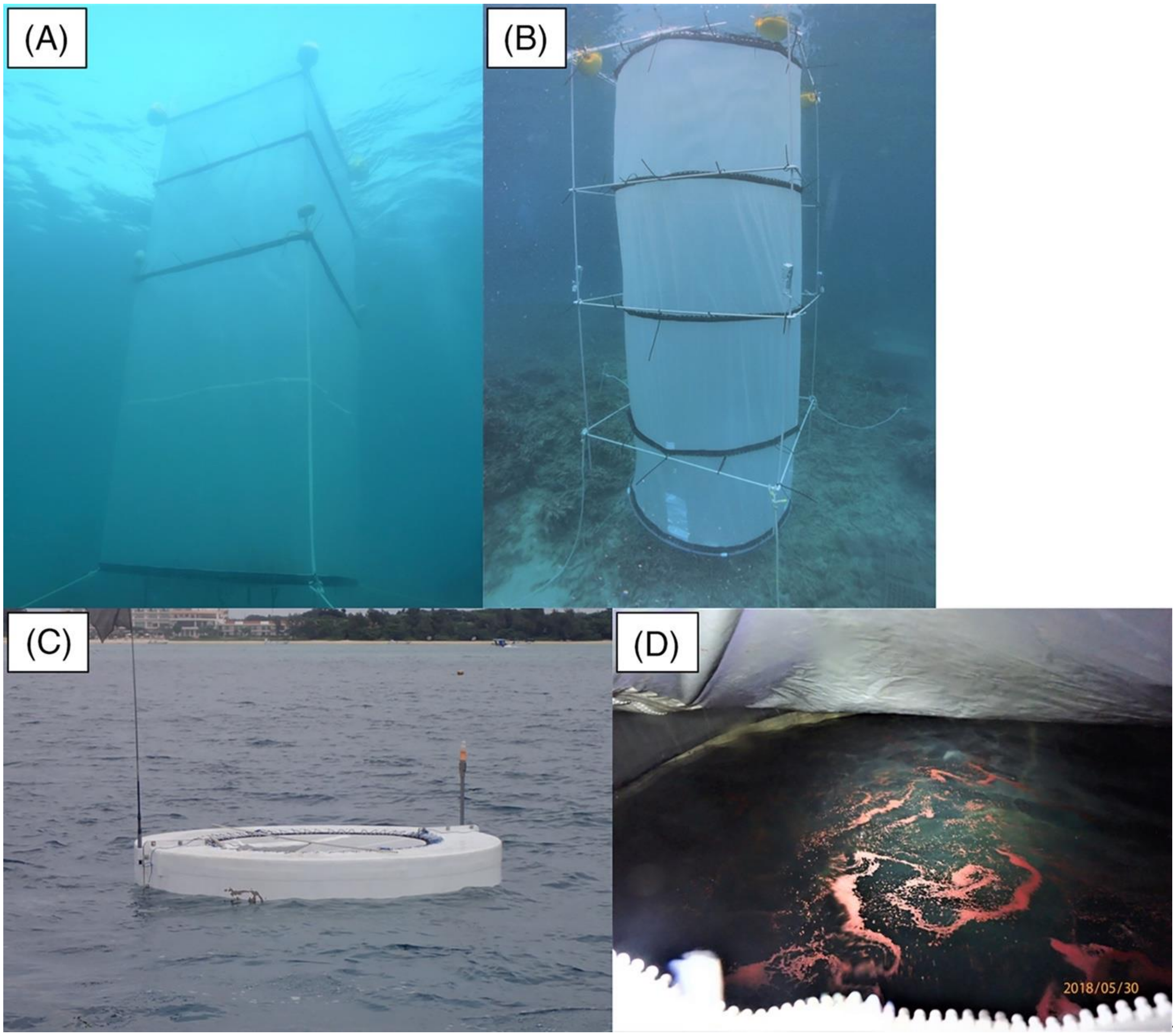

Figure 4 - (A) Cuboid, first beta type, (B) cylindrical, upgraded, (C) dedicated larval cradle float, and (D) larvae collection as observed from the top of the cradle. (Source: Suzuki et al., 2020)

