Fiji Marine Conservation Programme

Beqa, Fiji

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<td>Doryan Givel (DG)</td>
<td>Project Manager</td>
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<tr>
<td>Rachel Zimmerman (RZ)</td>
<td>Principle Investigator</td>
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<td>Zachary Penman (ZP)</td>
<td>Dive Officer</td>
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<tr>
<td>Kristin Hoel (KH)</td>
<td>Assistant Research Officer</td>
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<td>Adam Heath (AH)</td>
<td>Assistant Research Officer</td>
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<td>Emmanouil Symigdalas (ES)</td>
<td>Assistant Research Officer</td>
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</table>
1 Introduction

1.1 Frontier

Frontier, established in 1989, is a UK-based non-profit NGO. Its mission statement is:

"to conserve the worlds most endangered wildlife and threatened habitats and to build sustainable livelihoods for marginalised and under resourced communities in the worlds poorest countries and to create solutions that are apolitical, forward-thinking, community-driven and innovative, and which take into consideration the long-term needs of low income communities".

Frontier employs non-specialist volunteers, or Research Assistants (RA). Frontiers marine projects give RAs environmental science species identification training at the beginning of their placement, to enable them to collect data on local fish, benthic and invertebrate species. Frontiers project is currently located on Beqa Island, south of mainland Fiji, to assess the status of the coral reef systems around Beqa and within Beqa Lagoon.

1.2 Location

The Republic of Fiji is an archipelago in the South Pacific Ocean composed of approximately 330 islands and 500 islets and cays, with an associated land mass of 18,333 km$^2$ and an Exclusive Economic Zone (EEZ) of 1.3 million km$^2$ (figure 1) (Sulu et al. 2002). Approximately one third of Fijis islands are inhabited and, of these, the two largest islands, Viti Levu and Vanua Levu, contain approximately 90% of Fijis population (The Fiji Islands 2000).

Figure 1: Map of Fiji with Beqa marked with a blue arrow. Source: Google Maps

The relatively high proportional representation of sea to land mass area, (the land area is 70 times smaller than its EEZ), means that for much of Fijis population subsistence fishing on and near to coral reefs is a way of life (“The Fiji locally-managed marine area network: structure, strengths and scope for future developments”). Beqa is a large island and lies within the Beqa Lagoon, specifically, the Frontier camp is located within Vaga Bay (figure 2). The island is located approximately 10 km south of the main island of Viti Levu and has a population of around 3,000 people. Nine villages are present on Beqa, these are; Waisomo, Lalati, Soliyaga, Dakuni, Dakuibeqa, Naceva, Naiseuseu, Rukua and Raviravi. Of these the camp is closest to Naiseuseu and Rukua.

Fiji is world renowned as the Soft Coral Capital of the World and is also home to Beqa Lagoon (BL), where FJM is based, which is famous for baited shark dives amongst the diving community. The Beqa Lagoon area features over 50 world-class dive sites that are frequented by numerous species of megafauna, including dolphins, whales, sharks, rays and turtles. The primary source of income on Beqa
is tourism, largely through recreational scuba diving. There are five resorts around the island. No large-scale commercial fishing (including aquaculture), agriculture or horticulture occurs, and heavy industry is non-existent. Consequently, the surrounding reefs are reportedly largely unaffected by the impacts of such industry and therefore, represent an ideal location to study the implementation of traditional management systems in the absence of significant background variables.

1.3 Background

Coastal Governance and Fisheries Management

Beqa’s inhabitants, (along with most Fijis populations living on smaller islands) rely heavily on the coral reefs for both subsistence and income through semi-commercial fisheries (Gillett et al. 2014). These fisheries are predominantly focused in the reef to outer ridge areas which are governed through a dual system of traditional practices, named the iTaukei system, and English common law in a dual legal system (Sloan and Chand 2015). This dual system means that fishers are required to obtain a license with their picture on it from centralized, government systems. However, this must be signed by chiefs in their local communities (personal comms: Claire Collins). Millennia-old traditional practices controlled by chiefs and committees are responsible for regulating fisheries access predominantly through zoning and the traditional qoliqoli system. The qoliqoli system and associated methods differ slightly within Fiji, however, broadly utilize tools such as: seasonal bans and temporary no-take areas, or tabu areas (Tawake and Parras 2005). Traditional forms of marine management such as this across the Pacific have regularly attracted conservation attention and praise since the early 1990s, as it has been increasingly recognized that custodianship is a vital tool in the success of marine conservation and management (Govan 1999).

In Beqa, various no-take or tabu areas have been designated by chiefs of the villages to try to control extraction levels as village populations increase. The tabu areas surrounding Beqa can be seen in figure 3. Although village chiefs have no legal right to the reefs, they traditionally lay claim to certain reefs within their territories and consequently have the power to create tabu areas on reefs of their choice, in order to maintain populations of targeted fish species for subsistence. It is culturally expected that this unofficial law is respected and adhered to, by all inhabitants of Beqa Island. Villagers conduct surveillance and enforcement activities if it is suspected that fishing is occurring in tabu areas (personal comms: Claire Collins). Studies have repeatedly shown that traditional methods are an effective way to control and sustainably manage harvest rates of marine resources (Lopez-Hoffmann et al. 2002).
FJM’s work aims to provide evidence on the effectiveness of Beqas management. Previous evidence has suggested that fish communities in the least intensively fished qoliqoli and tabu areas significantly differ from elsewhere, with a much higher reported biomass of invertebrate feeding and piscivorous fishes (Jennings and Polunin 1996). That said, there is a paucity of available research to validate these management systems. Therefore, FJM also directly studies biomass and abundance in areas of differing fishing pressure. The map(s) below denote the qoliqoli areas in existence around Beqa and the presence of tabu areas around these areas. It is worth noting that the predominance of FJM’s research occurs within qoliqolos that belong to Rukua village, the tabu areas are subject to seasonal and occasional change at the behest of the chiefs/spokespersons.

Alongside the traditional management systems, Beqa is also a stakeholder to the Fiji Locally Managed Marine Area Network (FLMMA), this is a Pacific based network system in existence across the Pacific Island States which has been widely reported on as a highly successful management tool (“The Fiji locally-managed marine area network: structure, strengths and scope for future developments”). FLMMA has over 400 locally-managed marine area sites in Fiji, of which Rukua is one, and they support village committees in making decisions on marine conservation-based issues mainly by workshop activities, dissemination of vital information and logistical advice.

Figure 3: Map of the tabu areas around Beqa and Yanuca (red areas). The qoliqolos are also denoted (as marked in black). Source: FLMMA, 2013.

**Threats**

Fiji is dependent on its low-lying coastal regions for its socio-economic development (Teh et al. 2009) and coral reef fisheries are a vital component of life on Beqa. Overall, the direct contribution of coastal commercial and subsistence fisheries in Fiji is estimated to be anything from approximately US $64-73 million (Food and United Nations (FAO) 2007; Gillett et al. 2014). Aside from financial income and job security coral reefs provide food security/nutrition, which are integral to Fiji’s tourism industry and hold significant cultural and social values. The main sources of foreign exchange are the tourism industry (19% of GDP), the sugar industry (8.5% of GDP) and then fisheries (2.5% of GDP). Small-scale inshore fisheries represent the main protein source for at least 50% of rural households. This high reliance and the absence of alternative livelihoods and food options means coastal communities are reliant on the health of the reefs.

Similarly, to many other South Pacific islands, Beqa is extremely vulnerable to the impacts of climate change. Current predictions indicate a potential rise in global sea levels of between 0.5-1m by 2100 (Solomon et al. 2009). Such an increase would cause widespread devastation to Fiji’s coastal infrastructure and artificial preservation such as coral restoration efforts would be a substantial drain on
Fiji’s economy. In addition, the frequency of destructive environmental events is predicted to increase, occurring at a faster rate than potential recovery. Furthermore, coral reefs have a social importance and significance for the cultural identity of native Fijians which will be threatened by any loss of the country’s biological diversity (Geraghty 2018).

