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# A study of the survival rate of Acropora corals outplanted in Damselfish territories

A minor field study in Malolo Lailai, Fiji

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This study has been carried out within the framework of the Minor Field Studies Scholarship Program, MFS, which is funded by the Swedish International Development Cooperation Agency, Sida.

The MFS Scholarship Program offers Swedish university students an opportunity to carry out two months' field work, as a part of the student's final degree project, in a low or middle-income country. The results of the work are presented in an MFS report which is also the student's Bachelor or Master of Science Thesis. Minor Field Studies are primarily conducted within subject areas with connection to the Sustainable Development Goals and Agenda 2030 and in a country where Swedish international cooperation is ongoing.

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The International Relations Office at KTH Royal Institute of Technology, Stockholm, Sweden, administers the MFS Program within engineering and applied natural sciences.

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# Sammanfattning

Detta kandidatexamensarbete har gjorts som en Minor Field Study (MFS) på Malolo Lailai Island, Fiji. Arbetet har blivit finansierat av Styrelsen för internationellt utvecklingssamarbete (SIDA). Arbetet skrevs under våren 2023 på Kungliga Tekniska Högskolan (KTH) i Stockholm och projektet är grundat och utfört tillsammans med organisationen Corals for Conservation (C4C), beläget i Fiji.

Hälsan hos korallrev runt om i världen försämras allt mer på grund av flera olika antropogena stressfaktorer såsom exempelvis klimatförändringar. Detta har påverkat reven runt om Fiji negativt på grund av ökade havstemperaturer som resulterar i att koraller bleks. Flertalet åtgärder har utförts för att restaurera de korallrev som degraderats där utplantering och övervakning av koraller är ett exempel. När förhållandena i haven ändras blir korallerna alltmer utsatta för såväl ökade temperaturer som ökad mängd predatorer och sjukdomar. Med tanke på denna bakgrund har detta projekt skapats för att se om utplacering av koraller inuti eller nära ett territorium av Damselfish (*Stegastes nigricans)* utgör någon skillnad för korallers överlevnadschans. Resultaten har visat att koraller som blir planterade utanför Damselfish-territoriet löper större risk att påträffa både predatorer och betare vilket leder till att dess levnadschanser minskar. Slutsatsen som drogs var därför att utplantering av koraller inuti ett Damselfish-territorium ökar korallernas chanser för överlevnad.

# Abstract

This bachelor thesis was executed as a Minor Field Study (MFS) in Malolo Lailai Island, Fiji. The Minor Field Study was funded by the state agency Swedish International Development Cooperation Agency (SIDA). The thesis was written during the spring of 2023 at the Royal Institute of Technology (KTH) in Stockholm and the project was created and executed together with the organisation Corals for Conservation (C4C) located in Fiji.

Coral reefs around the world are degraded due to many different anthropogenic stressors, where climate change is a major one. This has affected the reefs in Fiji as sea temperatures are rising which is causing corals to bleach. Efforts are being made to restore the reefs which includes outplanting and monitoring corals in degraded reefs. As conditions in the seas change, corals are increasingly exposed to predators and disease. Against this background this project was created in order to see if outplanting corals inside or close to a Damselfish (*Stegastes nigricans)* territory makes any difference to the survival rate of the corals. The results show that corals outplanted outside of a Damselfish territory has a higher risk of exposure to predators as well as foragers which leads to a lower survival rate. The conclusion that was made was that planting corals inside of a Damselfish territory therefore increases the chances of corals surviving.

# Figures and tables

## Figures:

# Tables:

# Table of contents

# 1. Introduction

Coral reefs around the world are dying and it is a growing issue. Coral reefs are important ecosystems and home to 25 percent of the world's marine species. The coral reefs are of great importance to hundreds of millions of people, giving them economical, cultural, social and recreational benefits while also protecting them (Rolls, 2021). The reefs are under continuous stress from climate change, acidification, coastal development, overfishing (Cramer et al., 2022) and eutrophication (Zhao et al., 2021) causing mass bleaching and degraded reefs. If the global temperatures rise above 1.5-2 degrees from pre-industrial levels, the reef ecosystems are put at risk (McLeod et al., 2021).

In these diverse ecosystems, fish presence is a significant factor to the functioning of coral reefs. Certain fish species control the algae cover in which the corals live in symbiosis with and one of these is the Damselfish (Elston et al., 2020). This makes it so that damselfish could play a role in the work with coral restoration. Both local and global actions are taken in order to protect and restore reefs. One of the local actions is the reduction of algae presence through using herbivore fishes. Another local action is marine bioengineering which includes coral gardening and assisted migration (McLeod et al., 2021).

## 1.1 Aim

Coral reefs have, as mentioned before, been degraded due to several anthropogenic factors. Therefore the aim for this project is to investigate the survival rate of *Acropora* corals outplanted in different territories. This will be done to research the possibilities of restoration of coral reefs, more specifically in Fiji but with the possibility of being expanded to other areas. The following objectives have been worked out:

- Analyse the survival rates of the corals in the different territories.
- Conclude whether corals planted in damselfish territories have a bigger chance of surviving compared to corals planted directly onto the reef outside damselfish territories.

## 1.2 Limitations

This study is restricted to only testing one reef where all 10 replicates used in the experiment are outplanted. In each replicate only 3 spots are outplanted with corals with different distances to the damselfish territory. This is to minimise the project to match the timeframe that the project is bound to. The project is using corals of the same family which are *Acropora* corals, but not of the same species. Apart from this the experiment only investigates the effects and connections between one species of Damselfish (*Stegastes nigricans*) and its connections to the corals survival rate and therefore eventual connections between how other species may affect this is not brought up.

## 1.3 Fiji

Fiji is a part of the indo-pacific countries and the reef surrounding Fiji is the great sea reef. The reefs in Fiji are rich in biodiversity, housing 55 % of all fish species known, 74 % of all hard corals known, 40 % of marine algae known to Fiji and also 44 % of endemic reef species known to Fiji (Andradi-Brown et al., 2022).

### 1.3.1 Socio-economic importance

Fijian people are heavily reliant on the reefs where about one tenth of the people are directly reliant on the reefs in terms of subsistence and provision. The great sea reef provides fish for the population with over three quarters of inshore fish supplied to the markets coming from it. It is also of big importance to the country's economy through the tourism income it generates, accounting for over 25% of the GDP of Fiji (Andradi-Brown et al., 2022). Fiji is a country that is dependent on its tourism, the tourism industry corresponds to about 30% of the country's BNP. One of the main attractions is the clear oceans where you can snorkel and see beautiful fish and the many types of coral existing here. The effects now happening to the oceans will therefore affect the country very badly (Globalis, 2021).

## 1.4 Sustainable development

In the Paris agreement, which is an international agreement amongst 196 countries, there is a goal to try and minimise the rising temperatures to a maximum increase of 1.5℃ above pre-industrial levels. If the goal is not reached and we cross the line of 1.5 degrees the consequences could be even worse climate change impacts (UNFCCC, n.d.). The coral reefs are heavily affected by climate change and thus sustainable development is needed to protect the reefs and the people dependent on them. In the sustainable development goals oceans are included in goal no. 14; Life below water - which purposes to “conserve and sustainably use the oceans, sea and marine resources for sustainable development” (United Nations, n.d.). There are also two other goals that could be considered relevant for restoration of coral reefs which are:

- Goal no. 13; Take climate action - since coral bleaching is an effect of rising temperatures and increasing light, restoration is an important work against the harmful effects of climate change.
- Goal no. 8; Decent work and economic growth - securing the tourism income for Fiji by conserving and restoring the coral reefs while also securing work opportunities within both the tourism sector but also through the fisheries for the inhabitants of Fiji.