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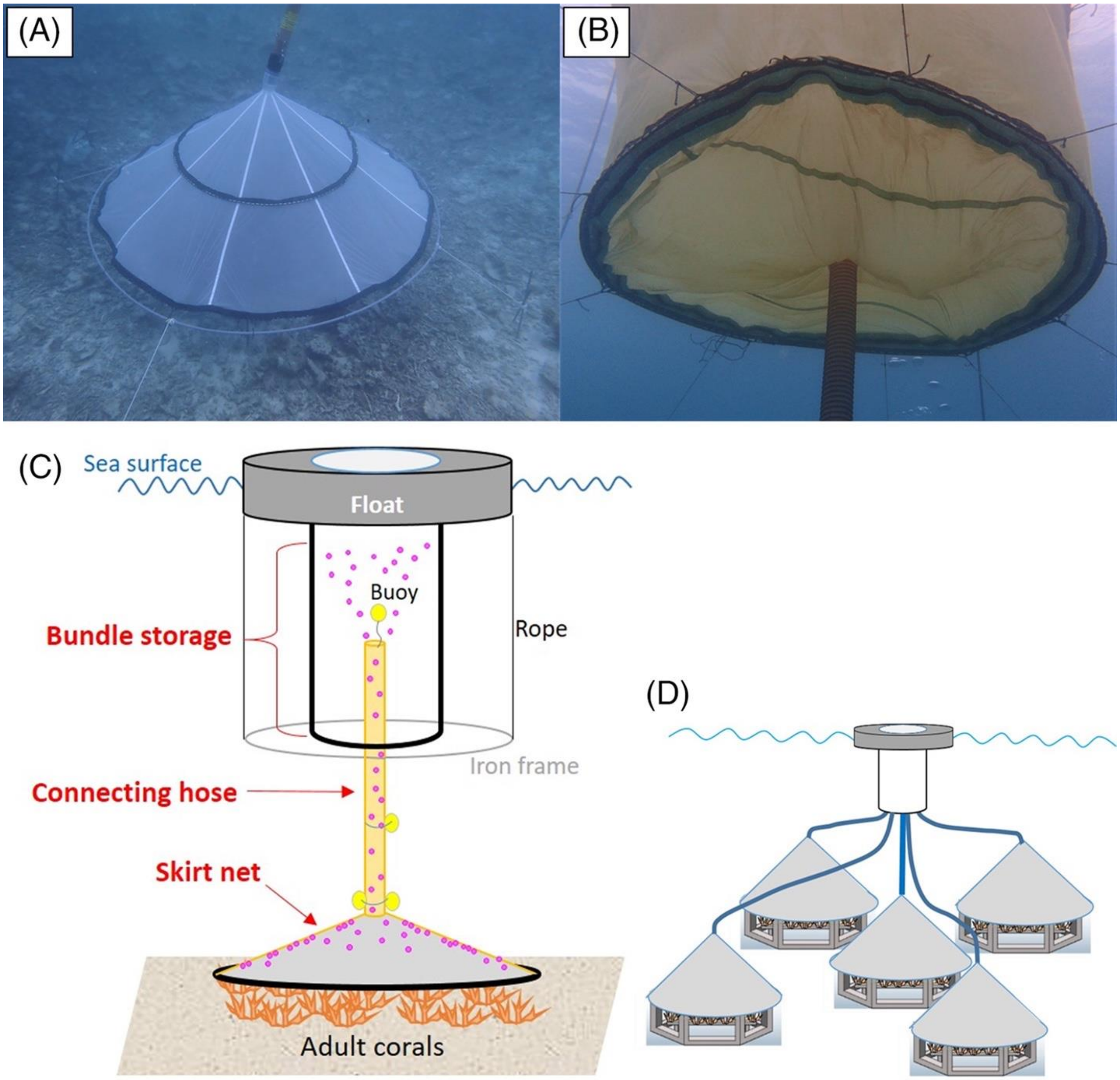