**Anthropogenic Sources of Reef Degradation**

The main anthropogenic sources of reef degradation include coastal development, overfishing, destructive fishing practices (such as dynamite fishing), poisoning, pollution, deforestation, and coral harvesting for the curio and marine aquarium trade (Lovell 2001; Teh et al. 2009).

The marine aquarium trade inflicts reef degradation in a variety of ways. According to Fiji’s Fisheries Department annual estimate, 311,097 aquarium fish were exported from Fiji in 2001 (Teh et al. 2009). The Convention of International Trade of Endangered Species (CITES) database recorded that 169,143 ornamental fish and 31,900 invertebrates were exported from Fiji in 2004 to overseas markets (Lal and Cerelala 2005). Live rock exports have also increased and are a major problem in Fiji as it significantly diminishes reef ecosystems by reducing the number of available spawning sites for marine species, reducing the buffer areas for sites of increased wave action, and decreasing carbon dioxide sequestration by reducing the amount of photosynthetic material in the marine environment. In 2001, a reported 800,000 kg of live rock was harvested and exported from Fiji; however, the actual figure is likely much greater as a substantial quantity is lost in the trimming and grading process (Lovell and Sykes 2008). Although this has not been observed around Beqa, compared to other areas around Fiji, likely due to tourism being the main activity, there is potential for harvesting to occur in the future.

Pollution in the form of sewage is a major threat to coral reefs in Fiji. Untreated sewage deposited directly into the ocean causes increased levels of phosphates and consequently macro algal blooms and eutrophication (Hughes 1994). Coral reefs are unique in that they possess low levels of nutrients and are highly efficient at recycling them. Consequently, they can cope with minor levels of eutrophication, however, when marine ecosystems are highly enriched with chemical nutrients, the result is excessive plant growth in the form of macro algae. Such algae are detrimental to the health of the reef because they use all available oxygen within the water column, causing fish populations to die off. In addition, these algal blooms reduce the amount of light penetrating the water column, inhibiting coral photosynthesis, subsequently causing rapid declines in reef system biodiversity (Fabricius 2005).

Unmanaged disposal of raw sewage is common in areas of dense population as well as in popular tourist destinations. Villages on Beqa use pit latrines for sewage, however, because they are close to the coast it is likely that nutrients leach through the soil into the surrounding coastal waters and increase levels of phosphates and nitrates, which in turn negatively affect near shore reefs. It is unclear how the resorts on Beqa manage their waste, but it is likely that septic tanks are employed. Incidents of dumping on reefs along the Coral Coast of Viti Levu, Mamanuca and Suva have been observed (Mosley and Aalbersberg 2003; Tamata and Thaman 2001; Zann and Lovell 1992).

Many families on Beqa lay claim to some plantation regions which they farm, both for local consumption and trading as well as to sell on the mainland (MRIS, 2012). It has been noted that there has been an increase around land cleared using slash and burn methodologies to make room for these farms (pers comm, 2015). These areas of clearing will increase sedimentation and the rate at which fresh water is being leached onto the reef. Mangrove forests help stabilize shorelines, filter freshwater runoff and reduce the impact of natural disasters such as tsunamis and hurricanes. In addition, many of the reef fish targeted for consumption are known to depend on the mangroves for refuge from predators and for ontological development (Food and United Nations (FAO) 2007; Giri et al. 2010). According to locals, the areas of mangroves have significantly decreased and with the added impact of slash and burn techniques this is likely to continue (pers comm, 2015). The combination of land clearing using slash and burn techniques as well as mangrove deforestation will be having measurable impacts on the reef.

The fisheries sector is the third largest natural resource sector in Fiji, contributing 2.5% to the national GDP annually. There has been an expansion and development of coastal fisheries, which have rapidly shifted from subsistence only to semi-commercial in the last 100 or so years and some suggest that this represents the greatest anthropogenic impact aside from climate change. In 2008, a study by Teh et al., (2008) reported that of Fiji’s 400 traditional qoliqoli, around 70 were over-exploited while 250 were fished to their maximum sustainable level. A further review in 2014 suggested that almost all target finfish and invertebrate resources were overexploited (Gillett et al. 2014). The Gillett et al. (2014) study reported that, rising domestic consumption and the growing export market were dually responsible for such dramatic expansion. For example, resources of invertebrates such as Bche-de-mer are rapidly being plundered for export markets based in Asia, as these countries look to source fish elsewhere due to the
collapse of domestic fisheries. Since the 1990’s within the Fijian population there has been increasing pressure on small scale fisheries, due to growing population sizes and increases in the demand for fish. A socio-economic study done in Beqa villages Rukua and Yanuca reported that of the fish caught locally 54% were consumed by the local community while 46% were either sold outside or to a middleman/agent, presumably to an outside source.

Common methods for targeting reef fish species include: hand-line, spear, gillnet, seine net, hookah (diving with surface supplied air) and reef gleaning (Teh et al. 2009). Of these methods hand-lining and spearfishing are used most frequently by residents of Rukua and Yanuca. Commercial fishing does not occur near the island of Beqa, however, overfishing in other areas may have reduced population numbers to such an extent that emperor species such as *L. harak*, *L. xanthochilus*, (*L. nebulosus*) and *B. muricatum* are not present or very rarely encountered. Species such as the bumphead parrotfish (*Bolbometopon muricatum*), have now become almost completely extinct in Fijian waters (Sulu et al. 2002).

Existing studies and reports from Fijian island communities, such as Beqa, potentially suggest that increasing pressures are threatening the effectiveness of traditional management systems. There is increasing recognition amongst government and non-government bodies that there is a need for additional regulations, e.g. fisheries input and output controls. Understanding the role of societal and economic factors on fishing is critical for designing appropriate fisheries management strategies. However, there is a lack of long-term monitoring programmes and no national level evaluation of Fiji’s reef fisheries. To tackle this at a national level, the Fisheries Division, Fiji Locally Managed Marine Areas (FLMMA) and the University of the South Pacific have started facilitating coral reef conservation initiatives by conducting socio-economic surveys of marine resource use. Teh et al., 2008 produced an overview of the socio-economic and ecological perspectives of Fijis inland reef fisheries. The result from this overview was that the status of Fiji’s reef-associated fisheries at national level is still uncertain due to lack of dependable data on the subsistence fisheries. Therefore, there is a clear need for an expansion of data collection at the village level and FJM intend to increase their collection of such data within the next phase.

1.4 Project Aims and Objectives

As FJM moves into the fifth year on Beqa, the recommended time period for baseline surveys has been completed and the project has moved into continued reef monitoring. This will create data sets that are more comparable both between survey sites and between reefs worldwide; using the globally practiced Reef Check methodology. This change in methodology will allow for a more efficient long-term monitoring program to identify changes and trends in coral reef health and organism abundance.

Phase 182 also saw the introduction of snorkel surveys aimed at monitoring the commercially important invertebrate species of Beqa Lagoon, separately from the tri-purpose marine surveys that monitor invertebrate species with a focus on reef health. These reef-front timed swims have a focus on the sea cucumber (*Holothuroidea*) and other commercially important invertebrate populations. Export of sea cucumbers, or *Beche-de-mer* was the 2nd biggest income generator in Fiji up until November 2017, when the Fijian Government imposed a moratorium banning all export of *Beche-de-mer*, due to consistent over-exploitation leading to drastically low population numbers (Lee et al. 2017). The long history of excessive fishing pressure has had the dual effect of not only reducing populations but thinning them to such low densities that detecting chemical cues for spawning populations is almost impossible. The area of Beqa Lagoon has suffered dramatically from over-fishing, due to its proximity to the mainland of Viti Levu making it common for fisherman from Suva to travel to the Beqa Lagoon area to fish due to higher population levels. This moratorium is an ideal time for FJM to begin monitoring of sea cucumbers and other commercially important invertebrates, to examine the effects of the moratorium on sea cucumber populations, as well as detect any shifts in the exploitation of other invertebrate fisheries. To date, little has been done to create an alternative livelihood plan for communities dependent on the *Beche-de-mer* fishery (Pers Comms: 2017).
In summary, the aims and objectives of FJMs research include the following:

Examine long term trends and changes with Beqa Lagoon coral reefs by conducting tri-purpose reef monitoring surveys that utilise a robust long-term monitoring protocol. This protocol will standardise data collection to facilitate collaboration with external partners, such as Reef Check and the Global Coral Reef Monitoring Network enabling submission of FJM data to global coral reef health databases. This data will be used to:

- Evaluate the long-term effects of locally managed marine areas (Tabu) on coral reef health, fish and invertebrate populations.
- Assess the resilience and recovery rates of Beqa Lagoon reefs in response to climatic events and changes; and compare data with USP sea surface temperature data loggers.
- Feed into the international databases of both Reef Check and the Global Coral Reef Monitoring Network, using globally recognised methodologies.
- Investigate the effects of the Bche-de-mer moratorium through a monitoring program specifically focused on commercially important invertebrate fisheries around Beqa.
- Examine both the ecological and the socio-economic impacts, and investigate any shifts to fisherman dependence on new invertebrate fisheries.
- Restore and rehabilitate areas of mangrove forest around Beqa Island to improve reef habitat through catchment management, reinforce storm protection for Beqas villages and increase the islands resistance to the future impacts of climate change.
- Gain further understanding and insight into the megafauna and reef shark populations of Beqa Lagoon and ecological reasoning behind populations.
- To understand the seasonal changes in mating and pupping behaviours in Black Tip reef sharks, in order to gain further insight into the movement patterns within Beqa Lagoon
- To assess the relationship between ecological characteristics and marine megafauna abundance within Beqa Lagoon, in order to inform future community awareness and management practices.

1.5 Phase Achievements

Phase 183 continued the globally recognised coral reef monitoring methodology, Reef Check, using this methodology to examine substrate, fish and invertebrate populations. FJM qualified four new EcoDivers this phase and sent off 45 full Reef Check surveys.

Phase 183 also had the introduction of four new dive sites around Beqa Lagoon thanks to the Sevu Sevus conducted by staff with the village of Naceva.

During this phase we also continued the recently implemented methodology for mangrove nurseries and restoration: involving site scouting, zonation, species-specific planting plans, protective walls, and continued monitoring of growth. A new mangrove nursery site was planted in front of the village of Naiseuseu, complete with protective barriers for future growth monitoring.
2 Training

2.1 Briefing Sessions

- Orientation; staff members show volunteers around the camp and its facilities.
- Bula and welcome; volunteers are introduced to all members of staff and their roles, the local community and local Fijian family members, as well as introduced to Frontiers role on the island and their role in assisting the project.
- Introduction to duties; the volunteers are introduced to how their weekly schedule works, what their duties are and volunteer code of conduct
- Health and safety; health and safety points for camp are outlined and volunteers are then given the Health and Safety and Medical lecture.
- Dive and boat safety; possible hazards of diving are explained as well as safety precautions and equipment which can be used in the event of an accident are explained.

<table>
<thead>
<tr>
<th>Briefing session</th>
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<tr>
<td>Orientation</td>
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</tr>
<tr>
<td>Bula and Welcome</td>
<td>DG/KH/AH</td>
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<tr>
<td>Intro to Duties</td>
<td>DG/KH/AH</td>
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<tr>
<td>Health and Safety/Medical Lecture and Tests</td>
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<td>Dive and Boat Safety</td>
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<tr>
<td>Surface Cover</td>
<td>ALL</td>
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Table 1: Briefing sessions conducted during phase 183

2.2 Science Training

Science Lectures

Research assistants (RAs), with the support of staff members, are fully responsible for all data collection on FJM. Therefore, there is a structured lecture and testing schedule that RAs are required to pass before they begin data collection. The structure of this training has undergone several key changes during the phase which have provided RAs with increased knowledge of general marine ecology and equipped them to conduct surveys to a high standard. The training is predominantly lecture-based, e.g Microsoft Powerpoint presentations and discussion-based workshops, there are also practical elements including; practice surveys, underwater size tests and Snorkel and Dive Point Outs (SPOs and DPOs).

This training is then validated through both theoretical and practical dry and wet ID tests, which require a pass rate of 75% accuracy.

The science lectures given to guide learning are as follows:

- An Introduction to Beqa concepts of traditional fisheries management and additional socio-economic background to the reef surveys
- ReefCheck intro + benthic presentation
- ReefCheck fish
- ReefCheck inverts
- Mangroves Introduction lecture and the introduction of mangrove survey techniques.
- Shark Biology and ID identifying shark species and shark anatomy of local species.
2.3 Field Work Training

To reinforce the lectures and testing there are a series of practical exercises that are carried out during RA training, comprised of (these are ordered sequentially to reflect the chronology of training):

- Snorkel Point Out (SPO) (research staff take RAs snorkeling out to House Reef for a point out of the coral morphologies, substrate types, and fish families).
- Introduction to environmental survey diving (briefing and subsequent dive aimed at teaching RAs conservation diving techniques including buoyancy, how to work safely in a buddy team, how to orient to the transect locations and how the equipment works e.g. reels, dive slates and compass).
- Practice survey dive (collection of benthic data collaboratively with staff members including the initial demonstration of the survey equipment underwater).
- Dive spot test (research staff members conduct an underwater spot test for fish which RAs are required to pass at a rate of approximately 95%), if they do not achieve the sufficient score they will be encouraged to review the fish species and will need to re-take the test.
- Fish size test (RAs are taken out onto house reef and a set of ”dummy” fish are floated by research staff, RAs are then required to fill out a dive slate as to their size and received feedback as to their accuracy).
- Practice survey dive (independently conducted dual-purpose survey during which an RA will take on the role of surveyor 2 and collect fish data which is then verified by the research staff, who was on the dive, afterwards).

2.4 BTEC and other qualifications

Two volunteers and two staff members were qualified as Reef Check EcoDivers by Kristin Hoel during this phase.

2.5 Survey Areas

Beqa lies within Beqa Lagoon, with the coordinates 18°24’5”  178°08’E. The island is located approximately 10 km south of the main island of Viti Levu and has a population of around 3,000 people.

Six survey sites were used for Reef Check data collection, the name of which and their GPS coordinates are shown in table 3 and in figure 4.
<table>
<thead>
<tr>
<th>Site Name</th>
<th>GPS Coordinates</th>
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<tbody>
<tr>
<td>Milky Bar</td>
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<td>Kobe</td>
<td>E 178°03'877&quot; S 18°24'07.5&quot;</td>
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<td>E 178°06'09.9&quot; S 18°24'07.5&quot;</td>
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<td>Vuvale</td>
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<td>Mala's</td>
<td>E 178°05'988&quot; S 18°24'171&quot;</td>
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<tr>
<td>Twins</td>
<td>E 178°06'547&quot; S 18°24'376&quot;</td>
</tr>
<tr>
<td>Crabbie</td>
<td>E 178°03'03.950&quot; S 18°24'412&quot;</td>
</tr>
<tr>
<td>Sese</td>
<td>S 18°25'272&quot; E 178°07'629&quot;</td>
</tr>
</tbody>
</table>

Table 3: Survey sites utilised by FJM and their GPS coordinates

Milky Bar  A near-shore site (0.92 nautical miles from camp) protected from westerly winds but is more prone to northerly, southerly and easterly winds. Average depth is 7.5m and a gentle slope drops down to a depth of 20 m at the edge of the reef. Milky Bar is on the far outer corner of Vaqa Bay and so will encounter freshwater dissipating out of the bay and from the local village of Rukua. The site is frequently visited by Beqa Lagoon Resort and a few other companies for tourism. Milky Bar is a non-tabu reef that is visited frequently by locals for fishing and rubbish dumping.

Kobe  an offshore site (2.5 nautical miles from camp) relatively protected from south easterly, easterly, and north easterly winds, and usually not subjected to strong currents. The reef is large in size and isolated by deeper waters. The reef has an average depth of 11m, with shallows approximately 4.5m and depths of 18m. This site was historically fished for Beche de-Mere, however this is no longer the case given the 2017 Moratorium.

Rabbit  An inshore site (0.44 nautical miles from camp) located within Vaqa Bay close to river outflows. The site is generally shallow with an average depth of 6m dropping down to 12m at the reef edge. The site is not visited for tourism and is a no-take zone.

