THE FISHWORLD
ISSN: 3049-138X
Vol.3(04) April 2026, 422-427

Coral Aquaculture for Reef Restoration and Biodiversity Conservation

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doi.org/10.5281/FishWorld.19564274

1. Introduction

Coral reefs, often called the rainforests of the sea are among the most diverse and economically valuable marine ecosystems. They support thousands of marine species and provide important services such as food production, coastal protection, tourism, and fisheries (Halpern et al., 2012). Coral reefs are also an important source of ornamental species and bioactive compounds used in pharmaceutical research. However, increasing human activities, climate change, and rising demand for ornamental corals have led to the degradation and decline of natural coral populations worldwide. To address this growing problem, coral aquaculture has emerged as a sustainable approach for producing corals and restoring damaged reef ecosystems. By growing corals under controlled conditions, coral aquaculture helps reduce pressure on natural reefs and supports reef conservation and biodiversity protection.

2. History

One of the first serious attempts to grow corals outside their natural habitat (ex situ) started at the Nouméa Aquarium in 1956. (Tsounis et al., 2010). At that time, many aquarium hobbyists in Germany were already creating small home “mini-reef” systems to keep and grow corals. Commercial coral propagation later began in the United States during the 1960s. The marine aquarium hobby grew rapidly in the early 1980s, mainly because hobby magazines shared information and techniques about coral care and reef tank setup. In 2009, the U.S. government provided $3.3 million for a project to grow 5,000 colonies of acropora. Researchers suggested that transplanting about 35 coral colonies each year could help restore coral populations to the levels seen in the 1970s within 10 years.

3. Importance of Coral Reefs

Coral reefs are very important because they provide many ecological and economic benefits. They have an estimated global value of about $9.9 trillion and support millions of people through tourism, fisheries, and coastal protection. (Goreau et al., 2005). Although coral reefs cover less than 1% of the Earth’s surface, they provide habitat for about 25% of all marine fish species, making them one of the most biodiverse ecosystems in the world. Coral reefs also play an important role in medicine, as they are a source of compounds used to treat diseases such as cancer, HIV, and heart disease. In addition, they support around 70 million tourism trips each year, contributing significantly to the global economy. Coral reefs help protect coastal areas by reducing wave energy by up to 97%, which prevents erosion and storm damage. They also support food production, with healthy reefs producing 5–10 tons of fish per square km. annually. Furthermore, coral reefs help maintain water quality by absorbing carbon dioxide and filtering particles from the water, which keeps marine ecosystems healthy and balanced.

4. Reef Restoration: Status of Coral Reefs at Risk

Currently, about 75% of the world's coral reefs are under threat due to climate change, ocean warming, pollution and overfishing. Scientists predict that if current trends continue, nearly 90% of coral reefs will be at risk by 2030. Without immediate and effective conservation and restoration efforts, all coral reefs (100%) could become threatened by 2050. This alarming situation highlights the urgent need for coral reef restoration and sustainable management to protect marine biodiversity and maintain healthy ocean ecosystems.

5. Impact of Climate Change on Coral Reefs

Climate change is one of the most serious threats to coral reefs worldwide. Rising sea surface temperatures cause coral bleaching, a process in which corals expel their symbiotic zooxanthellae (microscopic algae) that provide food and colour. This causes the coral to turn white and lose its main energy source. Corals have a very narrow temperature tolerance, so even a small increase in temperature can cause stress and bleaching. If high temperatures continue for a long period, corals become weak and may eventually die (Wernberg et al., 2025). Scientists predict that about 90% of the world's coral reefs could experience severe bleaching every year by 2055 due to global warming. In addition, increased carbon dioxide (CO_2) levels cause ocean acidification, which reduces the ability of corals to form their calcium carbonate skeletons, slowing their growth. Climate change also increases the intensity of storms and alters ocean currents, which can physically damage coral reefs. These combined effects reduce coral growth, reproduction, and survival. As a result, coral reef biodiversity and ecosystem stability are seriously threatened. Therefore, climate change is a major factor responsible for the degradation and loss of coral reef ecosystems.