Coral reefs are fragile and complex ecosystems that play an important role for the survival of thousands of marine species (Rolls, 2021). Their sensitivity for changes such as temperature, overfishing and other human inflicted causes makes their resilience very low. These reefs are at risk of tipping points which means that only small changes can lead to abrupt and big negative effects that are difficult to reverse. Once a tipping point is reached it can take a very long time to restore an ecosystem if it’s even possible at all, that’s why research of where these thresholds occur is important to strengthen the coral reefs resilience and prevent us from reaching these tipping points in the first place (Ravindran, 2016).

## 1.5 Coral reefs

### 1.5.1 Biology of corals and coral reefs

Corals are a group of invertebrate animals. Every individual coral is made of a single polyp and together corals build colonies of genetically similar polyps (ICRI, n.d.). Corals are mainly classified into two different types; hard corals and soft corals. Hard corals are sometimes called the reef building coral (ibid.). Reefs are ecosystems that create their own substrate, the limestone which they are made of (Sheppard et. al., 2018, p. 2-3). The reefs are formed when the corals extract calcium from the surrounding water and turn that into hard structures that protect the corals and allow them to grow on. This means that reefs are composed of millions of polyps that are forming large carbonate structures which are home to a large quantity of species (ICRI, n.d.). Corals reproduce in two different ways, sexual and asexual. The asexual reproduction consists of budding and fragmentation which both lead to exact replicates. The budding reproduction happens when the parent polyp reaches a certain size, it then clones and creates an exact replicate which thereafter expands the colony. The fragmentation happens when a section of the coral falls off and then settles on the foundation on its own which creates its own clowned colony [1].

The corals live in symbiosis with an algae, called *zooxanthellae* (ICRI, n.d.). Through photosynthetic activities of the algae, corals get nutrients which they depend on (LaJeunesse, 2020). The algae produces organic compounds which the corals use as fuel for their tissue growth and when they build their carbonate structure. As they live in symbiosis the algae profits from the byproducts of the coral's digestion and respiration by absorbing these and using the non-organic compounds for growth and maintenance. The mutualism of the algae and the coral is how all shallow-water corals exist (ibid.). The algae living inside of the coral is what gives it its colour, from photosynthetic pigment (chlorophyll) (Bruckner, 2013). This correlation between the coral and algae is also the reason why corals lose their colour, also known as bleaches, when exposed to stress, which will be explained in more detail under “threats”.

[1] Bowden-Kerby A, McDougall A. Marine biologists at Corals for Conservation. Malolo Lailai Island. 2023. Powerpoint

Together with mangroves and seagrass beds coral reefs create large ecosystems. The mangroves provide breeding ground and nursery for marine life which can then move over to the reefs. Besides this the mangroves are also important for producing nutrients, protecting coasts from storms and filtering pollutants that come from run-offs. The seagrass beds are producing food for marine life and, like the mangrove, acts like nurseries for juvenile fish. The beds also act as filters, filtering sediments and at the same time they release oxygen and stabilise the bottoms (ICRI, n.d.).

### 1.5.2 Fish guilds

The reef ecosystems are not only composed of corals but also reef fishes that make up a substantial part. The fishes are significant to the functioning of the ecosystems and of the fishes two groups are important for this, herbivorous and corallivorous fish (Elston et al., 2020). The herbivorous (e.g. Surgeonfish) fish consume algae thus keeping algae cover at functioning levels. Therefore, should herbivorous fish presence decrease, algae presence would increase, preventing coral growth by occupying space. The corallivorous fish (e.g. Butterflyfish (*Chaetodontidae*)) feed on coral tissue and are split into facultative and obligate feeders. The obligate feeders feed on mostly hard corals while facultative also feed on soft corals and algae. As the corallivorous fish feed on corals, it regulates distribution, abundance and fitness of different corals. Lastly, the group of piscivorous fish can also be of importance to the ecosystems as they feed on other fish which regulates the composition of reef fish (ibid.).

The herbivorous group of fish that control algae growth can be divided into two groups, foragers (such as Parrotfish (*Scaridae*)) and farmers (Damselfish). Foragers control the algae growth through grazing which leads to communities of algae of low diversity, whereas farmers can sustain high diversity algae turfs or turfs of one preferred sort. Farmers use a number of strategies to control the algae cover including reducing foragers grazing in their territories, removing unwanted algae, consuming only preferred algae species and fertilising algae (Ceccarelli et al., 2011).

## 1.6 Threats to coral reefs

Coral reefs around the world are under great stress as a result of climate change, overfishing, pollution, and acidification (Cramer et al., 2022; Hill, 2022). All of the above has consequences for both the reefs ecosystem and its persistence as well as for the millions of humans that depend on the reefs for food and provisioning. While all of these effects happen simultaneously the rising temperatures in the oceans is the most urgent problem and causes the biggest negative effects on corals [2] .

Right now, coral reefs are undergoing mass bleaching at a rate like never before. This affects shallow reefs the most, causing them great damage (Cramer et al., 2022). With the global temperature rising, marine ecosystems are at risk of irreversible loss at a temperature rise of only 2 degrees celcius from pre-industrial levels. A rise of 1.5 degrees could result in a decline in the reefs by 70-90 percent. We could be experiencing annual coral bleaching in 90 percent of all reefs globally by 2050, putting the corals at risk of disease, mortality and habitat loss (McLeod et al., 2020).

### 1.6.1 Coastal development and resource use

As human settlements develop on coastlines not only are coral reefs removed (e.g. pierbuilding) but their settings are affected by removal of surrounding environments. The nature (vegetation and soil) around the waters work as buffers against the freshwater running into the sea waters. When it is removed nutrients, sediments and contaminants can flow unfiltered into the water (Cramer et al., 2022). As nutrients are increasing in the water, due to agriculture and wastewater treatment, the quality declines which leads to eutrophication and stresses the corals. It also promotes benthic algae growth as waters dominated by corals are nutrient poor while algae grows in nutrient rich waters (ibid.).

The reefs are also affected by resource use, where overfishing is a major threat. Through overfishing important fish are removed, such as herbivorous fish, which leads to algae overgrowth. Marine resource use can also lead to both the introduction of invasive species from other marine areas and to native species becoming invasive. A good example of this is the Crown-of-Thorn Starfish (*Acanthaster Planci)* in the indo-pacific ocean. They are natural

[2] Bowden-Kerby A, McDougall A. Marine biologists at Corals for Conservation. Malolo Lailai Island. 2023. Powerpoint.

corallivores in these areas, however changes in reef ecosystems (removal of natural predators and increase of nutrients) has led to the increase of the species which has caused degradation of reefs (Cramer et al., 2022).

### 1.6.2 Eutrophication

Eutrophication is the effect of too much nutrients being released in soil and water (Zhao et al., 2021). The eutrophication of oceans has increased a lot in recent years due to accelerated coastal nutrient loads which is expected to increase even more due to global change. Ammonium, nitrogen and phosphorus are examples of substances that cause eutrophication and they all cause different effects on corals. Corals are adapted to low nutrient levels, the increased amount of nutrients in the oceans therefore leads to growth of algae that blocks sunlight and consumes oxygen that the corals need for respiration. More specifically increased levels of nitrogen has been shown to cause negative effects on the resilience leading to increased coral disease, bleaching and decreased growth due to the increased amount of viruses, pathogen bacteria and an enhanced growth of competitors such as macroalgae and phytoplankton. The nitrogen acts in conjunction with other nutrients such as phosphate which gives these effects. Ammonium on the other hand does not only cause bad effects on corals, studies have shown that ammonium seems to benefit the corals in strengthening their calcification and photosynthesis. Although positive effects have been found from ammonium, it still contributes to the eutrophication making the overall effects negative (Zhao et al., 2021).

### 1.6.3 Climate change and coral bleaching

Climate change is a human caused stressor affecting the reef ecosystems around the world. With the burning of fossil fuels the increased levels of CO2 in the atmosphere results in a variety of environmental changes such as rising sea temperatures, acidification, increased storm frequency and strength, decreased growth rate, altered currents and reef destruction (Cramer et al., 2022).

