**Ecosystem Restoration: Coral Reef and Seagrass**

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**Abstract**

Restoration of ecosystems is becoming an increasingly essential aspect of tropical and subtropical marine conservation. Seagrass and coral reefs provide a variety of ecological services, including nursery habitat, better water quality, coastal protection, and carbon sequestration. Ecological restoration is receiving more attention as a conservation tactic, hence methods to improve restoration success must be explored. Impacts of human activity pose a danger to seagrass, coral reef and the vital ecological services they provide worldwide. Appropriate conservation management is essential before the commencement of restoration operations to establish an environment in which restoration efforts are likely to succeed. Restoration must be viewed as an essential component of our future ecosystem longevity, and it requires an urgent emphasis and execution to address the rapid alterations and loss caused by both climate change and various direct human-related consequences.

**Introduction**

Restoration is defined as "any intentional activity that initiates or accelerates the recovery of an ecosystem from a degraded state"; irrespective of the kind or level of degradation (Pandit et al., 2018). Restoration responses vary depending on the environment (croplands, woods, rangeland, urban land, wetlands, etc.). To enable ecosystems to provide essential functions those responses should consider landscape-level strategies, responding to local and enabling conditions, as well as integrating indigenous and local knowledge (Pandit et al., 2018; CBD, 2019). The UN Decade on Ecosystem Restoration intends to scale up ecosystem restoration initiatives internationally to accomplish the sustainable development goals related to biodiversity conservation, poverty alleviation, improved livelihoods, food security, and climate change mitigation.

Ecosystem restoration is described as "the process of reversing the degradation of ecosystems, such as landscapes, lakes, and oceans, to regain their ecological functionality; in other words, to improve ecosystem productivity and capacity to meet societal needs." This can be accomplished by enabling overexploited ecosystems to regenerate naturally or by planting trees and other plants" (UNEP, 2019). "The goal of ecosystem restoration is to contribute to the conservation and sustainable use of biodiversity while also creating social, economic, and environmental benefits, with healthy and connected ecosystems helping to improve food and water security, people livelihoods, and mitigating and adapting to climate change" (CBD, 2019). Considering ecosystems as socio-ecological areas that provide multiple functions that benefit a diverse range of stakeholders can aid in identifying the drivers of ecosystem degradation and loss, existing management interests in the landscape, economic issues, and long-term ecosystem goals (Bjork et al., 2008).

**CORAL REEF**

Coral reefs are among our planet most ecologically and commercially significant ecosystems. Despite covering less than 0.1 percent of the world's ocean, they sustain about 25% of marine biodiversity and provide ecological services to up to a billion people, including coastal protection, fisheries production, sources of medicine, recreational advantages, and tourism profits. (UNEP, 2021). However, they are also on the frontline of the climate crisis due to their sensitivity to warming seas. We have already lost up to 50% of their original size. According to recent Intergovernmental Panel on Climate Change (IPCC) studies, even if warming is kept to 1.5°C, up to 90% of reef-building corals might be destroyed by 2050. The objective of coral reef restoration has now evolved from restoring to a historical baseline to recovering or preserving important ecological processes, functions, and services throughout the next few decades of climate change. The Coral reefs in India are mainly restricted to the [Andaman and Nicobar Islands](https://en.wikipedia.org/wiki/Andaman_and_Nicobar_Islands), [Gulf of Mannar](https://en.wikipedia.org/wiki/Gulf_of_Mannar), [Gulf of Kutch](https://en.wikipedia.org/wiki/Gulf_of_Kutch), [Palk Strait](https://en.wikipedia.org/wiki/Palk_Strait) and the [Lakshadweep](https://en.wikipedia.org/wiki/Lakshadweep) Islands. All of these reefs are [Fringing reefs](https://en.wikipedia.org/wiki/Fringing_reef), except [Lakshadweep](https://en.wikipedia.org/wiki/Lakshadweep) which are [Atolls](https://en.wikipedia.org/wiki/Atolls).