Vuvale  an offshore site (2.53 nautical miles from camp) relatively protected from south easterly, easterly and north easterly winds and usually not subjected to strong currents. The reef is extremely large, comprising of numerous patch reefs and coral bombies. The average depth is around 8 m dropping down to 16m at the reefs edge. Vuvale is located far away from Beqa and can be difficult to get to because of rough weather conditions. It will encounter no freshwater and there can often be strong currents. The site is not visited for tourism.

Malas  An inshore site (0.56 nautical miles from camp) found within Vaqa Bay and relatively protected from southerly and easterly winds. It is an estuarine environment with three freshwater streams flowing into it. Most the reef is at around 8m, whereas the outer reef is at around 18 m. It is near the local village of Naiseuseu and the site is not visited for tourism and is a non-tabu area. Targeted fish include parrotfish, unicornfish, porcupinefish, rabbitfish, surgeonfish and goatfish.

Crabbie  - An offshore site (2.4 nautical miles from camp) relatively protected from south easterly, easterly and north easterly winds and usually not subjected to strong currents. The reef is medium sized, and isolated by deeper waters. The average depth is approximately 12m, with shallows approximately 6m and depths of 19m and strong currents are rare. This site was historically fished for Beche de-Mer; however, this is no longer the case.
3 Research Work Programme

3.1 Reef Check Monitoring around Beqa Lagoon

3.1.1 Introduction

Worldwide, coral reefs are facing immense degradation due to their sensitivity to anthropogenic and climate-induced changes to their environments (Baker et al. 2008). Since the 1980s, the number of mass coral bleaching events has increased dramatically, mainly due to the global increase in sea surface temperatures (Hoegh-Guldberg et al. 2007). Reefs in Fiji have only experienced two major bleaching events in the last 20 years and have recovered surprisingly well through rapid coral re-growth (Lovell and Sykes 2008). It remains vital, however, to assess the impacts that these bleaching events may have had on fish populations and coral coverage. As expressed in Section 1.1.1, coastal development and the relatively recent introduction of semi-commercial fisheries in Fiji are also playing an increasingly large role in the current health of Fijis reefs, particularly those around Beqa.

Beqa Island lies within Beqa Lagoon, 10 km south of the main island of Viti Levu. The majority of Beqas fisheries represent what is classified by the Ministry of Fisheries and Forests (MFF) as solely subsistence and traditional fisheries and consequently are subject to minimal regulatory measures/legislation enforcement. The MFF currently monitors Beqa as part of their national monitoring plan, however, surveys are only conducted once a year in different areas around Fiji due to personnel restrictions which is too infrequent to provide useful data. Surveying throughout the year would be necessary to monitor fisheries fully and ensure appropriate management strategies are in place.

The most contemporary and comprehensive assessment of Beqas fisheries and resources was conducted in 2012 by the Marine Resource Inventory Survey (MRIS) team. This survey was intended to subsequently feed into a management plan for Beqa and was conducted in Yanuca and Rukua villages. Methodologies utilized included an underwater visual census and socio-economic surveys. It was reported that the main source of income for villagers was fishing and that over 90% of villagers always or sometimes consumed fresh fish in a week. The survey concluded that many of the marine inshore species that usually inhabit the Beqa reef system are under threat due to the continued destruction of the reef system from anthropogenic activities including; pollution from pig farms, reef-walking, over-fishing, anchor damage and the use of destructive fishing methods. It was also reported that many of the reefs in the region have a major algae overgrowth problem with large areas of reef totally covered by algae thought to be attributed to the combination of sewage stimulating algae growth and lack of major algae grazers from overfishing. The reef health-monitoring programme employed by Frontier is designed to collect analogous data on target species, coral type and health and the presence of indicator species.

Frontier utilise the globally recognised reef monitoring methodology introduced by the Reef Check Foundation. Reef Check (RC) is a citizen science based survey protocol designed to be used by volunteer recreational divers who are trained and led by marine scientists. The monitoring program is based on the use of high value, easily identified indicator organisms (Hodgson 1999). Through Reef Check methodology, with sufficient training, practice and feedback, volunteers have been able to help provide reef monitoring information of sufficient quality to augment the limited availability of professional marine biologists (Pattengill-Semmens and Semmens 1998).

3.1.2 Materials and Methods

A full Reef Check survey consists of two 50m transects at different depth profiles along the reef, a shallow transect at 4-6m and a deep transect at 10-12m. The 50m transect is separated into two 20m replicates with 5m gaps between each replicate; this gap is to avoid overlap between surveys and allow for accurate statistical analysis (figure 4).

Each site is surveyed up to two times per week, with surveys conducted between 9:00-10:00am or 14:00-15:00pm, noting that morning surveys are preferred given most fish species are more active during this time. To reduce diver movement bias on fish and invertebrate populations, the transect is laid, and researchers swim slowly back at least five meters away from the laid line to the starting point. This gives fish and invertebrates whose behaviors are more cryptic a chance to repopulate the transect area.
Reef Check survey teams collect four types of data:

- **Site Description:** Anecdotal information, observational, historical and location data are recorded, alongside socio-economic data.

- **Fish Belt Transect:** Four, 5m x 20m long segments are sampled for fish species that are key species in the fishing, aquarium or collector trade. Fish are recorded out to 2.5m either side of the transect line and 5m up, a total of 800m² is surveyed in one transect (figure 5).

- **Invertebrate Belt Transect:** The same four 5m x 20m segments as the fish transect are surveyed for invertebrates. The surveyor swims in an ‘S’ shape out to 2.5 meters either side of the transect, searching for key invertebrates targeted as food species or in the curio trade; paying careful attention to search under rocks and in crevices as many species are nocturnal and will be hiding during the day. Reef impacts, such as bleaching, trash and damage are also recorded.

- **Substrate Line Transect:** On the previous belt transect line, points are sampled at each 0.5m interval along the transect line. The substrate directly below the 0.5m mark is recorded into Reef Check substrate categories.

**Statistical Analysis**

All statistical analyses were conducted in RStudio version 3.5.1 (Team 2017) using the package car to determine whether sites had equal coral cover between shallow and deep transects. Data were first examined to determine whether the assumptions of normality and equal variances between groups were met for the Students T-test. Normality was assessed with a Shapiro-Wilk test, subsequent to testing
equal variances with an F-test (if data were normally distributed) or a Levene's test (if data were not normally distributed). If data were normal and exhibited equal variances, a T-test assuming equal variances was administered, whereas a T-test assuming unequal variances was administered if data were normal but with unequal variances. Data not conforming to a normal distribution were run with the non-parametric Wilcoxon rank sum test. Differences between reefs were determined using a Kruskal-Wallis test. A post hoc Dunns test was utilized to determine which reefs differed from one another in coral cover. Furthermore, differences in hard coral cover were assessed between sites situated inside and outside of the Lagoon, a T-test and a Wilcoxon rank sum test were applied to the data to determine any differences.

3.1.3 Results

To discover the predominant substrate at each site, the percentage of cover for each transect segment was totalled for all transects according to their substrate classification and divided by the number of segments; the substrate type with the largest percentage was then reported. For the predominant fish groups, their numbers were totalled for each survey and divided by the total number of fish. Also reported are the numbers of giant clams, crown of thorns, and tritons documented when all surveys were considered. Lastly, the numbers of surveys at each site were totalled (table 4).