When the sea temperature rises and the light increases, the corals start to bleach. This happens because the symbiosis between the algae living inside the coral and the coral itself is destroyed as the coral expels the algae as a stress response, causing them to bleach (Ainsworth et al., 2021;Cramer et al., 2022). The algae starts overproducing toxic substances instead of nutrition which is why the coral expels it (Vidal-Dupiol et al., 2009). If the corals remain under stress it will not take up new algae leading to mass bleaching of reefs. Since sea temperatures have continued to rise, mass bleaching has occurred more often leading to the death of reef building corals (Cramer et al., 2022).

### 1.6.4 Acidification

As humans burn fossil fuels, greenhouse gases are emitted which the ocean absorbs leading to rising acidity in the oceans (Cramer et al., 2022). The ocean absorbs carbon dioxide which causes the pH-level to fall which in turn reduces the availability of carbonate ions in the ocean (Hill and Hoogenboom, 2022). As carbon dioxide is dissolved in water, free hydrogen ions are formed which will bond with the carbonate ions easier than calcium ions from shell-animals in waters (e.g. corals) and thus lead to a lack of carbonate ions (Smithsonian Ocean, 2018). When the concentration of carbonate ions in the water reduces, the corals can not build their calcium carbonate structures on which many species depend on (Cramer et al., 2022). The corals are put at risk of not growing properly due to corrosion of already existing skeletons that at the same time grow slower. When the reefs get weaker they become more vulnerable to erosion (Smithsonian Ocean, 2018).

### 1.6.5 Diseases

There are several diseases causing coral degradation and severe negative effects on coral survival. The most common and dangerous ones in the Fiji area are White syndrome disease, black band disease, skeletal eroding band disease, brown band disease and stony coral tissue loss (Richardson, 1998) [3]. The white syndrome disease is caused by several pathogens which often hit when corals are stressed, high temperature and high levels of sedimentation. It mostly attacks *Acropora* corals but affects a wide range of coral in general too. The black, skeletal and eroding band and brown band disease both affect a wide range of species, the brown and skeletal eroding band is caused by ciliates while the black band consists of a consortium of bacteria and filamentous cyanobacteria (Richardson, 1998). Lastly the stony coral tissue loss wipes out massive corals and is confined to the caribbean, it spreads rapidly and causes extinction of species locally. It is also said that the pacific might be affected by these diseases in the future [4].

[3] Bowden-Kerby A, McDougall A. Marine biologists at Corals for Conservation. Malolo Lailai Island. 2023. Powerpoint
[4] Bowden-Kerby A, McDougall A. Marine biologists at Corals for Conservation. Malolo Lailai Island. 2023. Conversation

### 1.6.6 Predators

Coral predators, i.e. corallivorous fish, in the oceans also cause threats to the coral's survival rate. Examples of predators that affect the corals negatively are crown-of-thorn starfish, Drupella snails (*Drupella Rugosa*), Butterflyfish and the herbivorous Parrotfish (see more in section 1.4.2). The Crown-of-thorn starfish can consume a coral per day when fully grown, they release dubbel amount of larvae if there are high levels of nitrogen, eutrophication therefore makes them strive [5]. They often prey on sole survivors of mass bleaching events which prevent the corals from rebuilding the reef; they prefer *Acropora* corals (Oceana, n.d.). The crown-of-thorns starfish are active during the nighttime (Great barrier reef foundation, n.d.). The Drupella snails only prey on reef-building corals, more specifically *Pocillopora* and *Acropora* species. They have a high mortality rate on reefs and studies have shown that it causes up to 90% mortality [6]. Butterflyfish prey on both diseased and healthy corals and they also prefer the *Acropora* species (Brooker et al., 2013). They function as vectors of disease because of their cross contamination between the corals which forces the reef to shift to an *Pocillopora* dominated reef over time [7]. Parrotfish are technically foragers grazing the algae of corals, meaning they do not pose a direct threat to the coral itself, however they sometimes bite pieces of the corals off when trying to get the algae (Gray, 2017).

## 1.7 Acropora Corals

*Acropora* corals are dominant reef-building corals that often can be found in the Indo-Pacific ocean (Shinzato et al., 2011). They are considered to be one of the fastest growing corals in tropical coral reefs while they also provide habitat for many different species (Mercado-Molina et al., 2020). *Acropora* corals are one of many different types of coral, they are among the most sensitive to increased temperatures, already coral reefs around the world that have suffered losses of *Acropora* coral species due to the increasing temperatures. As temperatures are rising, reefs start to bleach and eventually die (Shinzato et al., 2011). The loss of *Acropora* species of corals could have serious consequences for the reefs and its surrounding ecosystem. When *Acropora* species vanishes, the reefs shift and another type of coral, *Pocillopora,* dominates the reefs before eventually being *Porites* dominated. This

[5] Bowden-Kerby A, McDougall A. Marine biologists at Corals for Conservation. Malolo Lailai Island. 2023. Powerpoint
[6] Bowden-Kerby A, McDougall A. Marine biologists at Corals for Conservation. Malolo Lailai Island. 2023. Powerpoint
[7] Bowden-Kerby A, McDougall A. Marine biologists at Corals for Conservation. Malolo Lailai Island. 2023. Conversation

affects the ecosystems badly causing an unbalance in different types of species within the reefs which will affect the predation patterns (Bowden-Kerby, 2022).

## 1.8 Damselfish

The Damselfish is a fish which could contribute to the increase of biodiversity and thus restoration of corals (Tiddy et al., 2021). The Damselfish is part of the family *Pomacentridae*, and there are about 250 species of the fish (Rafferty, n.d.). The herbivorous Damselfish are mostly spread throughout tropical oceans but can also be found in subtropical and temperate rocky coastlines (Ceccarelli, 2001). They can occupy the hard substratum of coral reefs, occupying up to 70% of the substrate (McDougall, 2020). The species of *Stegastes* is one of the herbivorous Damselfish and also one of the most aggressively territorial ones. Inside the coral territories, the Damselfishes farm algae which functions as their primary food source, along with the small benthic invertebrates living inside the farms. The farms can also be used to attract mates and protect eggs (Ibid.). The male Damselfish has a nest prepared for eggs in their territories, which they protect. When mating, the male produces a pulsed sound along with a signal jump which they repeat several times a day (Mann, 2006).

The occupied territories are defended against other fish of the same species, as well as other competitors and egg predators (Ceccarelli et. al., 2001). Besides this, some species also protect their territories against non-herbivorous fish. Intruders of the territories are chased away and bitten by the fishes, while smaller invertebrates are either bitten or they pick them up and swim away with them (McDougall, 2020). Individual fishes can not chase away schools of predators and competitors, despite their intensive aggressiveness. Therefore you can often find colonies of Damselfishes in the same territory to enhance their defence (Ibid.). The aggressive territorial behaviour of Damselfishes is considered to be significant in the maintenance of coral reef structure and algae presence (Ceccarelli et. al., 2005).

*Acropora* species of corals have been used to reintroduce the reefs with the goal of increasing biodiversity and habitat. The Damselfish creates territories where *Acropora* species lies, on which it grows algae gardens that they feed on. This leads to the Damselfish protecting the corals from degradation by controlling which algae species is present but also by their aggressive territorial behaviour leading them to exclude coral predators as corallivorous fish inflict stress on corals. While Damselfish might have an important role in conservation of corals their presence could also affect the corals negatively by promoting excessive algae growth which could instead decrease survival of corals (Ibid.).