**GOALS OF CORAL REEF RESTORATION**

**Socio-economic goals**

* Sustain or recover coastal protection- Protect coastal residents and infrastructure by attenuating wave energy and minimizing disturbances such as erosion and coastal flooding.
* Sustain or recover fisheries production- Maintain or restore fisheries productivity. Maintain or re-establish reefs' provisioning services by providing habitat and nursery regions for commercially valuable fisheries.
* Maintain or improve local tourist opportunities- Maintain reef aesthetics to encourage local reef tourism and/or to create chances for eco-tourist experiences.
* Promote local coral reef stewardship- Support local communities and/or Indigenous traditional owners in engaging and reconnecting with the local reef ecosystem, improving reef custodianship, and promoting reef intrinsic value (spiritual, traditional, and worship).

**Ecological goals**

* Restore the function and structure of the reef ecosystem- Restore deteriorated coral reef ecosystems function, structure, diversity, and health.
* Mitigate population declines and preserve biodiversity- Assist in the recovery of endangered coral populations, as well as the preservation of intrinsic reef biodiversity ranging from genes to phenotypes to ecosystems.

**Climate change adaptation and support goals**

* Reduce the consequences of climate change and increase reef resilience- Support resistance and recovery mechanisms to decrease impact risks and ensure that reefs survive present and predicted climate change.

**Disturbance-driven goals**

* Respond to sudden disturbances to hasten reef regeneration- When reefs are afflicted by acute disturbances such as storms, predator outbreaks, ship groundings, and other structural problems, assist the natural healing process.
* Reduce the likelihood of coral loss before disturbance- Adopt a 'no net loss' mitigation approach in which, if a disturbance (e.g., coastal development) cannot be avoided, it should be mitigated and offset, for example, by moving expected losses before disruption.

**CORAL REEF RESTORATION METHODS**

Methods for restoring coral reefs were originally derived from those employed in terrestrial ecosystems. For example, in the 1990s, the notion of coral gardening applied silviculture concepts to the mariculture of coral pieces (Rinkevich, 1995). Other techniques originated from emergency response interventions in the aftermath of disruptions that compromised the structural integrity of the reef substrate, such as ship groundings or extreme weather events (Precht, 2006). Recently, scientists and conservationists have collaborated to create techniques to help coral reefs adapt to climate change (McLeod et al., 2019). The following is a list of five of the most extensively utilized strategies for restoring coral reefs in the world today (Bostrom-Einarsson et al., 2020).

1. **Direct transplantation**- Transplanting coral colonies or fragments without an intermediate nursery phase.
2. **Coral gardening**- Transplanting coral colonies or fragments with an intermediate nursery phase. Nurseries can be in situ (in the ocean) or ex-situ (flow-through aquaria).
3. **Substrate addition (artificial reef) -** Adding manmade structures as a substrate for coral recruitment, coral planting, and/or fish aggregation for the goal of coral reef restoration.

Electro-deposition- The addition of artificial structures coupled to an electrical current to promote mineral accretion.

Green engineering- The addition of manmade structures meant to replicate natural processes and be integrated into reef landscapes (nature-based solutions, eco-built structures, and living shorelines).

1. **Substrate manipulation-** Reef substrate manipulation to aid in recovery processes. Substrate stabilization- refers to the process of stabilizing the substratum or eliminating unconsolidated debris to allow coral recruitment or regeneration.

Algae removal- The removal of macroalgae to aid in coral recruitment or recovery.

1. **Larval propagation-** Releasing coral larvae at a restoration location following an interim collecting and holding period in the water or on land in flow-through aquaria.

Deploying settlement substrates- inoculated with coral larvae.

Larval discharge- Directly releasing larvae at a restoration location.

**CORAL REEF RESTORATION METHODS IN INDIA**

1. **Coral restoration in the Gulf of Kachchh-**

The Zoological Survey of India (ZSI), in collaboration with Gujarat's forest department, is attempting for the first time to restore coral reefs through the use of biorock or mineral accretion technology. A biorock structure was built one nautical mile off the Mithapur shore in the Gulf of Kachchh. Biorock is the term given to a substance generated by the electrical buildup of minerals dissolved in seawater on steel structures dropped into the sea bottom and coupled to a power source, in this instance solar panels float on the surface. "The technology works by passing a small amount of electrical current through electrodes in the water," stated Ch. Satyanarayana, a scientist at the ZSI, Marine Biology Regional Centre. "When a positively charged anode and a negatively charged cathode are placed on the seafloor and an electric current is passed between them, calcium ions combine with carbonate ions and adhere to the structure (cathode)." As a result, calcium carbonate is formed. Coral larvae attach to the CaCO3 and develop rapidly." The biorock installation site was chosen with the significant tidal amplitude in the Gulf of Kachchh in mind. The biorock installation is four meters deep at low tide and eight meters deep at high tide.

