Coral Reef Restoration

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Road Map

The restoration of our coral reefs is essential to maintain balance in our mainline and global habit on earth. Through extensive research, I have identified that the sexual propagation of transplantation technique is the most proactive and productive approach toward restoring coral reefs today. This is not to suggest that all other techniques should be discarded. Rather, the proven benefits delivered through the sexual propagation of transplantation technique should be the leading method in the restoration of our coral reefs. This technique warrants additional human capital, monetary resources, and political action. Through this paper I will introduce the current state of the world's most biodiverse ecosystems; coral reefs. I will explain their significance and the concerns that are affecting coral reefs. Next, I will define the available reconstruction solutions and explain each of the different restoration approaches. To better clarify the science driving the solution, I will then explain the operation and function of the sexual propagation of transplantation and the organizations that will be initiating the reconstruction, the National Oceanic and Atmospheric Administration and the Coral Restoration Foundation. Lastly, the resources critical to the quality and success of the restoration will be reviewed to include economic resources, political demand, and ethical interest.

Current State of the World's Most Biodiverse Ecosystems

Coral Reefs: Significance

Coral reefs are an underwater ecosystem composed of colonial marine invertebrate skeletons found within the Tropics of Cancer and Capricorn. Coral reefs, globally, contain the highest biodiversity of any ecosystem. Viewed as a keystone species and crucial habitat, reefs offer rapid nutrient recycling, perform as a hideaway for countless organisms, and produce structural heterogeneity (Jaap, 2000). Covering less than 0.2% of the ocean floor, approximately one-hundred thousand depicted species have been recorded on coral reefs, and possibly five times that number of species have not yet been described. They are home to more than 25% of all oceanic fish species, 94% of the Earth's phyla, and roughly 30% of ocean species in its entirety (Edwards & Gomez, 2007; International Union for Conservation of Nature [ICUN], 2017; Omori, 2019).

Along with these important ecological functions, coral reefs provide ecosystem services that impact the economic, social, and health of humans. Universally, coral reefs assist over five-hundred million humans directly. They provide humans with food, commercial and recreational fisheries, coastal protection, recreational activities supporting tourism industries, and have been proposed as a reference of new pharmaceuticals to treat diseases including AIDS and cancer. These services supplied by coral reefs contribute roughly three-hundred billion dollars a year domestically and ten trillion dollars a year globally to the economy (Brander et al., 2007; Edwards & Gomez, 2007; National Oceanic and Atmospheric Administration [NOAA], 2019; Omori, 2019). Coral reefs act as an important ecosystem impacting both humans and the environment.

Coral Reefs: Concerns

While coral reefs have the most biodiversity of any ecosystem, they also are amid the greatest threatened ecosystems on the planet. Reefs and their major societal benefits are deteriorating due to both natural and human induced disturbances. These natural stressors include tropical cyclones, coral diseases, tectonic activity, low salinity following heavy rain, changing weather patterns, invasive species, and a few other disruptions (Edwards & Gomez, 2007; NOAA, 2019; Precht & Robbart, 2006; Sale, 2015). Coral reefs have been experiencing natural disturbances for thousands of years, preceding human induced stressors, and have been able to slowly recover independent of outside influences. With the introduction of anthropogenic threats on the environment, reefs are unable to regenerate themselves quick enough to keep up. Human induced disturbances impact reefs both directly and indirectly. Several direct impacts include ship groundings, dredging channels and/or harbors, dredge mining sand for beach renourishment, anchoring on coral reefs, coral mining, destructive and non-sustainable fishing practices, and non-sustainable tourism practices. Various indirect impacts by humans involve sedimentation, pollution and waste, overfishing, coastal development, and climate change related increases in temperature and sea-level (Bayraktarov et al., 2019; Brander et al., 2007; Jaap, 2000; Precht & Robbart, 2006; Sale, 2015).

The greatest stressors on coral reefs come from local anthropogenic disturbances and unprecedented global warming and climate change. According to Omori (2019), roughly 75% of Earth’s reefs are regarded as threatened when local disruptions and thermal stress are incorporated. This result greatly reflects the effects of increasing ocean temperature. Greenhouse gas emissions from anthropogenic actions have increased approximately 45% from 1990 to the end of 2019 (Dahlman, 2020). This increase along with local stressors has resulted in mass coral bleaching events. Coral bleaching occurs when the symbiosis of corals and their algae living in their tissues, dinoflagellate algae, is disturbed, causing stressed corals to reject the symbiotic dinoflagellates (Cunning & Baker, 2013; ICUN, 2017; Sale, 2015). While recovery from bleaching is possible, the frequency and intensity of these results will lead to universal mass coral mortality. Anthropogenic induced CO2 emissions, accounting for the majority of greenhouse gas emissions, are not only responsible for rising sea temperatures but also the reduction of ocean pH, ocean acidification. This results in diminishing coral growth rates and skeletal density. If human induced greenhouse gas emissions continue to rise, as they have over the past twenty-nine years, ocean temperatures will continue to increase and pH will continue to fall, leading to the end of coral reefs as a functioning ecosystem. The loss of this impactful ecosystem would have a great impact on the environment and humans. This occurrence would lead to a reduction of organism diversity, biomass and abundance, larger disease rate, loss of economic services and goods, and decline of food security and employment. Acting as an indicator of global ecosystem health, coral reefs serve as an early warning of the possible future less sensitive systems may experience on account of climate change. According to NOAA (2019), "The world has lost 30 to 50 percent of its coral reefs already." With anthropogenic stressors on the rise and an absence of implementation of intervention strategies, coral reefs will continue to rapidly decline until global extinction.