### 1.9 Previous studies

Similar studies have been executed previous to this study. In a study by Johnson et. al. (2011) one of the things examined was the Damselfish effect on the composition of fish around Staghorn *Acropora* (*Acropora Cervicornis)* corals. The results show that Damselfish of species *Stegastes Nigricans* accounted for 85 % of the Damselfish in the territories examined. The results also show that the Damselfish displayed aggressive behaviour towards other fishes, protecting their farmed algae on the corals. Their aggressive behaviour could be seen towards corallivores, other herbivores and egg predators, however not to the same extent towards piscivores (Johnson et. al, 2011). Another study, executed by Kamath et. al. (2018), showed that corals which were outplanted into Damselfish territories were superior in their performance compared to corals which were not protected by farmerfish. This could be explained by the Damselfish's aggressive behaviour against coral predators (Kamath, 2018).

## 2. Methodology

### 2.1 Corals for conservation

Corals for Conservation (C4C) is a Non Governmental Organisation, created in 2008 by Dr Austin Bowden-Kerby. The main focus for the organisation is to restore coral reefs without interfering with the natural cycles and ecosystems in the ocean; they do this by using heat adapted corals, also named “super corals”. The super corals are corals that are adapted to very high temperatures and can survive in rough environments. These super corals are located in hotspots where the temperature often is above 32°C. To make sure that they really are super corals, fragments are taken and then replaced on a rope in a test nursery. Here they are monitored for a year, looking to see if they bleach or not in order to see if they are super corals. After a year of testing, the corals are trimmed, a small fragment is then kept and put in a genebank and the rest is outplanted on A-frames if they are fit for saving. Monitoring is done monthly on nurseries and A-frames, that includes recording the bleaching, algae cover, mortality rate and eventual diseases. All corals that are dead or with diseases are then removed and new fragments are outplanted. Sometimes cleaning is necessary, there's a clam nursery that needs to be cleaned twice a week and sometimes the ropes need to be cleaned of algae but mostly the fish helps with this. Predator removal also happens occasionally, mostly once a week to remove predators such as Crown-of-thorn starfish and Drupella snail.

When corals are outplanted, fish houses and “cookies” made out of cement are often used. The cement creates a good foundation for the coral to attach to and the fish house also attracts different kinds of fish which work together with the coral by cleaning them and therefore getting nutrients in exchange. Fish houses also attract fishes without corals being attached to them since they work as shelter and protection.

## 2.2 Experimental design

The project consists of comparing the survival of out-planted coral when secured directly on the reef in damselfish territories and on a reef with coral predators such as *Drupella*, *Crown-of-thorn starfish*, *Butterflyfish* and *Parrotfish*. This is going to be executed on an experimental reef located in front of the “ Plantation Island Resort”. See Figure 1 for a satellite picture over the experimental reef and the island. This experimental reef was chosen mainly for 3 reasons: it's high amount of damselfish territories, it’s easy access and that the reef itself is also slowly starting to get degraded which is why coral work is necessary in this area.

The experimental study will investigate 10 replicates including 30 cement discs (cement cookies) and all using *Acropora* corals from the reefs close to the outplanting sights. For each replicate 3 cement discs, approximately 25 cm in diameter, were made by mixing cement, sand and water together, they were then left to harden before use. The 10 sites to plant the corals on were then chosen in the reef and marked with a metal rod and tape. The sites were chosen with the criterias of having at least 1m in diameter of reef surrounding the outplanted cookie, and having 2 spots (30 cm out and 1 m out) outside of the reef that were at the approximate same depth as the reef itself (See figure 2 for illustration of replicate). These criterias were developed based on the research questions created in section “1.2 Aim” where the goal is to create 3 spots that are far away from each other to not create interference. The goal of having the approximate same depth for all spots is also to create similar conditions in all spots to minimise the sources of error that could affect the results negatively. After this the corals were collected from the nearby reef, chosen by the same species (*Acropora)* and with similar size. When collected they were all then connected to the cement discs with cable ties before being put down 3 and 3 on each of the 10 sites. Monitoring was then done once per day for the first week and after this once per week the following 2 weeks where photos and data were collected. The monitoring consisted of identifying and counting the predators located in each site as well as deciding the survival rate of each coral.

## 2.3 Preparations

Before the experiment was started, a few preparations were made to set up the experiment.

### 2.3.1 Cement cookies

The first thing done was preparing the cement cookies. This was done by mixing cement, sand and water in a large container, with three parts cement and two parts sand and thereafter adding water to the right consistency. After the cement had the right consistency, which means the mixture should be thick enough to hold together if you throw it in the air, large “cookies” (around 25 cm diameter) were formed using hands and pushing them out on the ground to get the round shape. It is important that the cookies are thick enough (about 1.5 cm thick) so they do not break when drying. When the shape was made 4 holes were created in each cookie to allow for attachment of the corals to the cookies. When the cookies were finished they were left to dry. When the cookies had dried they were put in a bucket of water for one day before being ready to use.

Before using the cookies for the experiment each cookie was tagged with the corresponding replicate number. All 10 replicates where named depending on which spot within the territory they had and therefore each replicate got named according to the following attributes:

**R**(1-10) - Replicate 1 to 10
**S** - Small (the one inside the damselfish territory)
**C** - Close (the spot 30 cm away from the reef)
**F** - Far away (the spot 1 m away from the reef)

### 2.3.2 Identifying and marking spots

After making the cement cookies, the spots for the outplanting were marked out. The spots were all located on the reef in front of the resort which is shown in figure 1 below as "experimental reef". This was done using metal rods and flagging tape. Firstly the Damselfish territories had to be identified through looking for large reef areas (had to be at least 1,5 metre in radius) with Damselfish presence. If the areas were large enough, multiple replicates could be placed within the same territory, however there had to be at least a 2 metre distance between the replicates to prevent interference. After identifying a large enough Damselfish territory, a metal rod was pounded into the sand next to the territory. The metal rod was then marked with flagging tape to make it easier to locate the areas when doing the daily monitoring.


Figure 1. *Picture over experimental reef and Plantation Island Resort*

### 2.3.3 Gathering corals

*Acropora* corals were gathered from the surrounding reef. The first 4 replicates used corals gathered from a reef nearby the reef in front of the hotel. After they were gathered they were put in a nursery before being transported to our outplanting sites. They were collected from the nursery and then transported in a bucket of water on a kayak to the sites were they were put back down into the ocean to do the outplanting itself.

## 2.4 Outplanting

After the 10 areas were marked with the metal rod and flagging tape 3 spots within every replicate was cleared for outplanting of the corals, this was done in the following steps:

1. One spot was cleared around 25 cm in diameter for the cookie to fit within the identified territory (1m in diameter of reef surrounding the outplanted cookie) just big enough to do the following:
    - Outplant 1 coral fragment secured on a cement disc with cable ties
2. Next to the reef 2 spots were cleared, also around 25 cm in diameter, one 30 cm out from the damselfish territory and one 1 m away (far enough away so the damselfish won't claim it)
    - Thereafter 2 coral fragments were put out, one on each sight, secured on cement discs with cable ties

This was executed for all 10 replicates resulting in 30 spots to monitor. See Figure 2 for illustration of composition of replicate.