<table>
<thead>
<tr>
<th>Site</th>
<th>Predominant Substrate (%)</th>
<th>Predominate Fish Group (%)</th>
<th>Number of Giant Clams</th>
<th>Number of Crown of Thorns</th>
<th>Number of Surveys</th>
</tr>
</thead>
<tbody>
<tr>
<td>008</td>
<td>Rock (49.00)</td>
<td>Surgeon and Unicorn (45.00)</td>
<td>8</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Crabbie</td>
<td>Rock (40.88)</td>
<td>Butterfly (30.59)</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>House</td>
<td>Rock (34.17)</td>
<td>Surgeon and Unicorn (31.56)</td>
<td>6</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Kobe</td>
<td>Rock (41.44)</td>
<td>Parrot (32.66)</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Malas</td>
<td>Rock (45.30)</td>
<td>Butterfly (35.98)</td>
<td>5</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Milky Bar</td>
<td>Rock (34.63)</td>
<td>Surgeon and Unicorn (50.32)</td>
<td>8</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Rabbit</td>
<td>Rock (29.38)</td>
<td>Butterfly (36.59)</td>
<td>10</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Sandbar</td>
<td>Sand (42.75)</td>
<td>Surgeon and Unicorn (43.66)</td>
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<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Sese</td>
<td>Rock (32.88)</td>
<td>Parrot (27.95)</td>
<td>7</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Sici</td>
<td>Hard Coral (30.63)</td>
<td>Surgeon and Unicorn (34.48)</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Twins</td>
<td>Rock (50.75)</td>
<td>Surgeon and Unicorn (40.85)</td>
<td>7</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Vuvale</td>
<td>Rubble (32.94)</td>
<td>Butterfly (34.75)</td>
<td>10</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 4: General characteristics of each reef

On most reefs, the predominant substrate was rock, although for Sandbar it was sand, for Sici it was hard coral, and for Vuvale it was rubble. For fish, the main groups observed were surgeon, unicorn, butterfly, and parrot. The total number of giant clams and crown of thorns were lower at sites. Overall, only one triton was found during this survey period at Sandbar reef. The number of surveys conducted at each site was low and ranged from 1-5 times surveyed.

There was no significant difference between the mean hard cover percent on shallow and deep transects in the following sites: Crabbie (t-test p-value = 0.709), House Reef (t-test p-value = 0.520), Malas (p-value = 0.701), Rabbit (p-value = 0.271), and Vuvale (p-value = 0.900). There was no significant difference between the population distribution on shallow and deep transects on Kobe (P_value = 0.05) and Milky bar (P_value = 0.05) reefs. These sites were excluded from further analyses between sites. There was a significant difference between the population distribution at different depth profiles on the Twins reef (P_value = 0.05). For the remaining reefs in which coral cover was not significantly different between depths, shallow and deep transect segments were amalgamated for analysis of Scleractinia cover (figure 6). House Reef had lower coral cover than Crabbie, Rabbit, and Vuvale, and Vuvale was borderline significant as having higher hard coral cover than Malas (table 5).

According to the Shapiro-Wilk normality test, coral cover in Vaga Bay was highly abnormally distributed (p = 8.57e-06) but had equal variances (Levene's p-value = 0.709). There was a significant difference between the Scleractinia cover between sites that were located in and out of the bay (P_value = 0.05; figure 7).
Table 5: Results of Dunn’s test depicting differences between reefs in hard coral cover along with their associated p-values. *denotes nearly significant results

<table>
<thead>
<tr>
<th>Reef with higher hard coral cover</th>
<th>Reef with lower hard coral cover</th>
<th>Dunn’s test p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crabbie</td>
<td>House</td>
<td>0.00111</td>
</tr>
<tr>
<td>Rabbit</td>
<td>House</td>
<td>0.04229</td>
</tr>
<tr>
<td>Vulvale</td>
<td>House Malas</td>
<td>0.00021 0.05063*</td>
</tr>
</tbody>
</table>

Figure 6: Boxplot of the average percent Scleractinian cover per transect segment according to reef site. Twins is divided by depth (D = deep, S = shallow) as differences were determined to exist between the two with respect to coral cover.

Figure 7: Boxplot of the average percent scleractinian cover per transect segment according to whether reefs were in or out of Beqa Lagoon.

The average number of butterfly fish (of which banner fish were included) was not statistically different between depths at Crabbie (p-value = 0.591), House (p-value = 0.520), Kobe (p-value = 0.087), Malas (p-value = 0.288), Milky Bar (p-value = 0.655), Rabbit (p-value = 0.612), and Vulvale (p-value = 0.069). At Twins, the butterfly fish distributions for deep and shallow transects were not statistically different from one another (Kolmogorov-Smirnova p-value = 0.510).
3.1.4 Discussion

Reef Check surveys were conducted at twelve sites, although data from four sites had to be excluded from analysis due to a paucity of replicates. For the remaining eight sites, more replicates are needed to better understand population dynamics accurately.

Background coral information

Corals can exhibit several morphologies: encrusting, branching, digitate, tabulate, submassive, massive, singular, and foliose. Encrusting corals mold the substrate of which they grow over, branching corals have divisive projections akin to terrestrial branches, digitate corals are comprised of finger-like projections absent of branching, tabulate corals mimic tables in that they are horizontally-compressed colonies with a singular attachment point to the substrate, submassive corals are large colonies possessed by irregular knob-like columns, massive corals resemble boulders, solitary (mushroom) corals exist as free-living entities, and foliose corals are comparable in appearance to lettuce (Monitoring coral reefs for global change 1993).

Corals can reproduce either asexually or sexually. Asexual reproduction results in genetically identical offspring that is produced through budding or fragmentation. Budding occurs when a coral polyp detaches from the parent colony to form a nascent colony, whereas fragmentation occurs when broken fragments anchor themselves once settled onto the substrate. Corals can either be gonochoric or hermaphroditic, and they sexually reproduce either through brooding or broadcast spawning. Corals broadcast spawn simultaneously about once a year by expelling egg and sperm bundles that then float to the surface where fertilization ensues. The fertilized eggs then mature into planktonic planulae that eventually settle to the substrate, where they acquire their symbiotic zooxanthellae and transform into a single polyp that will mature into a colony through clone formation. Alternatively, fertilization occurs internally in brooding corals, and the embryo matures into a zooxanthellae-harboring planula. Upon release, the planulae are ready to settle (SECORE 2018).

Four life history strategies of scleractinian corals were developed by analyzing eleven different species traits encompassing morphology, reproductive strategy, size, growth, etc. Stress-tolerant coral species have the most varied number of different species, and their long lifespans that allow for the perseverance of these species in less than ideal environments even when recruitment is unsuccessful. They grow at a slow rate to form generally dome-shaped colonies and are highly fertile broadcast spawners. Competitive species outperform others by more effectively utilizing resources in their environment. They're fast growing, broadcast spawning species that form either plating or branching colonies in shallow environments. Although they can out-shade other species, their growth morphology leaves them vulnerable to storm damage and bleaching events. Weedy species are fast-growing, brooding corals that form smaller colonies than species in other categories. Their repertoire of species traits is also more diverse than other categories, and thus may be the reason why these species can successfully establish themselves in disturbed environments. Lastly, generalist species incorporate aspects from the other groups. They grow at an intermediate rate to form large colonies with branching, plating, or domed morphologies (Darling et al. 2012).

Corals as determinants of fish assemblages

By contributing to the structural heterogeneity of reefs, scleractinian (hard) corals influence fish assemblages by providing refuge and resources that modulate interactions between and within species (Darling et al. 2017). Furthermore, the concurrent increase in protective pockets as structural complexity increases allows for the co-existence of predator and prey by decreasing the likelihood one will encounter the other; encounters with competitors is likewise decreased (Komyakova et al. 2018). Therefore, as structural heterogeneity increases, fish diversity and numbers generally increase as well (Darling et al. 2017; Komyakova et al. 2018). Increasing coral size can also equate to a larger, more diverse fish community, which is presumably due to the fact that the increased availability of living space makes niche partitioning possible (Komyakova et al. 2018).

In a study conducted by Darling et al. (2017), heterogeneity was one of the predominant determinants of fish diversity, population numbers, and trophic assemblage. Other contributing factors (but to a far lesser extent) were estimated percent of total scleractinian cover, life-history strategy, coral growth and reproduction attributes (maximum size, yearly growth, spawning method, morphology, and fertility), and the consortium of coral attributes within a reef. However, the small influence on fish assemblage that these factors had may be due to the fact that only fish greater than 8 cm in length were surveyed.
Moreover, structural heterogeneity was in part determined by the amount, morphology, and growth strategy of hard corals (Darling et al. 2017).