1. **Micro-fragemention Method – Florida**

In this method certain objects were put into the ocean for transplanting coral pieces such as car tyres (as done in Florida) and alloy structures were found to be very polluting but using iron frames for this process has been a success. One of the methods being used worldwide is the micro-fragemention method was discovered by accident by a scientist in Florida. It is a significant accomplishment since it allows corals to grow 25-40% quicker. Small pieces of coral are gathered and grown in an aquarium or coral nursery before being transferred to a frame in the ocean.

1. **The Andaman Islands – Reef Watch Marine Conservation**

Reef Watch was established in 1993 and began coral restoration operations in the Andamans in 2018 utilising Mineral Accretion Technology under the Reef Generate program. Naturally, broken coral fragments are collected--which would otherwise be drowned in the sand and die--and re-attached to a nearby metal frame. A low-voltage electric current is transmitted through this frame, and floating solar panels are used to boost coral health and growth rates. The electrolysis causes the reef to grow 7-12 times quicker than usual, giving the coral greater energy to resist bleaching events, warmer temperatures and disease. Many creatures, particularly young fish, have made their homes in the rebuilt buildings.

1. **Gujarat – Mithapur Coral Recovery Program**

The Coral Reef Recovery Project, which began in 2008, it is a collaboration between the Wildlife Trust of India and the Gujarat Forest Department, with funding from Tata Chemicals Limited (TCL). It is the first time in India that a community is actively managing a portion of a sea environment. It aims to design and execute suitable conservation methods for the Mithapur Reef, which is located 12 km south of the Gulf of Kachchh in Gujarat. Locally accessible boulder corals are transplanted, and frequent coral walks are conducted with members of the fishing community to look for any up-turned and/or confused corals that are partially damaged. They are initially placed at the nurseries (they currently have 57 nursery sites/tables) and translocated to coral gardens after making sure they have shown signs of growth and are established. While nursery grounds are built with iron tables, coral gardens are built using locally mined limestone rocks arranged in a conical pattern. So far, 960 artificial reef modules have been built, totaling 2438.4 sq m of surface area dispersed throughout 30,000 sq m of spatial space.

1. **Temple Adventures, Pondicherry**

"The fishermen of Pondicherry have been building fish aggregation devices by dropping rocks and random stuff that become grounds for fish to spawn." Temple Adventures began work at 18m deep, using approximately 10 tonnes of recycled concrete bricks, shells of cars, trucks and metal bars. Over time, algae formed over these structures, providing a home for planktivores (aquatic animals that feed on plankton), attracting larger predator fish and forming an ecosystem surrounding the artificial reef. These locations, termed 'Temple Reef' and 'The Wall' have seen an upsurge in marine species sightings over the years. Silver moonies and rabbit fish are widespread in these areas.

**THREATS OF CORAL REEF**

Coral reefs are in decline phase in the U.S. and around the world. Many scientists now believe, the very existence of coral reefs may be in jeopardy unless we intensify our efforts to protect those (Frieler et al., 2013). Threats to coral reefs comes from both local and global sources The majority of coral reefs are found in shallow water near the coast. As a result, they are particularly sensitive to the effects of human activities, both direct exploitation of reef resources and indirect impacts from adjacent to human activities on land and in the coastal zone. Many of the human activities that damage coral reefs are tightly intertwined into the social, cultural, and economic fabric of regional coastal communities.