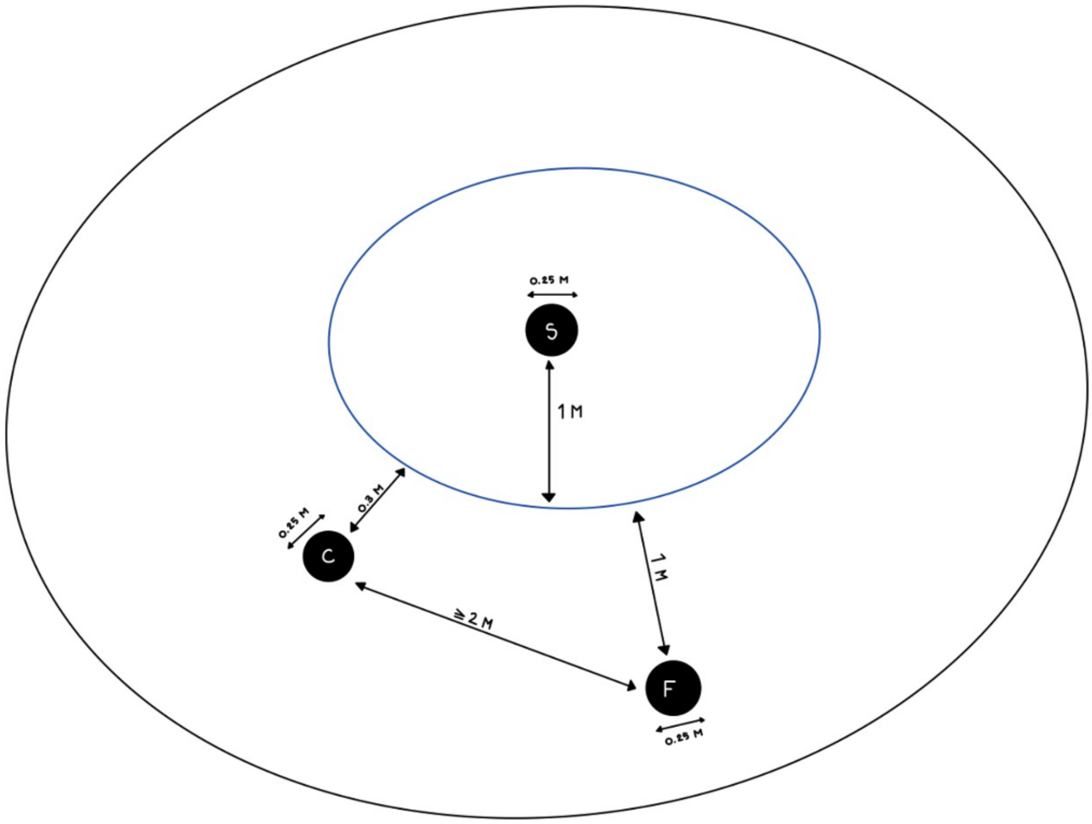


Figure 2. *Image over composition of replicate.*
*Outer circle shows the total area of the replicate. Blue innercircle shows the territory of the Damselfish. Cookies on each outplanting sight with measurements and distances from reef edge and distance from each other is also shown.*

## 2.5 Monitoring

Monitoring was done once per day the first week, and thereafter 2 times a week the following time. The monitoring was done by snorkelling during middle or high tide and the amount of time spent at each site was only enough time to write down the collected data, approximately 40 min for all 30 spots. The first day pictures were taken and each coral recorded. Thereafter the predation was recorded overseeing presence/absence and which types of predators that were recognized. The predators that were observed were COTS, Drupella snails, Butterflyfish, Parrotfish and any unknown species. The mortality rate was then rated on a scale of 0-5 where bleaching and algae cover after bleaching was included. The rating was decided as following:

| Scale | Rate (%) |
|---|---|
| 0 | None |
| 1 | < 25 |
| 2 | 25 - 50 |
| 3 | 51 - 75 |
| 4 | 76 - 90 |
| 5 | 91 - 100 |

*Table 1: Mortality rate on a scale of 0-5*

After predation and mortality had been recorded the amount of predation as well as which type of predation that accrued in each of the replicates was brought into a google sheet file. Here all replicates were gathered so that the mode (the most occurring data) of each predator could be calculated as well as the average presence of each predator. The same was done for the mortality rate. When all monitoring was done, a summary of all the monitoring was made. with the total mode and average calculated.

# 3. Results

The results show that both the predation and mortality rate are much lower in the area inside the reef (S in the tables and graphs above) compared to the outplanting close ( C ) to the reef and the outplanting sight further out from the reef (F). There was no predation found from either Drupella snails or Crown-Of-Thorns starfish in any of the areas. The average mortality rate was similar for both C and F showing that the distance outside of the reef from the damselfish territory does not matter too much for the results. It is only if the outplanting site is either inside or outside the damselfish territory that makes a difference to both predation and survival of the corals. The mode, which is the most frequently occurring data, is higher for the locations close to the territory compared to the areas further out when it comes to mortality rate.

The results are shown in table 1-4 where the modes and averages of both the predators and the mortality rates in total over the 7 days that the monitoring was done are shown. Figure 2-3 also shows the amount and type of predation as well as the mode and average mortality. The pictures below show the development and degradation of two of the replicates from firstly baseline photos, the second monitoring (for R9F only) and then the last monitoring.