As a branching morphology is associated with an increase in fish species richness, some sites may have differed in the number and size of branching corals. Eight branching species of coral in Australia typically hosted unique fish consortia, with the most diverse and abundant fish assemblages generally affiliating with species of coral that possessed intermediary inter-branch and total branch length. The extent of branching in corals presents a trade-off for fish species. Corals with extensive branching presumably decrease predation by providing an avenue of escape for fish sufficiently small enough to penetrate the small spaces. Alternatively, loosely branched corals likely increase predation as larger fish are able to navigate the corals inner network of spaces. Therefore, corals with intermediate branching attributes may allow for the most diverse fish communities (Komyakova et al. 2018).

Even after death, hard corals influence fish by leaving behind their calcium carbonate skeletons that are then modified by accretion and/or erosion. Therefore, even in the event of widespread coral demise, fish communities can remain relatively unaffected because of this. However, the vitality of fish assemblages requires living coral, as reef accretion and the integrity of structural complexity necessitates it (Darling et al. 2017).

However, results may be influenced by factors associated with sampling resolution. Trends may not be apparent at smaller scales due to unequal species distributions, whereas the unequal distributions may become balanced at a larger scale, but other physical parameters exert their influence (Komyakova et al. 2018).

Amongst other contributing processes, abiotic factors likely influence fish assemblages by driving coral morphology. Hydrodynamics theoretically select for structurally rigid colony morphologies that are able best suited to withstand waters potentially damaging effects (boulder, encrusting). With increasing light, colonies with possess an increase in the tissue exposed to the sun (i.e. tabulate). If colonies are subjected to aerial exposure, lateral growth along with limiting the surface area per unit volume would be the expected response (encrusting, colonies with morbid apexes). In regions of high sediment load, selected morphologies decrease the quantity of sediment per area of surface with polyp size taken into consideration (branching) (Chappell 1980).

**Depth differences**

Corals display depth zonation due to the effect increasing depth has on temperature, hydrodynamics, nutrient availability, and light. Light is a structuring factor in the depth distribution of corals as their symbiotic zooxanthellae necessitate solar irradiation for photosynthesis. Corals have evolved several adaptations to increase the efficiency with which light is acquired due to the exponential decline in light associated with increasing depth: malleable morphologies, different fluorescent pigment repertoires, and symbiosis with different zooxanthellae clades (Bongaerts et al. 2015).

The lack of detectable differences in coral cover between shallow and deep sites (with the exclusion of Twins) indicates that perhaps the coral species residing at these sites are able to colonize a wide depth distribution by changing their algal symbionts. Corals that generally harbored significantly different Symbiodinium types over increasing depths were able to inhabit a greater depth range than coral species that did not. This phenomenon is most likely due to the fact that different Symbiodinium types increase the adaptability of the coral host to particular depths (Bongaerts et al. 2015).

Depths effects on solar irradiation also influences algal distribution (Williams et al. 2013), and algae can have detrimental effects on corals (Rasher et al. 2011; Smith et al. 2006). Of five corals exposed to algal exudates, all bleached and suffered complete mortality. However, if the seawater was treated with the antibiotic ampicillin, the corals remained healthy. Therefore, the authors postulate that DOC derived from algal polysaccharides caused anoxic regions to develop as a result of enhanced bacterial growth on the corals surface (Smith et al. 2006). Of the eight different algal species tested in a study conducted by Rasher et al. (2011), several were able to induce bleaching, a decrease in photosynthetic efficiency, and/or mortality in three different species of coral by the release of allelochemicals. However, whether the algal species induced an effect (and the extent of severity) was dependent on coral species (Rasher et al. 2011). The depth differences at Twins may have been due to a difference in algal abundance, and/or different corals with varying susceptibility to algal effects.

**Coral cover differences in bay location**

Differences in coral cover between bay locations may have resulted from the disparity in sedimentation
and/or type of sediment between sites; the bay is generally more sediment-rich than sites located outside of the bay. Sand-size particles are generally characteristic to offshore regions, whereas silt-sized particles are characteristic to inshore regions. Consequently, sedimentation stress may be a function of sediments shore proximity (Weber et al. 2006). At 22 reefs situated around 11 Caribbean Islands, the proportion of terrigenous sediment was inversely correlated with coral cover, and which species of coral was present significantly depended on whether sites had a low (0-14%) or high (29-95%) abundance of terrestrial sediment. Yet of the fifteen coral species contributing to almost all of the observed differences between these sites, only one was significantly affected when the percentage of terrestrial sediment was considered. However, the amount of fine-grained sediment may be a poor indicator of the magnitude of terrigenous input since no significant proportional correlation was found between the two in samples collected from the Caribbean Islands of Saint Lucia and Saba. Classification of the proportion of fine-grain sediment (low: 0-0.8% vs. high: 2-18%) did not significantly affect which coral species were present, although this may be due to the fact that the amount failed to reach a damage-provoking threshold (Bgin et al. 2013).

Particle size also determines the severity of sedimentation damage to corals due to the corresponding extent of adsorbed nutrients. Silts adsorb more microorganisms and particulates than sand particles due to their larger surface area to volume ratio and are thus more adhesive. This adhesive propensity, along with a thicker settling layer, may explain why *Montipora peltiformis* fragments were more effective at eradicating nutrient-poor, sandy sediments. Furthermore, silt negatively impacted photosynthetic yield of this coral species, with maximum stress precipitating in less than two days; fine and medium-sized sands had no demonstrable effect on yield. However, although sands did not photophysiological stress treated corals, bleaching was later apparent and none of the treated corals returned to baseline conditions (Weber et al. 2006).

Coral mortality from sedimentation may derive from increased bacterial growth arising from adsorbed organic matter, zooxanthellae expulsion [due to anoxia stemming from photosynthetic obstruction], and/or hydrogen sulfide resulting from anoxic sulfate reduction. Yet Weber et al. (2012) discovered that the cause of mortality in *M. peltiformis* was anoxia and increased acidity stemming from microbial respiration of organic-enriched (0.3% and 0.6%) sediments. H2S concentrations only became toxic upon respiration of necrotic tissue and mucus, and although H2S accelerated the mortality rate, death precipitated in its absence. Photosynthetic yield, necrosis, and H2S were significantly affected by both exposure time and the concentration of organic carbon within the sediments, whereas oxygen and pH were solely dependent on the organic carbon concentration. If corals ferment in anoxic conditions, death may eventually result through increased cell acidification. Alternatively, cells may lose control of their pH if fermentation-acquired energy does not offset the energy required to sustain cellular pH. Sufficient carbon enrichment may also favor the growth of certain bacterial groups to the detriment of others (Weber et al. 2012).
3.2 Rehabilitation and Restoration of Mangroves around the Beqa Island Coastline

3.2.1 Introduction

Mangrove forests are coastal habitats that occur on low energy and sedimentary shorelines of the tropics, between mean and high tide elevations. To deal with environmental stresses from their intertidal habitat (e.g., high salinity, substrate mobility, low oxygen conditions of the soil and poor nutrient availability) mangrove species developed specific physiological and morphological adaptations (Molony and Levin 1995; Mangroves 2003). Among these adaptations are aerial roots and different halophytic strategies where each species is restricted to a certain area between the high and low tide mark for its survival (Mangroves 2003). Mangrove species show unique reproductive strategies and many mangroves develop viviparous seeds called propagules. Vivipary is a characteristic in which the propagules develop early and germinate while still on the parent tree receiving food to keep the propagule healthy for a long time after they fall into the water. These propagules are buoyant and are dispersed by water until eventually they strand and, if conditions are right, will develop into adult trees.

Mangroves are one of the most productive ecosystems on the planet. Ecosystem services they provide include shoreline protection where they act as natural barriers to wave action, shore stabilization, and erosion control; provisioning services include raw materials such as timber. Perhaps most importantly mangrove forests support the primary productivity and biological diversity of coral reefs by acting as nursery, breeding and spawning habitats for offshore species. In this way mangrove forests are also a fundamental support to offshore fisheries. Finally, mangrove forests offer cultural ecosystem services such as attracting tourism which is a large potential source of income (Salem and Mercer 2012).