Coral reefs face many threats from local sources, including:

* **Physical destruction** or **damage** caused by coastal development, dredging, quarrying, damaging fishing practices and gear, boat anchors and groundings, and recreational misuse (touching or removing corals).
* **Pollution** that occurs on land but ends up in coastal waterways. There are several forms and sources of pollution caused by land-based activities, such as:
* **Sedimentation** from coastal development, urban stormwater runoff, forestry, and agriculture.
* Sedimentation has been recognized as a key stressor for coral species and their environments' survival and recovery. Sediment deposited onto reefs can smother corals and interfere with their ability to feed, grow, and reproduce.
* **Nutrients** (nitrogen and phosphorus) emitted by agricultural and household fertilizer applications, sewage discharges (including wastewater treatment facilities and septic systems), and animal waste. Nutrients are well recognized as helpful to marine ecosystems; yet, coral reefs are evolved to low nutrient levels; hence, an overabundance of nutrients can lead to the growth of algae, which blocks sunlight and consumes the oxygen corals require for respiration. This frequently leads to an imbalance that affects the entire ecosystem. Excess nutrients can also promote the growth of microbes such as bacteria and fungus that can be harmful to corals.
* **Pathogens** from improperly managed sewage, rainfall, and livestock pens runoff. Although it is rare, parasites and bacterial infections from faeces can cause disease in corals, especially if they are stressed by other environmental factors. In healthy ecosystems, coral disease occurs, but pathogen-containing pollution can increase the frequency and severity of disease outbreaks.
* **Toxic substances** are found in industrial discharges, sunscreens, urban and agricultural runoff, mining operations, and landfill runoff, including metals, organic chemicals, and pesticides. Pesticides have the potential to disrupt coral reproduction, growth, and other physiological functions. Herbicides, in particular, have the potential to harm symbiotic algae (plants). This can harm their relationship with coral and cause bleaching. Metals like mercury and lead, as well as organic contaminants like polychlorobiphenyls (PCBs), oxybenzone, and dioxin, are thought to have an impact on coral reproduction, growth rate, feeding, and defensive reactions.
* **Trash and microplastics** are generated by inappropriate disposal and stormwater runoff. Trash such as plastic bags, bottles, and discarded fishing equipment that makes its way into the water can snag on corals and obstruct sunlight essential for photosynthesis, or entangle and kill reef creatures and break or harm corals. Degraded plastics and microplastics (for example, beads in soap) can clog the digestive systems of coral, fish, sea turtles, and other reef species, potentially introducing toxics.
* **Overfishing** can change the structure of the food web and have a cascade impact, such as lowering the quantity of grazing fish that maintain corals free of algal overgrowth. Blast fishing (the use of explosives to kill fish) can also cause physical harm to corals.
* **Coral harvesting** for the aquarium trade, jewelry, and curios can result in over-harvesting of certain species, habitat degradation, and decreased biodiversity.

The most serious worldwide risks to coral reef ecosystems are rising ocean temperatures and changing ocean chemistry. Warmer atmospheric temperatures and rising carbon dioxide levels in seawater are responsible for these hazards. Seawater temperatures rise in tandem with atmospheric temperatures. This warming causes corals to lose the microscopic algae that create the food that corals require, putting the corals under duress. Corals lose their coloring without these algae, a phenomenon known as coral bleaching since the loss of algae shows the white color of the calcium carbonate framework below the polyps. Bleaching that is severe or persistent might harm coral colonies or make them more sensitive to other hazards such as infectious diseases. Ocean acidification is an alteration in ocean chemistry caused by the absorption of carbon dioxide from the atmosphere. Because the quantity of carbon dioxide in the atmosphere is balanced by the amount in saltwater when atmospheric concentrations rise, so do oceanic concentrations. Carbonic acid is formed when carbon dioxide combines with saltwater, increasing its acidity. Ocean acidification (as indicated by decreasing pH values) reduces the availability of dissolved salts and ions required by corals to create the calcium carbonate structure. As a result, coral and reef growth might be impeded, with certain species being more impacted than others. Coral skeletons can disintegrate if acidity gets severe. On a local level nutrient enrichment from human activities on land can raise acidity in coastal waters, exacerbated by the consequences of ocean acidification.