Defining a Solution

Restoration

In response to the factors that are both diminishing and hindering the natural recovery of coral reefs, the intervention strategy of restoration can be implemented. Coral reef restoration is the process of returning the coral ecosystem back to its approximate original self-sustaining state by restoring its ecological functions. While restoration is a relatively new procedure, it is widely being accepted to assist coral reefs while the overarching problem of climate change is contemplated. The primary goal of restoration is to restore the reef structure while considering the ecosystem's biodiversity, complexity, biomass, and productivity (Vandenberg et al., 2021). The most prominent complication in coral reef restoration is global warming and ocean acidification. Although there is little that can be done against large-scale degradations, these factors should be taken into account to minimize the risks of restoring the ecosystem. Acute disturbances that impact the coral reefs function, however, can and should be removed from the ecosystem. The elimination of these stressors will prevent chronically stressed reefs and lead to a more successful restoration intervention. Coral reef systems are self-regenerating, but when under inadequate conditions their recovery and growth rate are too slow and unable to catch up with the degradation. Therefore, restoration measures will enhance reef recovery and bring the ecosystem back to its foremost state.

Restoration Approaches

Coral reef restoration is achieved through various different methods. Each of these methods are comprised of techniques centered around asexual and sexual propagation. Asexual propagation uses both adult colony fragments and numerous nursery farming techniques. Asexual propagation provides easily accessible small corals for transplant in emergencies and optimized benefits from the given quantity of material while decreasing damage to donor locations (Edwards & Gomez, 2007; Omori, 2019). The techniques using asexual propagation include: direct transplantation, nursery farmed coral fragments, and the electrochemical method. Although these techniques are reasonably lower priced and less labor intensive in comparison to sexual propagation techniques, the minimal genetic diversity through fragments leads to limitations in fertilization and the protection against stressors and diseases (Omori, 2019). Sexual propagation involves either broadcast spawning or internal incubating of planula larvae prior to planulation. The techniques that use sexual propagation are: cultivating and rearing larvae, inoculation of zooxanthellae, substrata for the settlement of coral larvae, and direct larval seeding. While these techniques are more expensive, labor intensive, and require further proficient technology than those of asexual propagation, sexual propagation methods provide greater genetic diversity and cause minimal damage to donor locations. This produces effective evolutionary capabilities, recovery, and resilience within the reef's ecosystem (Edwards & Gomez, 2007; Omori, 2019). There are two restoration techniques in which both asexual and sexual propagation can be applied. Those being transportation and transplantation. The Restoration technique that is being advocated for within this paper is the sexual propagation of transplantation.

Science Driving the Solution

Sexual Propagation of Transplantation

The identified location for this restoration intervention will take place in the Florida Keys, a chain of islands off the coast of southern Florida. The Florida Reef Tract, extending from Martin County, through the Keys, and to the Dry Tortugas, is exceedingly popular for commercial and recreational shipping and boating activity. When exclusively examining the Keys, 57% of surveyed shallow water reefs sites have indicated boating and anchor damage as well as over six-hundred vessel groundings being annually reported (Kerrigan, 2017; Lirman et al., 2010). Due to these and numerous other statistics, the most productive and proactive approach for restoration of this selected location is the sexual propagation of transplantation.

The sexual propagation of transplantation technique is a method used to "benefit recruitment, accelerate recovery, and improve the visual perspective" (Jaap, 2000, p. 353). Before performing this technique, it is important that the water quality in the given location is adequate and it is not a high-energy environment (Edwards & Clark, 1999). On account of the Water Quality Protection Program and specific site chosen in the Florida Keys, restoration can undergo the transplantation method. To execute this, corals and other biota are acquired and transplanted to the damaged area. Sexual propagation is used in acquiring these organisms. Planulating or broadcast spawning species are collected and stored in aquaria until larvae are ready and able to settle onto the degraded site. Being stored in aquaria with factors similar to those of the degraded site lowers stress after transplantation has been completed (Edwards & Gomez, 2007; Omori, 2019). By using this restoration method damage to donor locations are minimal and survival rates drastically increase. It has also been suggested that this technique may attract other reef species improving recovery (Boström-Einarsson et al., 2020; Edwards & Clark, 1999). Restoration is not one-time situation, rather an ongoing process of monitoring and maintenance. Routine maintenance must be established to prevent the loss of transplants to predators, while regular monitoring can record success and cost-effectiveness.