5.1 Pollution

Pollution is a major threat to coral reefs, mainly caused by human activities such as industrial discharge, agricultural runoff, sewage, and plastic waste. These pollutants degrade water quality, increase sedimentation, and introduce harmful chemicals to the coral population. As a result, coral growth is reduced, stress and diseases increase, and overall reef health and biodiversity decline.

5.2 Irresponsible Tourism and Coral Reef Damage

Irresponsible tourism harms coral reefs through activities like diving, snorkeling, and boating. Actions such as touching corals, collecting fragments, and disturbing sediments reduce water clarity and block sunlight. This damages coral structures, harms marine life, and leads to long-term reef degradation.

5.3 Ocean Acidification and Coral Reefs

Ocean acidification, caused by increased CO_2 from fossil fuel burning, lowers ocean pH and makes seawater more acidic. This reduces coral ability to form calcium carbonate skeletons, leading to slower growth and weaker structures. As a result, corals become more vulnerable to stress, diseases, and damage, causing reef degradation.

5.4 Coral Disease and Reef Decline

Coral diseases, caused by bacteria, fungi, and viruses, are a major factor in reef decline worldwide. They are often linked to poor water quality and heat stress. Common diseases like white syndrome, black band, and brown band damage coral tissues and can cause large-scale mortality, contributing to about 6% of global coral deaths.

Figure 1. Coral Disease-Induced Reef Decline

6. Coral Aquaculture

Coral aquaculture, also known as coral farming or coral gardening, is the cultivation of corals for reef restoration and conservation purposes. In this method, small coral fragments or larvae are collected from healthy colonies and grown in controlled nursery systems until they reach a suitable size for transplantation onto degraded reefs. This process improves coral survival and enhances reef recovery. Coral aquaculture can be carried out in two main ways: in situ (sea-based) and ex situ (land-

Figure 2. Coral Gardening for Marine Ecosystem Restoration

as light, temperature, and water flow, which improves coral growth, survival, and overall health. (leal et al., 2016). This method plays an important role in restoring damaged reefs, supporting sustainable coral production, and conserving marine biodiversity.

7. Type of coral culture

7.1 In situ Coral Culture System.

The in situ coral culture system involves the cultivation of corals directly within their natural reef environment. Coral fragments are transplanted onto degraded reefs to facilitate ecological restoration and habitat recovery. This system utilizes naturally available resources such as seawater, sunlight, and planktonic food, making it cost-effective and environmentally sustainable. However, it provides limited control over abiotic factors, including temperature, salinity, and light intensity. Coral growth and survival are influenced by seasonal variations, climate change, and anthropogenic disturbances. Additionally, biotic stressors such as algal competition and predation by organisms like the Acanthaster planci significantly reduce coral survivability.

7.2 Ex situ Coral Culture System (Extu Culture)

The ex-situ coral culture system involves the cultivation of corals under controlled environmental conditions in aquaria, laboratories, or hatchery systems. This approach allows precise regulation of key parameters such as temperature, light intensity, and water quality, thereby enhancing coral growth and survival. Commonly employed systems include flow-through aquaculture systems (FTAS) and recirculating aquaculture systems (RAS), both of which utilize advanced mechanical, biological, and chemical filtration techniques. Coral propagation can be achieved through asexual fragmentation or sexual reproduction, the latter contributing to increased genetic diversity. Survival rates can be further improved through targeted feeding strategies and the co-culture of grazers such as Trochus niloticus and Thalotia to control algal proliferation. Despite higher operational costs, ex situ systems provide greater efficiency, control, and applicability in research and conservation programs.

7.2.1 Tank Culture

Linden described a simple method for growing coral larvae using Petri dishes lined with special prepared paper disks. The larvae (planula) of Stylophora pistillata were placed on these disks and allowed to grow under controlled conditions. After one month, the surviving young corals were

Figure 3. Coral Larval Settlement and Growth in Tank Culture

plastic nets to protect the corals from predators and to prevent them from falling off. After four months, more than 89% of the corals survived, showing that this method was very effective for coral growth and restoration.