**SEAGRASS**

Seagrass beds are one of the world's most valued ecosystems (Costanza et al., 1997). For decades, large-scale losses of these beds have been reported. In the past, worldwide seagrass loss was projected to be 12,000 km2 between the mid-1980s and the mid-1990s (Short and Wyllie-Echeverria, 2000). This has resulted in a slew of restoration initiatives (Paling et al., 2009). Seagrasses are plants with roots, stems, and leaves that are suited to life in the sea and may produce blooms, fruits, and seeds. Although the seagrass is sometimes confused, these plants are more developed and complicated than seaweed, which has a simpler structure. Seagrass beds are common in shallow seas and can reach depths of 40 meters or more provided the environmental circumstances allow photosynthesis. Present in warm and temperate waters, they form "seagrass meadows". There are 60 known species of seagrasses in the world that can create meadows. The major seagrass meadows in India exist along the southeast coast (Gulf of Mannar and Palk Bay) and in the lagoons of islands from Lakshadweep in the Arabian Sea to Andaman and Nicobar in the Bay of Bengal. The flora comprises of 14 species and is dominated by *Cymodocea rotundata*, *C. serrulata*, *Thalassia hemprichii*, *Halodule uninervis*, *H. pinifolia*, *Halophila beccarii*, *H. ovata* and *H. ovalis* (Jagtap et al., 2003).

**WHY RESTORE SEAGRASS BEDS?**

Seagrasses are one of the most valuable coastal and marine ecosystems on the planet. They provide a wealth of highly valuable ecosystem services and benefits that greatly contribute to the health of our seas, our well-being and the security of coastal communities.

**Fisheries:** Seagrass beds are one of the most biodiverse subtidal ecosystems on the planet, containing diverse fish assemblages. Seagrass beds are critical nursery and feeding habitats for invertebrates and fish, supporting fisheries and adjacent habitats. Fish density within temperate eelgrass beds is highly variable and abundant, with fish density 4.6 times higher than in nearby sand habitats.

**Climate regulation:** Among the numerous important ecological services that seagrasses provide, their capacity to sequester CO2 has generated considerable interest for its potential role in mitigating climate change. Seagrass beds are major worldwide carbon sinks due to their great ability for absorbing and storing carbon in sediment, commonly known as blue carbon.

**Biodiversity:** Among the several vital ecological functions that seagrasses provide, its ability to store CO2 has sparked great interest in its possible involvement in climate change mitigation. Seagrass beds are significant global carbon sinks due to their exceptional capacity to absorb and store carbon in sediment, often known as blue carbon.

**Genetic diversity:** Seagrass species have lost genetic diversity, along with their beds and connections, according to research. This diversity and connection is critical for developing healthy populations that can resist and even adapt to changes in their settings, such as climate change, new pests and diseases, and other changes in their immediate surroundings.

**Habitat connectivity:** Seagrass ecosystems do not exist in isolation, but rather are linked by a continuous land-sea interface. Seagrasses are commonly found near saltmarshes, kelp forests, and bivalve reefs (such as mussels and oyster beds). This connectivity allows for a direct transfer of carbon and nutrients important for the ontogenetic and foraging movements of marine fauna across different habitats.

**Ocean acidification buffer:** Seagrass beds may reduce low pH (acidic) conditions for long periods, occasionally by up to 30% (Ricart et al. 2021). The time of year, as well as the local oceanographic circumstances, are crucial factors, with greater buffering happening in the spring when seagrasses are extremely productive.

**Disease control:** Compared with non-vegetated areas, seagrass can reduce general bacteria (and more specifically, those belonging to the genus Vibrio) by 39% for all Vibrio species, and 63% for the potentially harmful *V. vulnificus*/*cholerae* subtype.

**Tourism:** Seagrasses provide habitats for wildlife watching (e.g. birdwatching, SCUBA diving) and recreational fishing; clearer, cleaner water for swimming, and a stable beach.

**SEAGRASS RESTORATION TECHNIQUES**

In recent years, seagrass beds have been restored around the world using a variety of techniques that may be divided into two basic groups; activities focused on collecting and transplanting plants, and activities focused on obtaining and planting seeds:

**1. Transplanting adult plants-** Traditionally, this is the most widely used method, probably because habitats are immediately created. This method focuses on removing core plugs, or adult plants, from healthy beds, mature plants with rhizomes and glued substrate, or shoots without adherent substrate, for transplanting into deteriorated regions. After a storm, the shoots may be harvested in large quantities straight on the shore. The core plugs are either planted directly into the substrate or in a biodegradable "pot." The shoots may be weaved onto grids or frames, preferably made of a biodegradable material, or attached directly to the substrate. This form of transplant is distinguished by high rates of transplanted plant mortality, which have been seen in virtually all trials conducted to date. It also has considerable economic and logistical expenses for both manual and machine transplantation. Furthermore, it has the potential to badly harm or destroy donor beds. No transplant project has been demonstrated to be effective to date.