Figure 5 - Bundle/larvae collection device. (A) Conical net; (B) hose connecting the conical net to the "larval cradle"; schema showing (C) hose setting and (D) multiple deployment of conical nets. (Source: Suzuki et al., 2020)

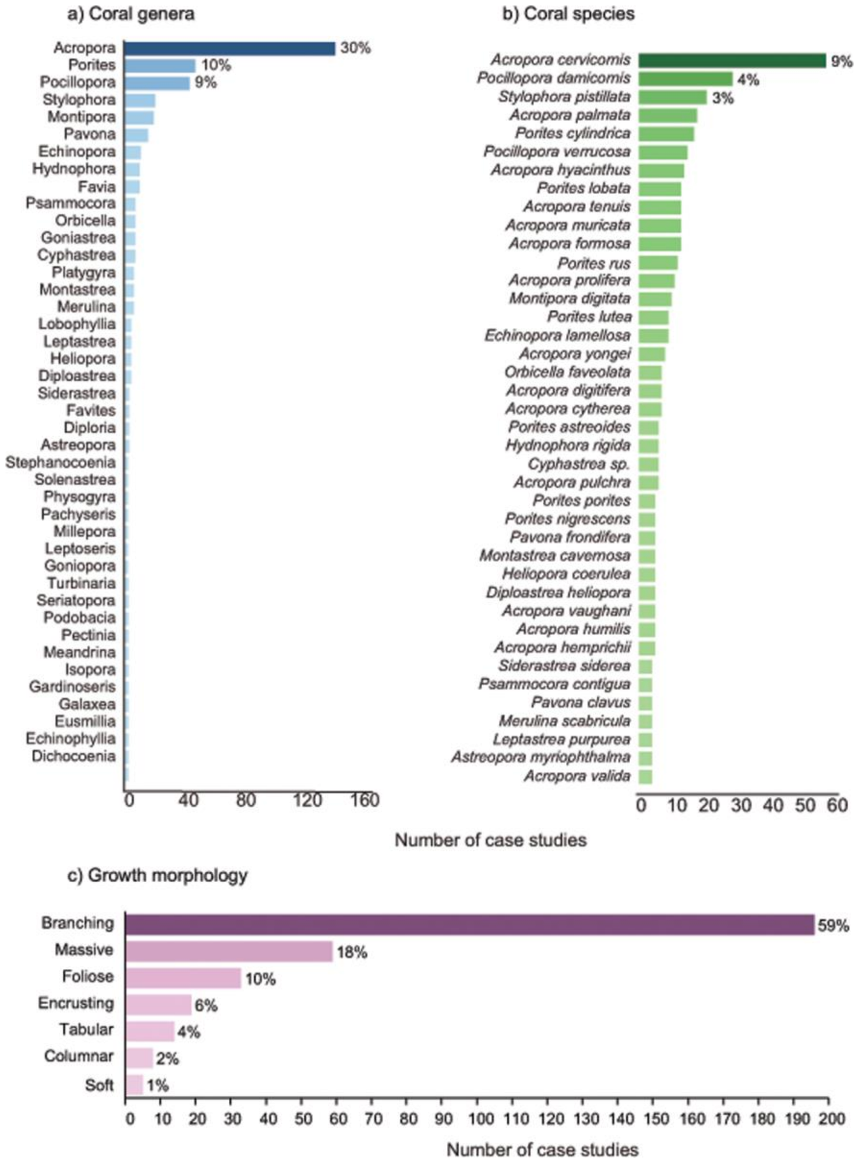

Figure 6 **- "The a) species b) genera and c) growth morphologies of corals used in coral restoration projects**. Note: The y-axis for genera and species is substantially truncated for visual purposes. The complete species list can be viewed in the online database. A large proportion of survey respondents did not report species or genera (but opted for 'mixed'). The numbers reported here are therefore from the total number of case studies that reported on species or genera." *Pocillopora damicornis* and *Stylophora pistillata*, in genera, is not native to the Caribbean. (Source: Bostrom-Einarsson et al., 2020)

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