Artificial Reef Design Plan

Waidroka Bay Resort

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1. Briefing

This report was created to outline the implementation of an artificial reef beside Waidroka bay resort. With the lack of coral growth in Waidroka Bay Resort, an artificial reef may be an extremely beneficial tool to facilitate coral reef growth and increase tourism.

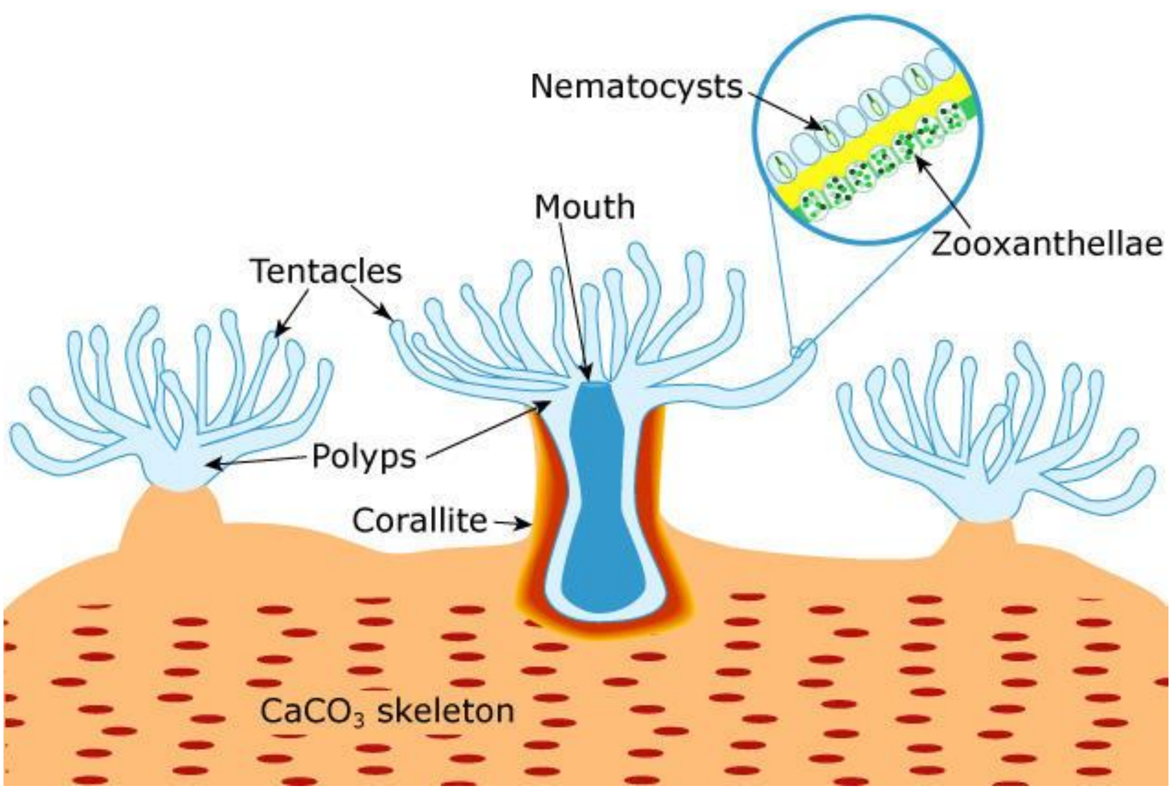
Fiji has undergone rapid changes in growth and development and unfortunately the coastal ecosystems are increasingly threatened by a number of anthropogenic activities such as overharvesting and overexploitation of land and sea resources, mining and coastal development (Mangubhai et al., 2019). Of the 650,000 square kilometres of coral reefs within the Pacific, more than 60% of them are now at risk of environmental damage, due to pollution, ocean acidification and increasing ocean temperatures from increased anthropogenic activities (Secretariat of the Pacific Regional Environment Programme, 2013, National Geographic Society, 2019). Action need to taken against this issue and this topic is also discussed in detail in this report.