7.2.2 Ocean Cultivation

In ocean cultivation, corals are transferred from land-based or laboratory nurseries to floating nurseries in the sea. These nurseries are placed in the water column and attached to submerged structures to allow natural growth conditions. Many researchers recommend placing the corals at a depth of about 6 meters so they receive enough sunlight for proper growth and photosynthesis. (Yentsch et al., 2002). The corals are attached to artificial supports such as strings, wires, mesh, monofilament lines, or epoxy to keep them stable and secure. These structures help protect the corals and allow them to grow safely. The corals remain in these ocean nurseries for about 8 to 24 months, during which they increase in size and strength. Once they reach a suitable size, they are ready to be transplanted back onto damaged coral reefs for restoration.

7.2.3 Coral Nurseries

Coral nurseries are essential tools for coral reef restoration and conservation. In this method, small coral fragments are collected from healthy colonies and grown on artificial structures such as ropes, frames, or lines under controlled conditions. Nurseries can be established either in the ocean (in situ) or on land (ex situ). These systems provide protection from predators and environmental stress,

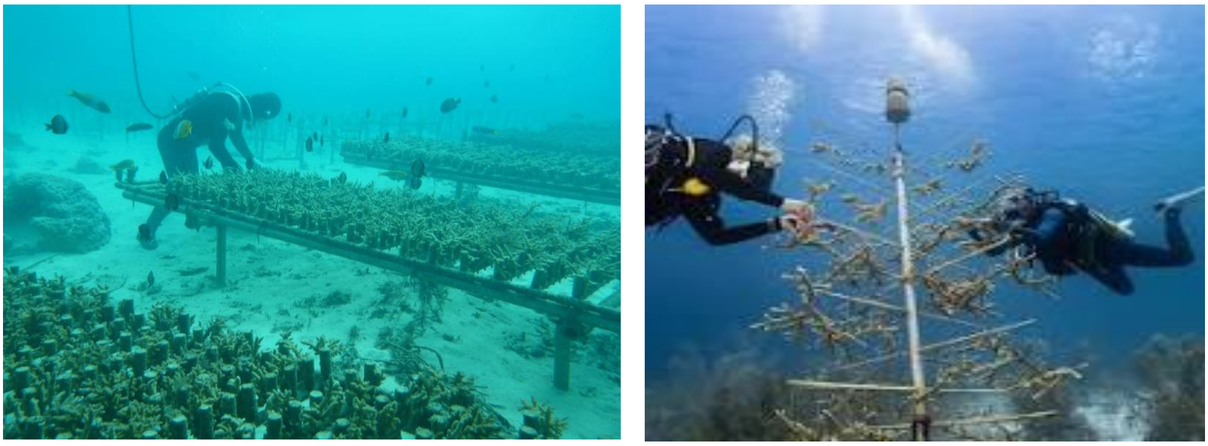

Figure 4. In situ and Ex situ Coral Nursery Setup and Transplantation

resulting in higher survival and faster growth rates during early development. Coral nurseries also allow researchers to select resilient and fast-growing species for effective reef rehabilitation. Once the corals reach an optimal size, they are transplanted onto degraded reefs to restore biodiversity and ecosystem stability.

8. Conclusion

Coral reefs are among the most valuable and diverse ecosystems on Earth, supporting marine biodiversity, protecting coastlines, and providing economic benefits through fisheries and tourism. However, these ecosystems are rapidly declining due to climate change, pollution, ocean acidification, disease, and human activities. Coral aquaculture has emerged as a promising and sustainable solution for reef restoration and biodiversity conservation. By growing corals in controlled nursery conditions and transplanting them onto degraded reefs, it is possible to accelerate reef recovery and reduce pressure on natural coral populations. Effective conservation also requires reducing pollution, managing fisheries sustainably, protecting marine habitats, and raising public awareness. Scientific research, strong environmental policies, and community participation are essential for long-term success. If immediate and coordinated actions are taken, coral reefs can recover and continue to support marine life and human societies. Protecting and restoring coral reefs is not only important for the ocean but also for the future health and balance of the entire planet.

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