**2.** **Planting seeds-** Researchers have focused their attention on this approach in recent years because of its lower costs. Furthermore, the importance of seed sowing compared to clonal reproduction is presently being confirmed, both in terms of seagrass bed expansion and natural recovery. The collection, maintenance, transportation and planting processes are easier and more cost-effective. The mature seeds are collected directly from the bed. Eventually, large quantities of seeds may reach the beach, where they may be collected, although this type of collection cannot be predicted. Once the seeds have been collected, they may be planted directly in the area to be restored or maintained and treated in a laboratory to promote or even induce germination (using temperature and salinity variations) before being taken to sea. Mechanical planting technologies have been developed in recent years to speed up the process and reduce expenses. As a result, this strategy outperforms transplanting adult plants.

**The success of the different methods depends on a series of key factors:**

* Species of seagrass.
* Location of the donor bed (oceanographic and climate conditions, type of substrate, etc.).
* Future location of the adult plants, shoots or seeds.
* Manual or mechanical methods are used during the entire process.
* The magnitude of the project.
* Time of year.
* Other factors (experience of the personnel involved, unpredictable weather conditions, etc.).

**IDENTIFYING SUITABLE RESTORATION SITE LOCATIONS**

Selecting appropriate sites is critically important in restoration. In practice, potential sites are often broadly identified during the early planning phase, through general indications of possible locations.

* **Donor sites:** Identify and evaluate the suitability of existing seagrass beds for harvesting plant material (seeds or shoots) for use in restoration.
* **Sites of transplantation:** Locate and evaluate appropriateness (for example, biotic and abiotic properties). Assess why seagrass is not currently growing at the site.
* **Costs:** Where possible, reduce project costs by planting in intertidal and shallow subtidal areas. Seagrass can subsequently grow in the subtidal zone.
* **Designated status**: Consider protected conservation features of both donor and restoration sites.
* **Reference beds:** Identify control sites against which to gauge the performance of restored areas.
* **Seagrass survival and persistence:** Assess the possibility of long-term seagrass bed growth by comparing neighboring locations to the planned restoration site. Consider the most appropriate location within bigger restoration areas for long-term seagrass growth.
* **Present and historic distribution:** This indicates likely success in seagrass growth and persistence.

**WHAT ARE THE MAIN THREATS TO SEAGRASS ECOSYSTEMS?**

Due to their shallow coastal location, seagrass beds often come into direct contact with humans, such as for anchoring of boats, fishing and recreational activities, and coastal development areas, causing conflict between conservation interests and commercial or sustenance users. Furthermore, indirect effects of land operations like sedimentation, eutrophication, and chemical runoff such as pesticides endanger seagrass health and survival.

**Direct pressures-** Coastal zone development, mobile fishing gear, recreational boating (anchoring, chain moorings), eutrophication, siltation from agriculture, urban trash, and aquaculture are a few examples of the mechanical damage caused to the environment. Deposition of physical material results in smothering by either accelerated sedimentation or direct deposition of sediment onto the seagrass beds. The fragmentation and even loss of numerous beds are being brought on by these forces more and more. Increased development of epiphytic algae (especially filamentous), drift algae, and phytoplankton has all been associated with nutrient enrichment from sewage, agricultural run-off, and more localized inputs (from boating and aquaculture, for example). Loss of seagrass exposes the seabed to wave action, causing resuspension, which further increases turbidity, creating one of several positive feedback loops of eutrophication.

**Indirect pressures**- Include climate-driven changes, changes in global sea levels, increases in both CO2 and ultraviolet (UV) rays, and anthropogenic impacts on marine biodiversity, leading to changes in oceanic and coastal food webs.

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