2. Background

2.1 What are Coral Reefs?

About

Corals are invertebrate animals that are typically found across the world's oceans, from the coast of Alaska to the warm tropical waters of the Caribbean Sea , in both shallow and deep water (Ross, 2018). There are about 800 known species of hard coral (corals the build reefs) (International Coral Reef Initiative, n.d.). A coral has tentacles with stinging cells that surround a mouth at the top of the central body cavity (Florida Fish and Wildlife Conservation Commission, n.d.). Corals are sessile organisms, meaning that they are attached to a base and cannot move (US Department of Commerce, 2018). They live in colonies of hundreds to thousands of tiny coral creatures called polyps. Corals rely on their relationship with plant-like algae called *zooxanthellae* to build coral reefs, the largest biological structures on Earth (US Department of Commerce, 2018). The largest coral reefs are found in the clear, shallow waters of the tropics and subtropics, with the largest coral reef system in the world measuring more than 2,400 kilometers in length! It is known as the Great Barrier Reef and is located in the oceans of Australia (Ross, 2018).



(Public domain)

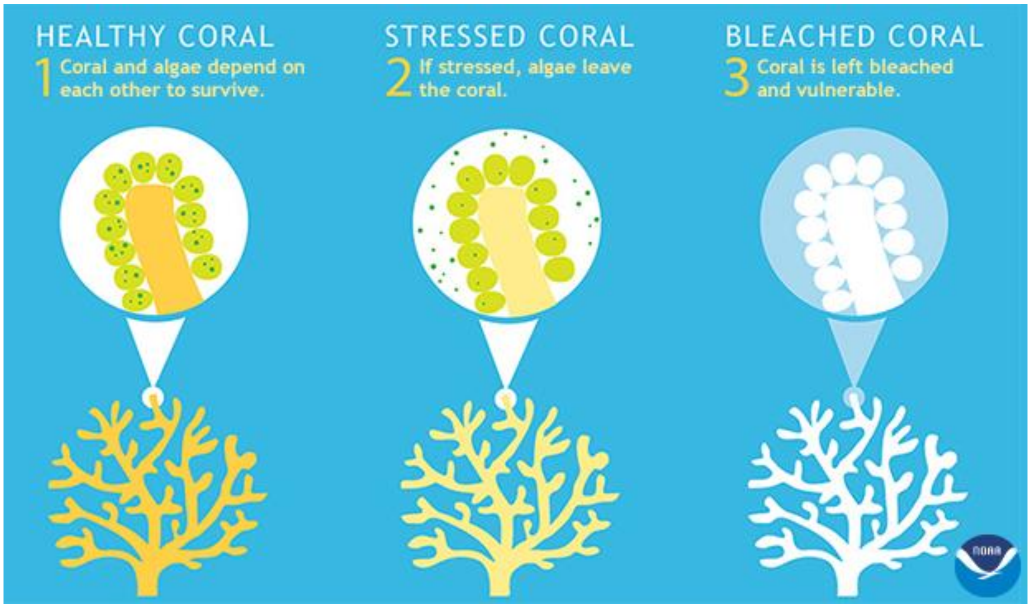
Importance

Sometimes referred to as "the rainforests of the sea" for their biodiversity, coral reefs are the primary habitat for more than 4,000 species of fish, 700 species of coral and thousands of other plants and animals (Ross, 2018). An estimated 25 percent of all known marine species rely on coral reefs for food, shelter and breeding. Coral reefs and their associated ecosystems are fundamental to Fiji and cultural practices, providing goods and services such as food from fish, molluscs and algae, tourism benefits, the economy and shoreline protection. Coral reefs are also vital to land protection and food security across Fiji. (Secretariat of the Pacific Regional Environment Programme, 2013).

2.2 What threats are corals facing?

Warming Temperatures

Corals live with algae in a type of relationship called symbiosis. This means the organisms cooperate with each other. The algae, called zooxanthellae, live inside the corals, which provide a tough outer shell made from calcium carbonate. In return for that protection, the algae provide their host with food produced through photosynthesis. Zooxanthellae also provide corals with their striking colors (National Geographic Society, 2012). As the temperatures of the world's oceans increase due to global warming, coral polyps expel the zooxanthellae they depend on for food. Once the zooxanthellae are gone, the coral loses its brilliant color, and all that can be seen is the white exoskeleton; this is referred to as coral bleaching. Coral colonies subject to bleaching usually die off (Ross, 2018) However, coral bleaching does not always mean the death of a coral reef. Corals can recover their zooxanthellae in time, but the process requires cooler temperatures. (National Geographic Society, 2012)



NOAA, 2021

Ocean Acidification

The increasing acidification of the ocean is a huge concern because it makes it very difficult for corals to build their hard exoskeletons (National Geographic Society, 2012). Ocean acidification occurs because of rising carbon dioxide levels. Oceans absorb immense amounts of carbon dioxide released into the atmosphere through the burning of fossil fuels (Ross, 2018). Carbon dioxide alters the chemistry of seawater by reducing pH, making the ocean water more acidic. (National Geographic Society, 2012) These conditions inhibit coral's ability to produce the calcium carbonate exoskeletons they rely on for shelter (Ross, 2018).