Organization Initiating Reconstruction

In order to carry out this restoration intervention strategy, two organizations will be assisting in the reconstruction. These organizations are the National Oceanic and Atmospheric Administration, NOAA, and the Coral Restoration Foundation. NOAA is an agency of the U.S. government that addresses conditions of the oceans, major waterways, and the atmosphere. This project would be working with the NOAA branch, National Marine Fisheries Service, within their Reef Conservation Program. This program works with state and local organizations across the country providing technical support and funding for coral restoration. This is facilitated through their established partnerships among local organizations, state governments, and federal agencies (NOAA, 2019). The Coral Restoration Foundation is the world's largest non-profit coral reef restoration organization. Headquartered in Key Largo, Florida, this organization is dedicated to restoring coral reefs in Florida and globally. The Coral Restoration Foundation is partnered with leading researchers, universities, scientists, and other organizations, such as NOAA and the Florida Keys National Marine Sanctuary (Coral Restoration Foundation, 2020). Both of these organizations are huge assets in accomplishing this restoration project in the Florida Keys.

Resources Critical to the Quality and Success of the Restoration

Economic Resources

When determining the price of restoration both capital and operating cost must be considered. The cost of coral reef restoration can vary between $10,000 to $50,000,000 per hectare (Edwards & Gomez, 2007). While sexual propagation can spread from $5.3 to $163, the technology being used has the ability to be improved, amplifying production and decreasing cost (Omori, 2019). When determining the practicality of coral reef restoration expenses, the economic benefits and success are analyzed. The greater the success of the restoration the more practical the expense. If sexual propagules expand the colony size greater than the reef's original state, success increases. Omori (2019) states, “a coral survival rate of more than 40% at 3–4 years post-transplantation/outplantation would be a reasonable performance target for active coral restoration” (p. 395).

The revenues to afford this project will come from funding through the NOAA and the U.S. Environmental Protection Agency (EPA). EPA is the primary Federal agency allocated to protecting human health and the environment from pollution. Their environmental grants to fund education, research and solutions are allotted to states, local governments, nonprofits, and more. Agreements that increase funding for restoration would also be utilized. These agreements include the Convention on Biological Diversity's Aichi Biodiversity Target 15, the Sustainable Development Goals adopted by United Nations Member States, or the United Nations newly declared 2021 – 2030 Decade on Ecosystem Restoration (Bayraktarov et al., 2019). Volunteers from local communities and organizations will also be considered in the production of the restoration.

Political Demand

In order to implement and produce a sustainable restoration program, mandates and restrictions must be set in place. The U.S. government is allocated authority to recover coral reef resource damages, through a variety of federal regulations. The Natural Resource Damage Assessment, NRDA, is a process to identify natural resource damage, determine the damage, and develop and apply suitable restoration measures. The evaluation of natural resource damage requires interaction among many different positions including scientists, regulators, lawyers, law enforcement officers, economists, and resource managers (Lirman et al., 2010; Precht & Robbart, 2006). Within southern Florida alone there are numerous regulations concerning the protection of coral reefs. The National Marine Sanctuaries Program Amendments of 1988 provides regulations in Federal waters that claim, "any person who destroys, causes the loss of, or injures living or nonliving resources of a National Marine Sanctuary may be liable to the United States for damages, including the cost of replacing or restoring the resource and the value of the lost use pending the replacement or restoration" (Precht & Robbart, 2006, p. 9).

Regulations and restrictions such as these will assist in the implementation and protection of coral reef restoration.

Ethical Interest

Before going through with restoration, one must contemplate the ethical question of whether or not it is truly possible to restore the coral reef ecosystem back to its primary and undisturbed state. By using the restoration method sexual propagation of transplantation, survival rates and genetic diversity are high while damage to donor reefs are low. This specific method is the foremost solution for the issue of substantial boating and anchor damage on the Florida Keys reefs. Substantial improvements will only result if ample effort is implemented. Consistent monitoring and maintenance in addition to mandates and restrictions on the restoration site after completion will assist in the long-term success. It is important for each individual to contribute for the reef to succeed. These contributions for locals can be in the form of following the mandates and restrictions along with managing the local stressors on their coral reefs.

Ultimately, it is our ethical responsibility as humans to preserve, maintain, and save species on Earth. It is apparent that humans are to blame for the decline of not only coral reefs but also millions of other species. Human intervention is needed to ensure the persistence of all species around the world, including coral reefs. While coral reef restoration is not an end all solution, it is a step in the right direction and buys time until major improvements in climate change are established.

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