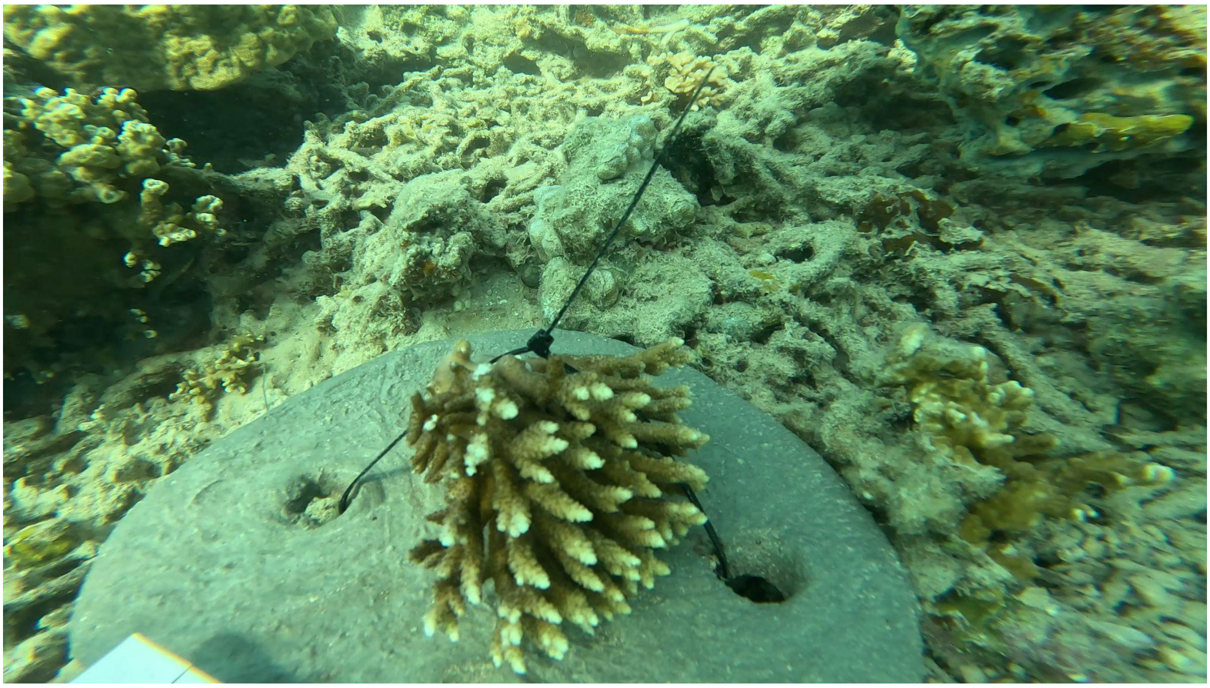

Figure 3. *Replicate number R9F from baseline photos*

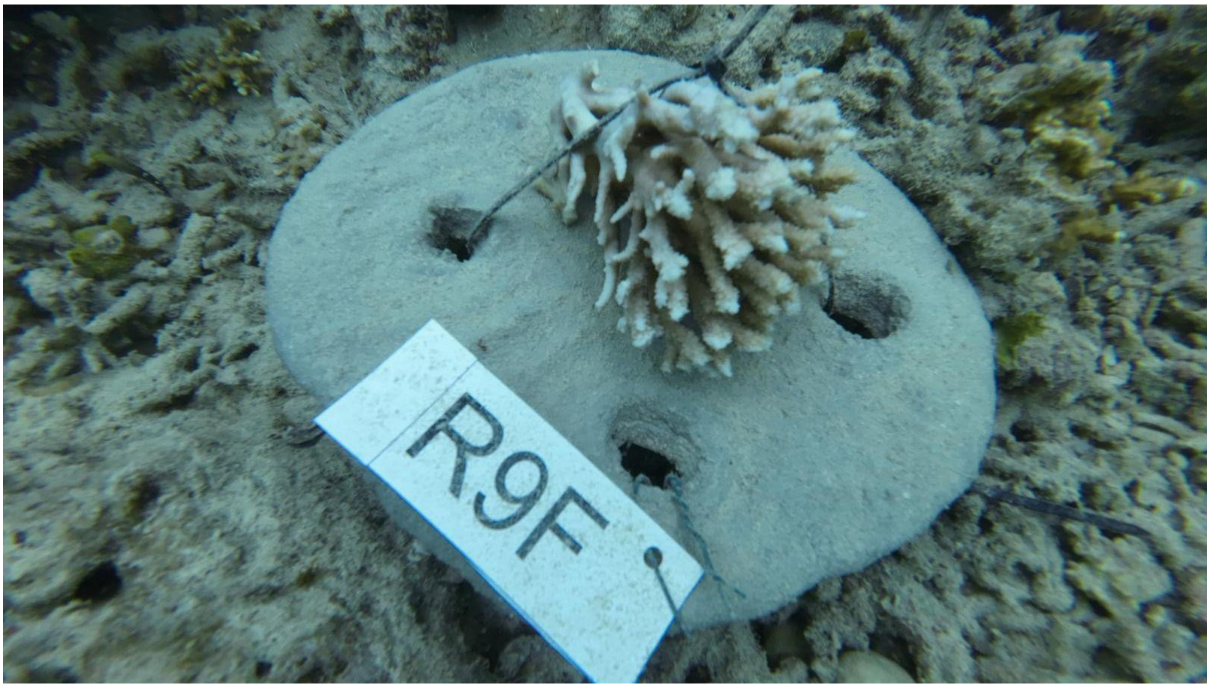


Figure 4. *Replicate number R9F from monitoring 2*

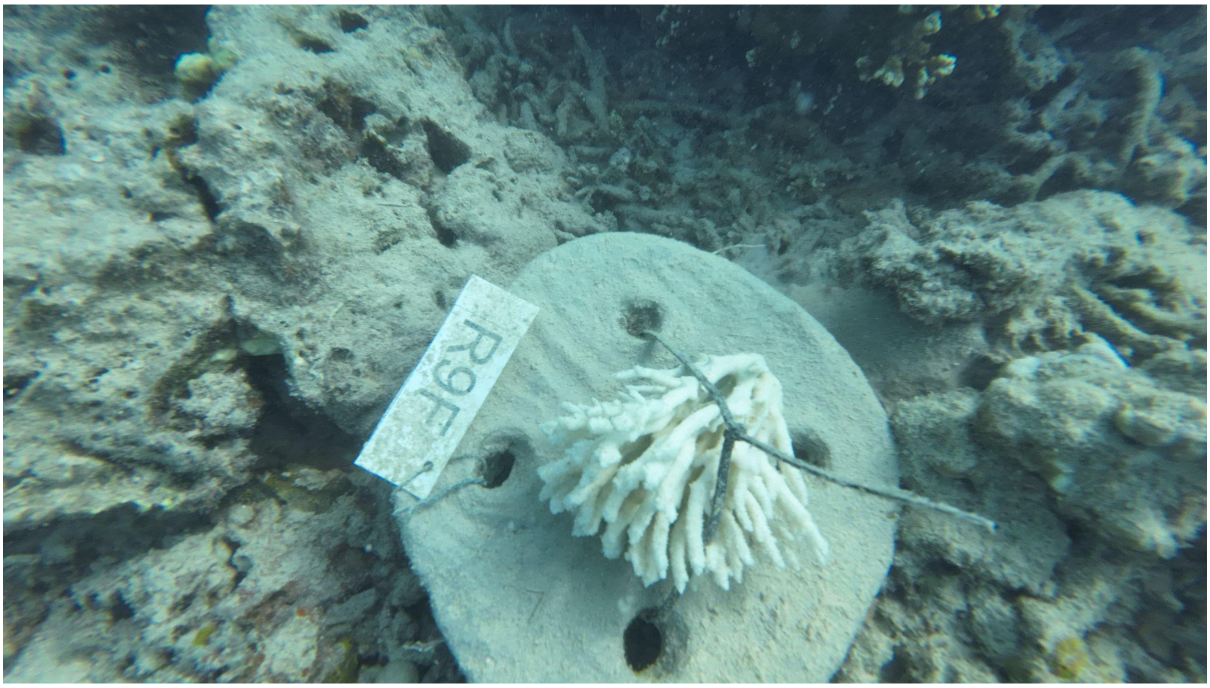


Figure 5. *Replicate number R9F from last day monitoring*

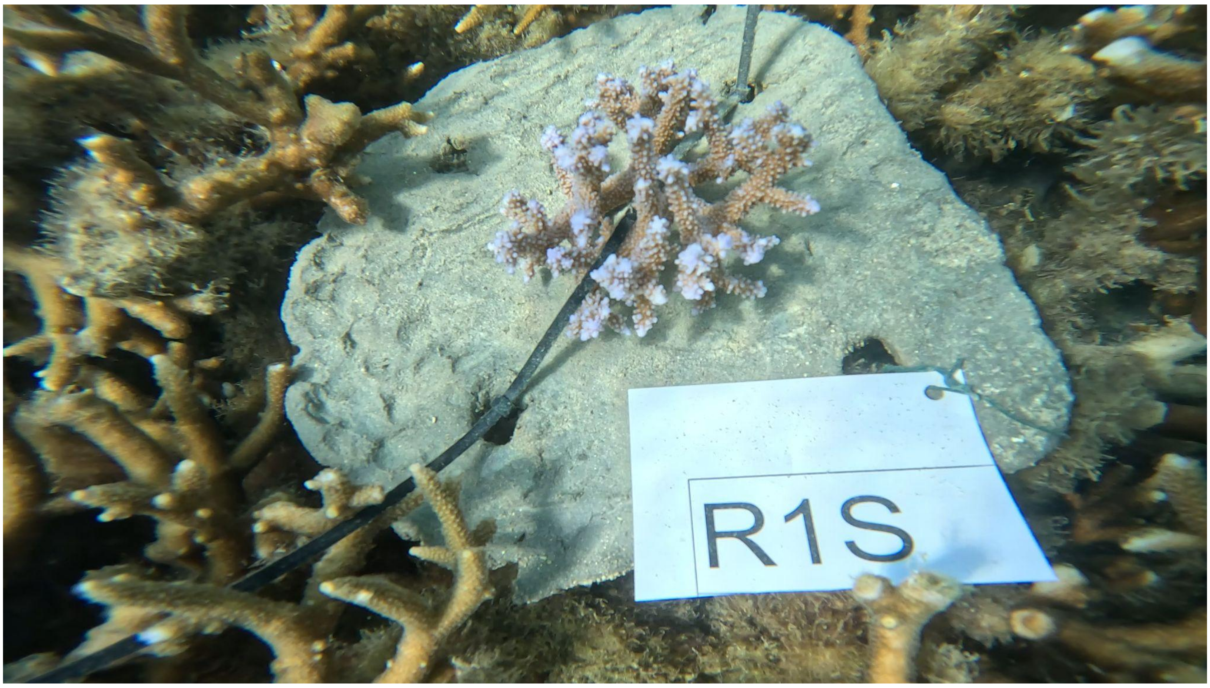


Figure 6. *Replicate number R1S from baseline photos*


Figure 7. *Replicate R1S from last day monitoring*

| **Mode** | COT | Drupella | Butterflyfish | Parrotfish |
|---|---|---|---|---|
| S | 0 | 0 | 0 | 0 |
| C | 0 | 0 | 0 | 0 |
| F | 0 | 0 | 5 | 0 |