Water Pollution

Agricultural pesticides and fertilizers, oil and gasoline, sewage discharge and sediment from eroded landscapes that seep into the oceans directly or through streams, rivers and groundwater make it difficult for coral to thrive (Ross, 2018). Watershed-based pollution/sedimentation from developments and deforestation, such as mining, vegetation clearance for agriculture and forestry also make it difficult for corals to flourish (Secretariat of the Pacific Regional Environment Programme, 203)

2.3 Artificial Reefs

How do artificial reefs facilitate coral growth?

An artificial reef is a manmade structure that mimics some of the characteristics of a natural reef. It is a structure that serves as a habitat for reef organisms such as soft and stony corals, fishes and invertebrates (US Department of Commerce, 2013). Implementing artificial reefs can replace structure and habitat diversity, enhance local marine resources, improve biodiversity and create artificial snorkeling sites for tourism, in areas where water quality is still conducive to coral growth (Chad, 2018). Long-lasting artificial reefs that are typically constructed of limestone, steel, and concrete. A sunken ship is a common example of a successful artificial reef (US Department of Commerce, 2013). Artificial reefs can be an integral part of an effective and holistic coral reef restoration program when used in conjunction with other actions such as establishing rules and regulations, reducing threats, reducing over-fishing/over-use, and other mitigation or protection methods (Chad, 2018).

However, artificial reefs only work in areas where water quality is still conducive to coral growth (Chad, 2018). There are many examples of unsuccessful artificial reefs that have been built without focusing on solving the problems and reasons why coral reef populations are declining in that area. The implementation of an artificial reef needs to be part of a holistic coral reef restoration program. (Chad, 2018)

Conditions for artificial reef success

Generally, the location determines about 60% of the success of a reef, 20% is due to the reef units and 20% the reef design. (Lennon, D., 2018)

Ideal design/ units must be:

- Stable in normal to large storms
- Made from long-lasting, solid, non-toxic materials
- Designed to have a high surface complexity (texture) for the recruitment of corals, sponges, and other organisms
- Designed to provide a high amount of structural complexity for fish and other animals
- Designed to either blend in with the natural reef (Chad, 2018)

Ideal location/ conditions:

- Sufficient light for the species and productivity you need
- Sufficient stability of seabed
- Good water flow and quality
- Adequate access for user groups
- No threat of future dredging, shipping, trawling, pollution etc.
- Close enough to deployment budget
- Proximity of natural habitats (Lennon, D., 2018)

Case Studies

Komodo, Indonesia - After 4 and a half years growth on an artificial rock structure some table and staghorn corals reached 60-80 cm in diameter. On the nearby untreated rubble fields, no change in coral cover was detected after 6 years. (Dive the World, 2007)

Sarawak, Borneo - Malaysia, artificial reef balls have contributed to green turtle conservation efforts at the Talang - Satang National Marine Park, where illegal trawling was decimating populations (Dive the World, 2007). The project started 7 years ago to protect the nesting and swimming areas of the turtles, and has helped reduce the number of dead turtles washed up on the islands by 75%.

2.4 Permissions Required, Funding and Funding Proposal

Permissions Required

Artificial reefs are considered foreshore development and need to go through the development process through the Fijian government.

Potential funding organizations

While the costs for the design of the artificial reef in this report are minimal, funding may be necessary for the continued maintenance or if project is unsuccessful. This artificial reef project needs to be a part of a integral coral restoration program to obtain funding.

Organizations that have funded similar projects in Fiji:

- Reef Explorer
- Sylvia Earle Alliance
- the PADI Foundation

Note: If the artificial reef is successful, additional funds may be received to support the implementation of associated educational, research, and ecotourism development activities.