Fiji has the third largest mangrove area (517 km$^2$) in the Pacific Island region, after Papua New Guinea (4265 km$^2$) and the Solomon Islands (525 km$^2$) (World Mangrove Atlas 1997). Mangrove areas are one of the better wetland types inventoried in the Pacific Islands (particularly in Fiji), though the information sources are fairly dated (“Review of wetland inventory information in Asia” 1999). The mangrove area was estimated by Spalding et al. (1997) from a forest cover map prepared by the Ministry of Forests of Fiji and based on a 1985 survey, with mangroves distinguished using the Fiji Forest Inventory carried out in 1966-1969. This gave a total mangrove area for Fiji of 517 km$^2$. Largest areas are on the southeastern and north-western Viti Levu shorelines, and the northern shore of Vau Levu (Richmond and Ackermann 1974).

The mangrove flora in Fiji is floristically simple and consists of only four species in two genera; black mangrove (Dogo in Fijian) (Bruguiera gymnorrhiza) and red mangrove (Tiri in Fijian) (Rhizophora stylosa, Rhizopora samoensis, and Rhizopora x selala). Rhizophora x selala is a sterile hybrid formed by a cross between R. stylosa and R. samoensis. There is one associate mangrove species, the Fish poison tree (Barringtonia asciata), which can be found by the high tide line and seems to cover approximately 11% of the wetland in our previous study area. Studies conducted by Frontier in 2016 suggest that the representation of true mangroves in the area is predominantly Bruguiera gymnorrhiza (representative of 47% cover) and R. stylosa, R. samoensis, and Rhizopora x selala (representative of 37% of cover). Interestingly, 21% of the Rhizophora species were Rhizophora x selala. The coverage of this sterile hybrid could potentially have implications for the availability of natural propagules in Beqa.

Mangrove wetlands are one of the most threatened natural communities worldwide, with 50% of the global area lost since 1900, with 35% lost just in the past two decades (Food and United Nations (FAO) 2007; World Atlas of Mangroves 2010). Threats include expansion of residential and tourism developments, pollution, estuarine dredging for flood mitigation, drainage activities and sand mining (Watling 1985). In Fiji, an estimated 1.5 to 4.5 thousand cubic meters of mangroves are harvested each year, for poles, charcoal and firewood (Jaffar 1994). This is reduced from past levels, owing to increased use of imported petrol. Threats to mangroves identified in Fiji were classed as high, medium or low. High threats included: coastal development, dumping and improper waste disposal, reclamation and collection of firewood. Medium threats included: overfishing, watershed alteration and coastal sedimentation, and industrial and hazardous waste spills. Low threats included: global warming and sea level rise, aquaculture ponds, sewerage, pesticide runoff, animal waste, introduced species, logging, and bio-prospecting for natural products (Ellison and Fiu 2010).

Besides anthropogenic destruction, the reasoning behind mangrove degradation is often multi-faceted with a combination of several factors including hydrological change, subsidence, climate variability and storm events (Lewis 2011 et al. 2016). Often stressors that cause only apparently slight changes will manifest over a few years and gradually lose the percentage canopy cover will alter the physical environment until it becomes such that no individuals can survive (Lewis 2011 et al. 2016). Changes in a
single individual stressor pathway (e.g. slight changes in hydroperiod) can eventually lead to mortality of a whole entire mangrove ecosystem.

Mangrove ecosystems are sensitive to climate change impacts, particularly to associated relative sea level rise. Intertidal mangroves are most extensively developed on sedimentary shorelines, where mud accretion determines their ability to keep up with sea-level rise (Gillman et al. 2008). The IPCCs 4th Assessment projected a global sea level rise of 0.18-0.59 m by 2099 (1.5-9.7 mm per year), and mud accretion rates are usually less than this, resulting in dieback at the seaward edge, and inland recruitment (Gillman et al. 2008). Rise in temperature and the effects of increased CO2 levels should increase mangrove productivity, change phenological patterns, and continue the expansion of mangrove ranges into higher latitudes (Gillman et al. 2008). Rehabilitation of degraded mangrove and inshore reef areas will most likely increase their resilience to climate change effects.

Fiji has a relatively small area of mangroves compared to Asian countries and so mangrove restoration research is crucial as loss of the services provided by these ecosystems may have a disproportionately large effect on Fiji's coastline. Threats include expansion of residential and tourism developments, pollution, estuarine dredging for flood mitigation, drainage activities and sand mining (Watling 1985; “Mangrove ecosystems of Asia and the Pacific.” 1985; Singh et al. 1996). Site selection for rehabilitation projects should consider value for money, the level of community or stakeholder support, benefits to adjacent systems and the relative risk of sea-level rise. Any program should initially remove the stress that caused decline, decide on whether to use natural regeneration or active replanting techniques, in which case use of local sources of seeds or juveniles will reduce genetic variation across Fiji.

Mangroves in Beqa are predominantly located within bay areas in which human settlements are most likely to occur. Together with the added impact of land clearing using slash and burn techniques this decrease is likely to continue (personal comms: 2017). The combination of land clearing as well as mangrove deforestation will most definitely have measurable impacts on adjacent reefs. Replanting mangroves is often unsuccessful as their removal changes the hydrology and chemistry of the soil, therefore the need for protecting existing mangroves should be emphasized over replanting. That said, community sentiment is overall highly positive towards mangrove restoration and rehabilitation in Beqa, particularly on the west side where FJM is located. This can also be seen among villagers in Ravi Ravi, who have re-planted areas that have previously been cleared. As mangroves exist on the land-water interface, jurisdiction over them is highly complex and all intertidal and submerged land in Fiji is technically owned by the state. However, Fijians do have customary rights of use to the living resources in these intertidal areas and therefore community engagement with replanting processes is of paramount importance (Thaman 2008).

The mangroves of Rewa delta (the province in which Beqa is located) were listed as needing urgent consideration for biodiversity conservation by WWF (Ellison and Duke 2010), with Beqa only currently having 72 hectares of mangrove forest on the island (Ellison, 2010). In light of Cop23 in 2017 in which Australia provided $6 million to support protection of carbon sequestering ecosystems including mangroves, the villages of Beqa are asking the Rewa provincial council to provide extra funding to build sea walls, as many villages such as Rukua and Naiseuseu are deemed to be at high risk from climatic events, such as cyclones.

Through planting and tending to mangrove propagules, and continually monitoring their growth, FJM aims to explore mangrove restoration not only as a method for protecting coral reefs and improving marine ecosystems, but also as a more long-term, sustainable method of storm protection for vulnerable coastal communities facing the future impacts of climate change.

### 3.2.2 Materials and Methods

#### Site Selection

Selection of site will primarily rely on the desires and needs of local villages to rehabilitate mangroves in proximity to their village to increase storm protection and increase fish yields in the future. Before beginning rehabilitation at a site, a Sevu Sevu (A Fijian permission ceremony) must be conducted with prospective village to explain the intentions of the project and ask for permission to conduct work upon the villages land.

There are multiple criteria that need to be considered for successful mangrove rehabilitation:

- Establish and understand historical mangrove growth in the area, identifying areas of past mangrove extent through socio-economic data collected in the local villages. For a recommended questionnaire to complete with local villagers.
• Determine the causes of mangrove deterioration, their current stressors and land use practices. If the stressors are ongoing, this must be addressed before restoration can begin (Lewis 2005).

• Understand species ecology in the area, such as reproduction and propagule distribution to ensure propagules are planted in the most appropriate environment (Lewis 2005).

• Locate a reference forest and propagule source. Assess the presence of propagules and potential for natural propagule establishment through beach walks in the rehabilitation site.

• Planting mangroves should only be considered if natural recruitment cannot be promoted either because of propagule limitation, limited seedling establishment, low rate of stabilization or mangroves not taking root (Lewis III and Marshall 1998).