Table 2. *Mode of predators in each area*

| **Average** | COT | Drupella | Butterflyfish | Parrotfish |
|---|---|---|---|---|
| S | 0 | 0 | 0,2 | 0 |
| C | 0,1 | 0 | 4,6 | 1,2 |
| F | 0 | 0,1 | 3,6 | 0,4 |

Table 3. *Average amount of predators in each area*

| **Mode** | Mortality |
|---|---|
| S | 0 |
| C | 4 |
| F | 3 |

Table 4. *Mode of mortality rate in each area*

| **Average** | Mortality |
|---|---|
| S | 0,5 |
| C | 2,8 |
| F | 2,8 |

Table 5. *Average mortality rate in each area*

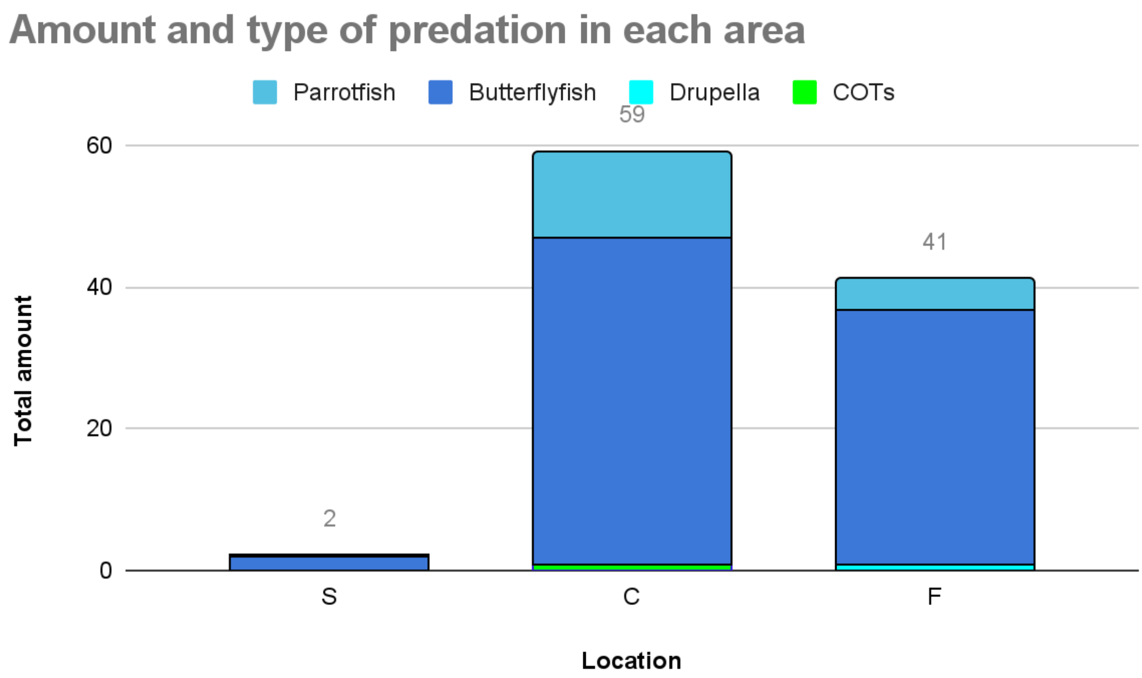


Figure 8. *The total amount of predation and type of predation in each area from all monitorings*

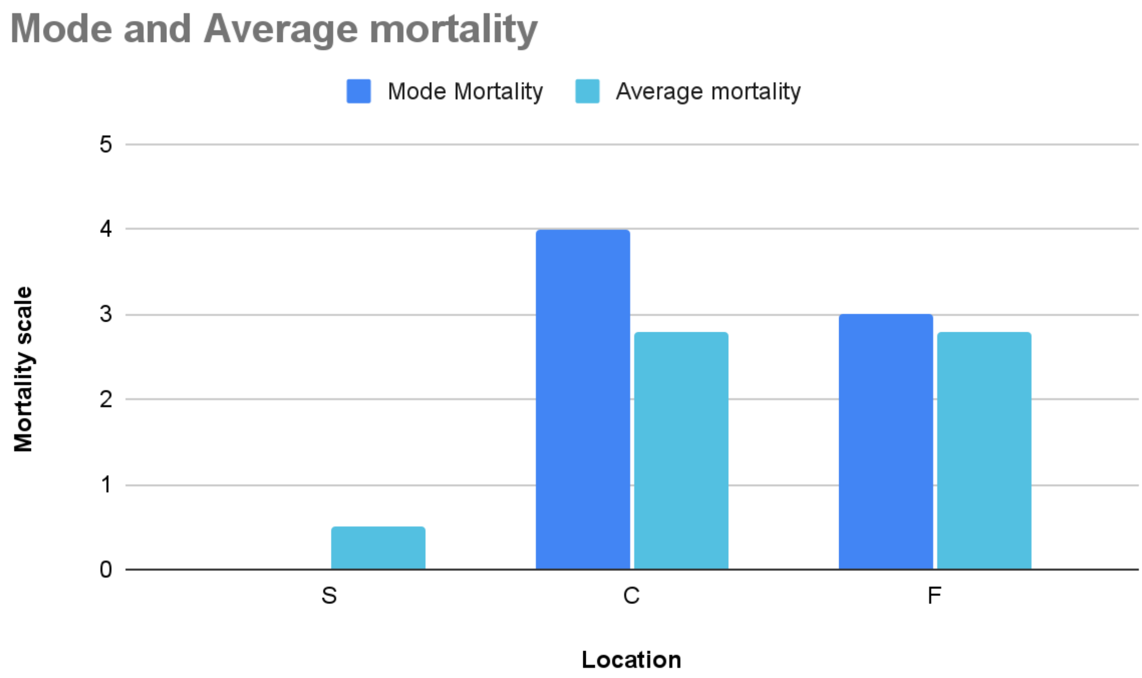


Figure 9. *Mode of mortality and average mortality in each area on the mortality scale for all replicates*

# 4. Discussion

## 4.1 Discussion of results

The overall result showed that the corals inside the territories had a much lower mortality rate than the ones outside. The corals furthest from the territory had the same average mortality rate as the corals closer to the territories. This shows that the damselfish does not extend their territory to protect corals outside their reef but manages to protect the corals living within the reef of their protection. However our results show that we could see an effect from outplanting corals in Damselfish territories in order to protect the corals from predators and disease. Our results correspond to the findings of previous studies. In both studies made by Johnson et. al. (2011) and Kamath et. al. (2018) it was found that the Damselfish was successful in protecting corals from coral predators and thus ensuring a higher survival rate of corals inside Damselfish territories compared to corals not protected by the fish. This provides more certainty and confirmation of the results that were obtained and that it is a possible outplanting method.

As can be seen in the photos from replicate number R9F, the coral was healthy when first outplanted. After only two days the coral health started declining, where you can see some of the tips having been bit off, presumably by parrotfish, and some incipient bleaching. When looking at the last day monitoring there are still bites on the tips and the coral has fully bleached from stress from predators. This can be put in comparison with pictures from replicate number R1S which was put inside a damselfish territory. In the pictures the coral has maintained its health throughout the experiment, not showing any major changes in its state. In the picture from the last monitoring algae growth is visible on the cement cookie and the tag. This shows that the Damselfish promotes algae growth as well as protects the coral from predators. One important note is that corals are capable of recovering from severe bleaching, since it is a result of the algae being expelled, if the coral manages to regain its food source it would be able to recover. However this can take a very long time and most of the time when a coral has bleached, it starves and dies (Australian Marine Conservation Society, n.d.).