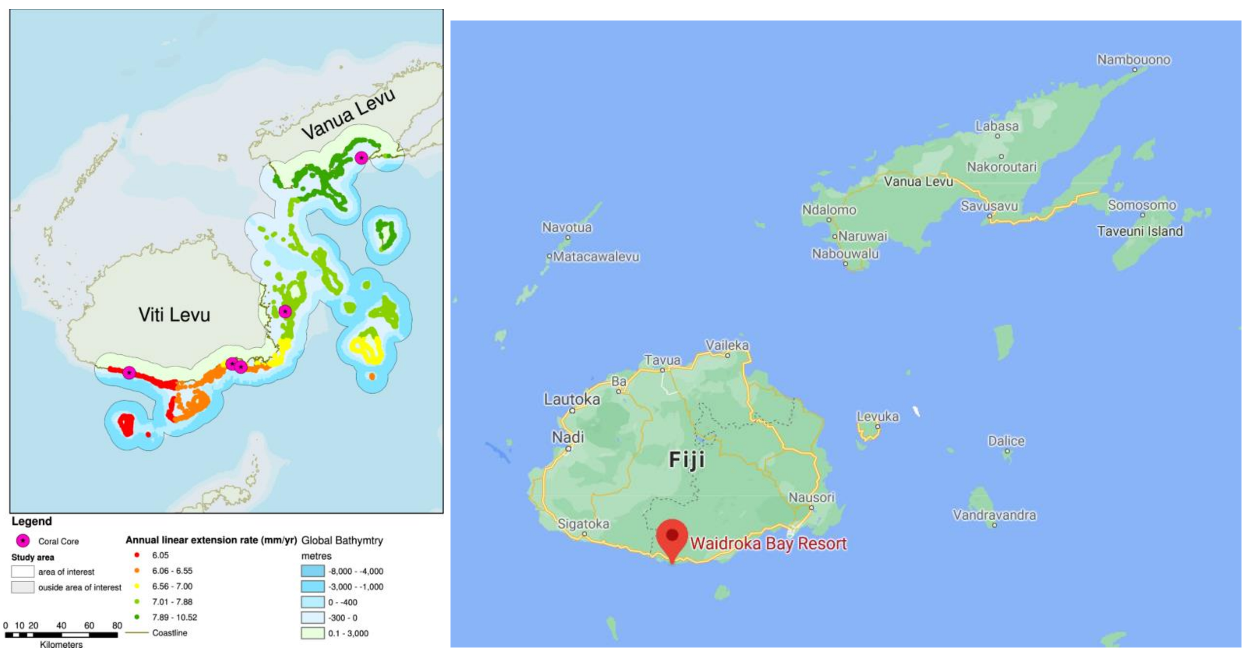
Funding Proposal Outline:

1. Summary
    a. Overview of proposal
    b. Requested amount
    c. Other resources
2. Introduction to applicant
    a. Describe organization
    b. Explain reason for request
    c. Share organizations history and success and it is right for the grant
3. The Need/The Problem
    a. Who will benefit and how will they benefit?
    b. State the consequences of not funding the project (eg. the lack of tourism and lack of fish habitat and the affects on economy, lack of coastal protection and Fiji is vulnerable to hurricanes)
4. Objectives and Outcomes
    a. Define goals and how they will be measured (Objectives should be consistent with your statement of need)
5. Program Plan
    a. How project will be executed
    b. How to achieve objectives
6. The capacity
    a. How organization is preparing for the project (e.g. Is there adequate, trained staff and a supportive board and community)
7. Evaluation plan
    a. Describe how objectives will be evaluated
8. Budget
    a. Include expenses and revenue
9. Sustained Impact

3. Evaluation of Area

3.1 Regional Area

Predicted coral growth distribution showed that lowest growth rates are predicted around the southern and south-eastern coast of Viti Levu, highlighting the need for better marine protection at these highly populated coastlines. (Goberdhan & Kininmonth, 2021). Waidroka Bay Resort is located in this area and although the extent of coral reef in this region is relatively stable, seeing as corals are still growing, it is important to note that the health of the corals in this region is compromised.



Left; *Map of predicted growth rates (mm yr–1) for randomly selected sites across FijiSites on the southern coast of Viti Levu are predicted to have low annual average growth rates ranging 6.1–6.6 mm yr and Waidroka Bay is located in this region (Goberdhan & Kininmonth, 2021)*
Right; *Map of Fiji with Waidroka Bay's location shown with the red pin (Google maps, 2021)*

3.2 Local Area

The waters directly outside the Waidroka Bay Resort are within a reef. The area has limited depth and current, and although inhabited by various sea creatures, including sharks, has a rather featureless bottom and lacks natural coral growth. Limited data and studies have been done in Fiji and specific information is difficult to retrieved, but a good plan can be reduced from case studies in nearby areas in Fiji and the south pacific region.

4. Materials

It is important for the reef to be constructed from long-lasting, solid, non-toxic materials and the material should not be able to break apart easily. Tires secrete toxins that pollute the water. Mixed metal alloys are not effective because they can degrade and break apart only after a few months, due to the effects of electrolytic degradation that occurs between different metals when placed in a saltwater solution (Chad, 2018). Tires, cinderblocks and cars are all bad examples of artificial reefs.

4.1 Bottle Units

For the purpose of this artificial reef development **modular units of bottle units** will be deployed and coral will be transplanted. Modular units are easy to assemble because they are smaller units that are easily deployed (light enough to be carried to a boat by volunteers) and then assembled into larger structures underwater (Chad, 2018). These Structures last about 8-10 years underwater. Once they do collapse, they are usually so covered in coral that things just keep growing as normal (Chad, 2018).

Bottle unit artificial reef In Chalok Ban Kao, Koh Tao (Chad, 2018).

New Heaven Reef conservation, as organization specializing in reef conservation, found that bottle units have been one of their most successful techniques to date. Their bottle nursery units are easy to make, easy to deploy, and work great. The units consist of a concrete base, into which glass bottles are placed and become the securement point for corals. The units are sunk into the sands to prevent them from moving around.

Concrete

Concrete will be used for the base of the structure and to attach the corals. Concrete is one of most favoured reef material is concrete as it proves good for coral settlement and growth (Dive the World, 2007). This is because it is very close in composition to natural coral limestone, and also it is strong, heavy, cheap, and readily available all over the world (Dive the World, 2007). Concrete is largely made from lime, a component of limestone. Limestone is comprised primarily of calcium carbonate, which is the substance of which coral reefs are made (Lukens, R. & Selberg, C., 2004). Concrete can be made into nearly any shape or size, and lasts a long time under the ocean (Dive the World, 2007). Concrete structures can quickly become too heavy to deploy, but since they will be used in small units, this would not be a big issue (Chad, 2018).

→ Material Sourcing and cost:

- Premixed Ready to use Cement
- Websites:
  - https://www.gmr.com.fj/product/pacific-blended-cement-gp-x-40kg-bag/
  - https://www.vinodpatel.com.fj/org-rockite-fast-set-expansion-cement-4-536kg-10lb-6210306
- Cost: $35 – 55 per unit

*Concrete needs to be cured to reduce alkalinity otherwise corals may not grow until after a few months. This can be done by:

- Curing for 6 months
- Mixing with coal combustion fly ash, diatomaceous earth, clays, shales, pumicites, or micro-silica

Glass Bottles

→ Material sourcing and costs:

- Glass bottles can be easily source from upcycled glass bottles in the community
- Cost is negligible since they are upcycled

Corals

Since this area has a limited current and has failed to recruit corals, transplantation should be viewed as an important tool for the success of this project (Dive the World, 2007). Corals are colonial organisms which reproduce primarily asexually to grow larger or to repair damaged tissues. Thanks to this asexual reproduction new coral colonies can be grown from smaller or naturally broken pieces of coral called fragments. (Chad, 2018).Transplanting corals from one reef to another act as a means of reintroducing corals to areas which have limited larval supply or low natural growth rates, increase coral larvae settlement, lead to an immediate increase in coral cover and diversity and improve the survival rate of rare or threatened coral species (Dive the World, 2007).

→Material sourcing and costs

- Corals can be transplanted from nearby coral reef in neighboring community members with the help of the people in the area

5. Design

5.1 Evaluation

The design should allow the reef to be stable in normal to large storms, to have a high surface complexity (texture) for the recruitment of corals, sponges, and other organisms, designed to provide a high amount of structural complexity for fish and other animals and designed to blend in with the natural reef.

It would be favourable to design a large and complex block pile because they show high recruitment of phototrophic organisms and Zooxanthellae (symbiotic algae that live within corals) is a phototrophic organism and are more sturdy (Rouanet, E., et al., 2019)

5.2 Case Studies

Komodo, Indonesia

Larger designs have been found to be more favourable by corals. In Komodo, coral was found to grow quicker on designs 70-90cm high and 140 cubic metres each rock pile (Dive the World, 2007). This is because coral recruitment can be significantly increased by creating stable, spatially complex structures that are high enough above shifting sediment to minimise burial or abrasion, sometimes 20 times higher than natural sea bottoms. Small plots are more likely to break apart, and tests in Komodo showed that large scale reefs with total surface areas of 1,000 square metres or more lead to quicker and more sustained growth. (Dive the World, 2007)

Bay of Marseille - France, Mediterranean Sea

From one study, it was found that a simple reef design with only a slab on the was able to create a more biodiverse ecosystem than a complex reef made of beams, several cubic unit pileups and different building materials (Rouanet, E., et al., 2019). Large and complex block piles of limited height influenced showed limited species settlement.