Early on in the experiment the results showed that tips of the coral had been bitten off at a few of the corals, these were assumed to be from parrotfish and appeared mainly on the corals far off from the reef. This shows that predation from fish mainly affected the corals further away from the damselfish territory at first. Later on the results showed that the predation was higher on the corals close to the territory and the main predator that was present in the different spots were butterflyfish. The butterflyfishes were mostly observed in the spots that were outside of the damselfish territories, both on the ones close and the ones far away. The reason why more fish was observed on the areas close to the reefs could be explained by the behaviour of the damselfishes who promote algae growth on corals, which means fishes might be drawn to the damselfish territories because of the algae supply and then scope the surrounding areas when being excluded from the territories. The spots which were further away from the reefs did not have the same amount of corals surrounding them which could also explain why the predators would rather be present where there were more coral cover.

Inside the Damselfish territories only one single butterflyfish was observed. This is due to the fact that Damselfishes are highly territorial, protecting their territories from corallivorous predators. One COT and one Drupella snail were found during the last day of monitoring which is mostly a positive and expected result. The Drupella snails mostly attack older corals in a close radius and since our coral pieces were moved and only lived in these certain locations for a short amount of time the predation of Drupella snails was not expected to affect these corals [8]. The COT:s are animals that prey at night, since our monitoring took place during daytime no COT:s should be detected. During the last day of monitoring one COT was seen in one of the spots (R6C) which is a sign of overpopulation because they have to change their predation time in order to get enough food. Normally the absence of COT:s is a good indicator of a normal population in this area, but the observations showed that the amount of these predators is probably a bit too high in this area at current time. That the COT was found in area C and not in the area inside the damselfish territory (S) is another proof of how the damselfish protects the corals inside their territory from their predators, but does not extend their protection to even as low as 30 cm out.

The results in this experiment show that a certain edge effect has occurred. Within the territories of the damselfish the corals are mostly thriving and have a much higher survival rate compared to the spots outside. Even the spots just outside the territory (spot C) have a much lower survival rate than the ones inside creating a clear line of where the protection from the damselfish is effective and where the damselfish protection stops. These edge-effects are often created where two microclimates occur close together which creates a line and marks the edges of the two parts where the conditions are different (Nationalencyklopedin, u.å).Examples of further edge effects that is shown from the results is that the spots furthest away from the reef had less fish in general recorded. This could be explained (as mentioned before) by the excessive algae growth near the damselfish territory which therefore attracts more fishes and they are then more likely to be found near the corals close to the territory rather than the ones further out.

## 4.2 Coral restoration as a sustainable development tool

Since the results show that outplanting corals in Damselfish territories has an effect on the protection of the corals, this could be an additional strategy of outplanting. This means that there could be an additional solution to restoring coral reefs which have been degraded due to many anthropogenic reasons. When outplanting corals, it will be helpful to use the Damselfish and its territories to give the corals a higher chance of survival. Restoring the coral reefs is important both to save the complex ecosystems that the coral reefs are a part of,

[8] Bowden-Kerby A, McDougall A. Marine biologists at Corals for Conservation. Malolo Lailai Island. 2023. Conversation

but also to the inhabitants of Fiji who rely on the reefs. Restoration of coral reefs is an important tool when working with sustainable development, especially for countries that depend on the reefs for several reasons, like Fiji do. For Fijian people the reefs not only provide food and security but contribute to the national economy through the tourism sector. When restoring reefs which have been degraded, they become more attractive for tourists to visit which means that the income from tourism will increase. If the reefs continue to decline the tourism sector will instead be at risk of decreasing, causing economical, environmental and social consequences for the country.

Even though the overall impact of this experiment is to help the environment and create a positive effect regarding sustainable development, a few parts of the work have the opposite effect. When the cookies that the corals are connected to is made cement is used, cement is a substance that leads to very high emissions of carbon dioxide. When making cement limestone is quarried out of mountains releasing large amounts of carbon dioxide that has been bound in limestone for millions of years. When handling the limestone to create the cement fossil fuels are often used which creates even higher emissions in total. Using this substance therefore leads to emissions of carbon dioxide which could have been excluded if another substance had been used instead (Naturskyddsföreningen, n.d.).

The increased mortality of coral reefs have big effects on the marine ecosystems in the ocean leading to decreasing amounts of fish species in these areas. This difference in the amount of fishes that will be able to survive in these areas will therefore lead to a change in the already existing food chain. This interruption will cause other kinds of predators that are more fit for these circumstances to increase which will cause a shift in the species that will live in these areas and this can therefore cause a huge amount of side effects which in the worst case can lead to the extinction of some species. To prevent loss of biodiversity working with corals and maintaining their overall health and keeping the ecosystems balanced is therefore an incredibly important work.

## 4.3 Sources of error

There are several aspects that may have affected the results in this report. The gathering of coral is one. All corals used in the project were of the *Acropora* species, but they were collected on different times and from different parts of the reef. The corals used for the first 4 replicates were gathered a day before the rest and then left at one of the organisation's nurseries before being gathered the next day to use for the outplanting. When collected they were transferred in a kayak in a bin with water but with direct sunlight which may have affected upbringing of stress to the corals. This difference in gathering as well as transport to the outplanting sight may have resulted in unequal original conditions for the corals.

Within the first few days of the outplanting, one of the corals outplanted close to the Damselfish territories died very quickly. This could have been due to several reasons, but since no predators were observed present, one of the reasons could be bleaching due to high levels of stress. The stress could have come from us removing the coral from its original space to the damselfish territory. It could also be stress from us fragmenting the coral with a chisel which is best done with a few hard pounds rather than many soft ones. This was seen in replicate R7C.

The monitoring of fish predation but also the monitoring of the coral's survival rate can also have been affected by lack of knowledge. The results may have been affected negatively due to lack of education about fish species and coral health. The lack of knowledge in this field may therefore have resulted in misinterpretation of species and accurate health assessment.

Another source of error could have happened when observing the fish present in the different spots. Since our monitoring was only done once a day with a few minutes of observation in each spot, all the fish that are actually present were not observed. The fishes could also have been scared when humans entered their surroundings, causing them to temporarily relocate to other areas.

A few of the corals from the spots within the territories, two out of ten (R4S and R6S), started bleaching despite being in the protection of the Damselfish territory. This could be due to stress from being moved from its original location. The stress could also be caused from the removal from its original substrate and thereafter being fragmented into smaller pieces.

## 4.4 Further research

This experiment could be expanded to research what length the Damselfish stretches their territory and protects corals. This could be done by repeating the experiment but placing more outplants within the same territory in different lengths from the territory itself. In our experiment we used one outplanting close to the territory and one far away where the fish would not claim it. If testing how far the Damselfish expand their territory, several outplantings can be placed with different distances from the territory itself. This could present additional information about how to use the Damselfish as an outplanting strategy in the future.

# 5. Conclusion

In conclusion, the corals had a higher chance of surviving inside damselfish territories rather than outside of these reefs. The corals inside the territories were protected from predators and disease while the corals outside the territories did not get protection from the Damselfish. This shows that planting corals inside of damselfish territories gives the corals a higher chance of survival and protects them from predators. It can therefore be an outplanting strategy on reefs that are undergoing stress and bleaching. It could also be a strategy when it comes to growing healthy corals before planting them out in reefs that are already degraded or that are under a period of bleaching. That could help the marine ecosystems and therefore the work with handling climate change and the effects that come with it.

# 6. Acknowledgements

Finally we would like to thank the organisation Corals For Conservation as well as their partnering hotel Plantation Island resort for the possibility to come to Fiji and to do this experiment. The hospitality, knowledge and help that we have been given has been beyond our expectations and we would not have been able to learn so much without this opportunity. We would like to give an extra thanks to Annelise McDougall who has been our contact person as well as Austin Bowden-Kerby who is the founder of the organisation. Their coral reef program and their eagerness to spread their knowledge about outplanting, monitoring and corals is admirable and they play an important role in the future work of trying to save our planet and marine life.

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# 8. Appendices

- Googlesheet with all data collected from the experiment: Experiment

TRITA-ABE-MBT-23488