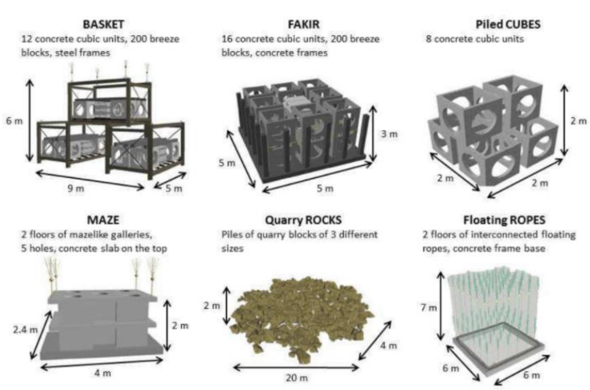


Figure 1: The 6 types of artificial reefs deployed on Marseilles.

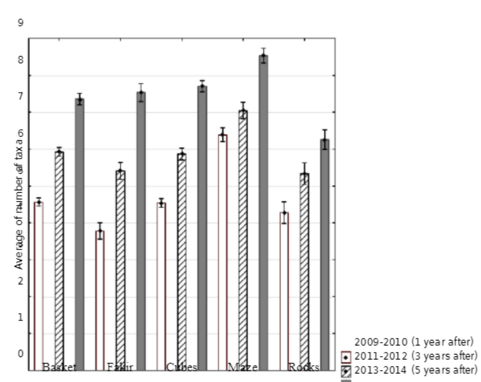
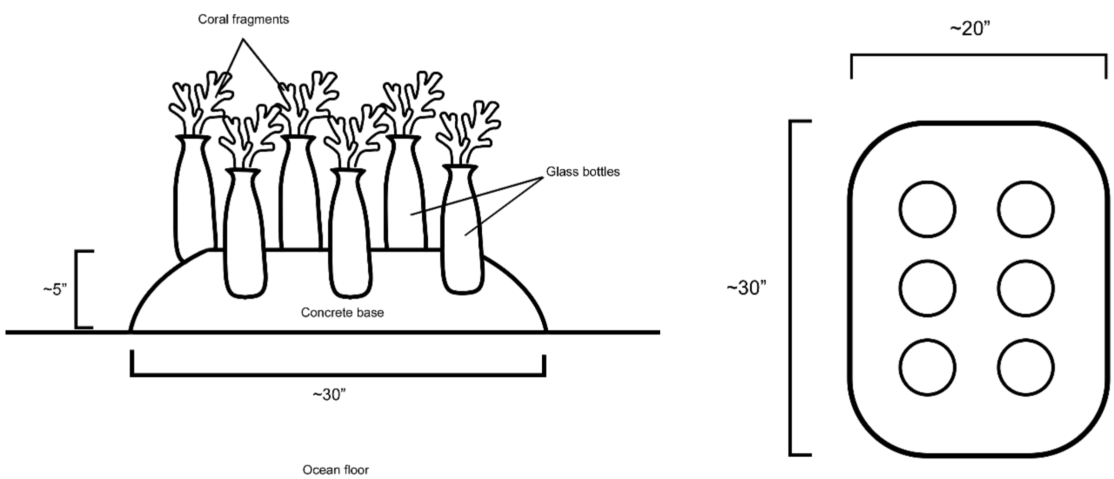


Figure 2: Mean number of taxa (± standard error) by artificial reef design over time after AR deployment.

However, the large and complex block piles are favoured by phototrophic (this is good because coral need these to survive) and show colonization on their surfaces compared to other artificial reef designs. (Rouanet, E., et al., 2019)

5.3 Diagram

Based on the information gathered, a tentative design for a modular unit with a rectangular like concrete base that provides room for coral growth and glass bottles attached with regular spacing to create maze like complexity that may be favoured by phototrophic organisms. In addition, the combination of materials also encourages biodiversity. Creating units large in height should be explored in the future.



Tentative diagram of a modular unit. ***Left;*** *Side view.* ***Right****; Top view*

6. Implementation of an Artificial Reef

1. **Learn**: learn about how to manage and maintain an artificial reef. Information is available in the management and evaluation section of this report.
    a. Consider joining Reef Resilience to be connected with global experts, tools, and knowledge to innovate and promote solutions for training, technical assistance, and seed funding.
2. **Preparation**: Generate community-based action to help construct the artificial reef units, manage the area by preventing overfishing, harvesting and pollution (see management section for more details)
3. **Location**
    a. Ideally place in an area with the best light for early succession
    b. Develop in a relatively flat surface, without irregular bottom topography
4. **Build units**
    a. Create a concrete base
    b. Place the glass bottles in the base securely
5. **Coral transplant:** Simple asexual coral propagation methods can be quickly learned and effectively implemented by community members for coral restoration efforts (The reef resilience network, 2019).
    a. Propagate a variety of coral species is best from nearby coral reefs.
    b. Attached finger-sized fragments on cement pieces attached to the glass bottles
    c. Corals reattached themselves after approximately 3 months, and became large adult corals after 4 years. If coral transplant is not working, further intervention is needed.
    d. If corals to not take then perhaps they need to be grown coral nurseries until they are larger (6-10 months) and later transplanted
6. **Deploy units**
    a. Start with little amounts of artificial reef
    b. The units are sunk into the sands to prevent them from moving around.
7. **Future additions**
    a. Modify according to results after monitoring
    b. Add units around over time if successful
    c. Build in height, because it is a favourable by phototrophic organisms and may promote coral growth

7. Management

For artificial reefs to work, they need to be used in conjunction with a wide variety of other actions such as establishing rules and regulations, reducing local land and sea based threats, reducing over-fishing/over-use, and other mitigation or protection methods to create an effective and holistic coral reef restoration program. (Chad, 2018)

7.1 Threats to be managed

These stressors pose a medium to high level of threat to Fiji's coral reefs:

Fishing

- Use of traditional poisons (duva), blast or cyanide fishing
- Overfishing

Land Based Impacts

- Sedimentation from developments and deforestation
- Poorly planned coastal development (cities, settlements, airports and military bases, mines and tourist resorts)
- Agricultural pesticides and fertilisers

Watershed-based pollution

- Marine pollution ports
- Oil terminals
- Pollution from mining
- Shipping channels
- Sewage from residential/ tourist centres
- ship-based pollution
- antifouling paint pollution

Predators

- Corals are vulnerable to outbreaks of crown-of-thorns starfish

7.2 Management Strategy Framework

Four types of management strategies: mitigate, protect, repair and adapt. Mitigating is a long-term solution to manage coral reef threats, but in the short term it is essential to protect, adapt and repair.

Mitigation - This involves reducing the amount of greenhouse gases (GHG) such as CO2 emissions over the long term and minimizing the affects of GHGs Minimizing pollution entering the ocean can help protect corals. This requires policymakers to work with a much broader range of social actors, including commercial and recreational fishers, farmers, the tourism industry, mining companies, energy providers, property developers and individual citizens. (Morrison et al., 2019)

Protect - By supporting marine protected areas in key conservation sites, reducing other environmental stressors, protection of ecosystems.

Adaptation - This involves solutions to cope and to adapt to the adverse effects of climate change. Adapt to loss of coastal protection, loss of tourism from and fishing. Also, people can help by making sure that the seafood consumed is sustainable and not contributing to a depletion of fish species that keep algae in check, following fishing regulations when fishing (National Geographic Society, 2012)

Repair – Include rebuilding fish stocks, restoring degraded ecosystems, local engineering and improving water quality (Morrison et al., 2019)

7.3 Local case study example

While the programs from this case study did not involve artificial reefs, it provides valuable information about an area not too far from Waidroka Bay Resort that was able to restore coral reef communities by implementing restrictions listed in the figure below and through transplanting coral nurseries.

Korolevu-i-wai district, Fiji

A community-based marine management plan was held from 2014-2019 to boost local incomes and traditions by replenishing and reviving local marine resources (The reef resilience network, 2019). This included the establishment of community-based no-take marine protected areas (MPAs), fisheries enforcement and compliance activities (see figure below), addressing pollution threats, enterprise development, and biological and socioeconomic monitoring for use in adaptive management of the community's conservation and development activities. 6 to 10 years after their establishment, the MPAs had 500% more live coral cover and 50% greater species richness of coral than adjacent fished areas, little to no seaweeds, and 30% more food fish, 50% more species of food fish, and 500% more biomass of food fish than the adjacent fished areas. This studies shows that with the correct efforts, it would be possible to bring back coral reefs in Waidroka Bay Resort (The reef resilience network, 2019).

Left; *Map of Fiji emphasizing the coral coast (the area of the management plan). Waidroka bay is located and the end of this region. Adapted from The reef resilience network, 2019.* ***Right***; *Close up of the coral coast, illustrating which types of MPA's have been done in selected areas and a list of bans.*

8. Evaluation

For this project a very simplistic approach will be taken to monitoring the development of the reef. It will consist of monitoring the organism growth of the reef. It can be conducted by swimmers or divers with only minimal training. In the future, when funds are available, physical conditions of the area (i.e. water sampling analyses) should be monitored.

8.1 Roving Diver Survey

This is a very easy survey for non-professionals or non-divers. This survey covers a large area, which is necessary when evaluating organisms which are not very abundant (giant clams, Crown of Thorns, etc) Data can be easily collect in many locations and collected in a global database (Chad, 2018). While this method is rather subjective, it would be a great way to monitor when resources and people are limited.

Steps:

1. This survey can be conducted while either snorkeling or diving, and only requires the surveyor to have a slate and pencil.
2. The surveyor swims along the reef for a set distance or time, or evaluates a reef area of predetermined size (i.e. 10m x 10m).
3. The surveyor records their observational data on a slate (Chad, 2018)

Observations from the survey should answer the following:

- What is on the reefs (Abundance, biodiversity, etc)?
- What species are special or important for our area?
- What is the current health of our reef?
- What changes are being seen over time?
- What is causing any declines in health?
- What can be done to stop declines in reef health or abundance?
- Are the reef management techniques being used effective and efficient? (Chad, 2018)

Notes:

- Surveys should be done on a consistent cycle (eg. every 2 weeks at a specific time of day) to avoid any false observations
- Surveys should be done frequently over the first year and can be done less frequently
- It should be noted that communities change through the seasons of the year
- If waterproof cameras are available, the slate and pencil can be substituted with a camera and photos can be taken

8.2 Future Monitoring

If fund become available, it will be important to monitor in more detail. Typically, coral reef ecosystems need to monitor for biodiversity, taxa, as well as water quality. Important water quality tests for coral reefs measure nutrients (nitrate, phosphate, ammonia), salinity, pH and turbidity. Other water quality tests the be done measure microbiology, major ions, heavy metals, dissolved oxygen content and pesticides (Mosley, Singh, & Aalbersberg, 2005).

Table 3: ANZECC (2000) guidelines for inshore marine waters. Levels above these values may lead to adverse effects on the ecosystem.

Total N mg/L	NH_4 mg/L	NO_3,NO_2 mg/L	Total P mg/L	PO_4 mg/L	PH
<0.1	0.001-0.010[a]	0.002-0.008[a]	<0.015	0.005	8-8.4

a. values typical in clear coral reef dominated areas.

The Australia and New Zealand Conservation Council comprehensive guidelines on water quality (ANZECC 2000) (Mosley, Singh, & Aalbersberg, 2005).

9. Limitations and Conclusion

9.1 Limitations

There are several limitations that can arise during the development of an artificial reef and there have been many artificial reefs to fail in the past. One main issue that may arise is the coral transplants not working. This may occur due to coral sensitivity and damage during transplantation, but it may also occur due to a poor environment for coral growth. Another issue that may arise is the materials breaking. Especially with the use of glass bottles, breaks can occur, but can be avoided with careful handling. In addition, a fundamental part of this initiative involves community engagement and involvement. Community members and volunteers will be needed for the coral transplant and for management of the area. Managing the area will play a crucial component for the success of this project and longevity if the coral reefs. Policies are the best way to implement restrictions and since there is currently a lack of guidelines and laws for environment protection in Fiji, it is up to the community to manage the environment.

This plan is optimized for cost efficiency to reduce financial barriers for the community. However, if structure of the artificial reef fails, interventions will need to be made which could be costly. The design may need to be redone with different materials for example, being completely made of concrete, being made of rebar metal or even electrifying reef made from Biorock™.

9.2 Conclusion

Artificial reefs are efficient tools to restore biodiversity and have been integral parts of restoration programs. With the lack of coral growth in Waidroka Bay Resort, an artificial reef may be an extremely beneficial tool to facilitate coral reef growth and increase tourism. If the area is managed correctly, the reef can become self sustaining in the future. It is essential that people raise awareness of this issue and that more research is done in this area to implement policies and help this initiative as best possible.

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