• Understand hydrological patterns in the rehabilitation site as necessary for species distribution dependent on elevation gradient in the area (Lewis III and Marshall 1998; Lewis 2005). Locate areas of fresh water influx; the site should be within close proximity to a fresh water influx (approximately 50-100m to the start of the restoration site). Identify and measure Mean Sea Level (MSL) and the neap tide boundary (The highest low tide in a tide cycle). Planted mangroves must be exposed at neap tide for successful restoration. Mangroves prefer areas above MSL which is tidally less than 30% of the time (figure 8). The lower muddy parts with sea grass beds are often inundated for too long (PTFCF and ZSL 2015).

• Divide rehabilitation area into zones according to mangrove habitat; seaward and landward (PTFCF and ZSL 2015). Identify species specific substrate preferences, such as mud, sand, or rocks.

• Involve communities in the project from the start, allow them to have substantial input in site selection while offering some scientific guidance, to ensure a long-term sustainable project further than FJM; local communities must have complete ownership of the restoration project.  

Mangrove Quadrants

The sites for mangrove restoration are chosen by assessing the presence of propagules and potential for natural propagule establishment. If there is a reasonable number of propagules and natural recruitment, planting may not be the preferred rehabilitation method. If propagules are present and no natural recruitment is taking place the reasons for why they are not recruiting naturally should be assessed (Lewis III and Marshall 1998; Lewis 2005). If these stressors can be removed, natural recruitment should be reassessed after removal . If necessary natural hydrology needs to be restored to promote natural recruitment (Lewis III and Marshall 1998; Lewis 2005). Mangroves can survive in the rehabilitation area for years as stunted mangroves or die off if hydrological conditions do not support mangrove growth.

The chosen number of quadrants will be adapted to the size of the site and while the project develops. Building protective barriers is essential in order to grant a level of protection to propagules in rougher weather. The walls were built from a combination of cinder blocks, chicken wire, and naturally occurring rocks; up to a height of minimum 50cm, along the length of each quadrant. The 2m gap between each wall should, over time, create channels that will help direct water flow to the mangroves sprouting roots. This is especially essential during the first phase of planting as this is when propagules are most vulnerable to being washed away (figure 9). Quadrants will consist of approximately ten rows with ten propagules planted in each row. All four corners of each quadrants will be clearly marked with cinder blocks, which line can be attached to when monitoring to clearly identify zone boundaries. The boundary of the mangrove area will be marked by attaching fishing buoys to cinder blocks to warn off boat traffic of areas not to cross over (figure 9).
Planting

The preferred mangrove seed stock is naturally occurring, live propagules which are collected directly from the mangrove trees when ripe or from the beaches close to the reference forest. Propagules are assessed for viability; key elements to look out for are an intact sprout and no breakage of the propagule. Propagules are kept in fresh water for a minimum of three days and maximum of four weeks after collection. If they are still deemed viable after this, they will be planted into the site. The mangrove species planted will depend on propagule availability according to season. Preferably the two species of red mangroves should be planted every other season.

The propagules will be planted in a zigzag pattern to simulate a random pattern, with a two-meter gap between rows and 1-meter gap between propagules on the same row (figure 14). Normally propagules should be planted with a two meter gap between them to avoid stunting and to avoid artificial channelling between roots. By planting mangroves with one-meter gaps it will account for plants that will die or be washed away. If plants survive for 1-2 years and there is still only one meter gaps between them these plants should be relocated to new rehabilitation sites to prevent stunted growth, artificial channelling between roots and competition for the remaining mangroves. This approach allows quadrants to function as a seedling source for future rehabilitation sites. After one year there should be a two meter gap between the planted mangroves to allow for natural mangrove recruitment ("Ecological mangrove rehabilitation, a field manual for practitioners").
Other seedling sources that can be used instead of planting propagules directly are mangroves grown in the bottle nursery, wildlings (seedlings and saplings found growing under the parent trees, these are unlikely to survive to adult mangroves and can be relocated to rehabilitation sites), spreading propagules at the water surface to promote natural recruitment and raised seedlings in natural nurseries (Lewis 2005). Bottle nursery propagules should be left to grow for approximately three months or more in the bottles before being transplanted into a site. When nursery mangroves are relocated they tend to experience stress and can go into shock so this method is not a priority (“Ecological mangrove rehabilitation, a field manual for practitioners”). Nursery mangroves can be relocated after they have reached a height of a minimum of 70cm.

To increase chance of survival after planting, the hole size should be 1.5 times wider and 1.5 times deeper than the root ball. To avoid stunting roots should dangle freely inside the hole. Squashed roots can cause stunted growth or even kill the plant. The roots are then covered with loose soil/mud/sand, but not packed too hard because this eliminates the air pockets needed for the roots. No fertilizers are needed for mangrove planting.

**Monitoring**

We aim to provide information on the status of Beqa mangrove rehabilitation and contribute data to inform international mangrove rehabilitation. Long term monitoring in rehabilitation programs are rare (“Ecological mangrove rehabilitation, a field manual for practitioners”). Planted mangroves should be monitored for a minimum of three years, but preferably five years (“Ecological mangrove rehabilitation, a field manual for practitioners”). Planted mangroves can survive on their energy reserves for up to a year or two and appear healthy even when stressed and then die off within three to five years (“Ecological mangrove rehabilitation, a field manual for practitioners”). Natural regeneration monitoring should be undertaken for six months up to two years. For the first year or two a minimum of one monitoring event should be undertaken every phase to detect any issues, to evaluate progress and make early stage corrections (“Ecological mangrove rehabilitation, a field manual for practitioners”). More frequent data collection events will take place based on the availability of volunteers and which projects are currently running. After two years, data can be collected less frequently.

Fixed photo stations should be selected for each section of the rehabilitation area to record visual progress over the years and should also be clearly marked with cinder blocks. Photos can be taken each phase, or every half year or each year, possibly before and after each cyclone season. To monitor survivability, recruitment, density and species composition, during every monitoring event the number of propagules should be recorded according to species within a quadrant. Any natural recruitment within a quadrant should also be monitored separately from planted mangroves. Monitoring the survival of planted mangroves is especially important within the first year or two to record how many mangroves
have survived and how many have died or been washed away. If less than 50% of the mangroves planted survive, a scientific explanation for the low survival rate should be presented. For example, is the area being drained at low tide properly or are the propagules protected effectively? Depending on the reason for low survivability, replanting should be considered within the first one to two years. After one to two years mangrove survivability and density should naturally decline over a period of 0-21 because of competition ("Ecological mangrove rehabilitation, a field manual for practitioners"). A 10% survivability in the future can be considered a successful rehabilitation project (PTFCF and ZSL 2015).

When monitoring growth, the height in centimetres and the number of leaves of every single mangrove within a quadrant should be registered according to mangroves species. A single mangrove height should be measured from substrate to the sprout tip. The number of propagules with leaf damage should also be recorded. After data collection the average height and average number of leaves within a quadrant should be recorded in a data sheet.

A single mangrove height should be measured from substrate to the sprout tip. If a mangrove is crooked, the mangrove should be measured along the stem and not just height from substrate. Measurements should be taken every phase and can be measured less frequently in the future, but should preferably be monitored for 3-5 years ("Ecological mangrove rehabilitation, a field manual for practitioners"). Record elevation and GPS coordinates in the middle of each quadrant.

When the mangroves reach a height of 1.3 meters their diameter should be measured and they can be categorized to have either a diameter at breast height (DBH) above or below 2.5cm. When the mangroves have grown in size and have a diameter at breast height (DBH) above 2.5cm which could take 3-5 years relative dominance can be measured and the trees can be categorized into size groups; seedling, sapling or tree. A rehabilitation goal after 7-10 years can be a canopy cover of 75%. Measure present cover according to species ("Ecological mangrove rehabilitation, a field manual for practitioners").

Additional data that will be recorded per monitoring event for individual mangroves include: date, month, phase, location, natural or planted, quadrant, row, propagule number, condition, species, height in cm, number of leaves, leaf damage, classification, category, origin, elevation, GPS coordinates, wall height, wall length, comments. Data recorded per quadrant include: phase, month, date, location, quadrant, category, species, number of propagules, number of propagules dead and missing, number of natural recruitment, average height within a quadrant, average number of leaves within a quadrant, number of propagules with leaf damage, number of seedlings within a quadrant, number of samplings within a quadrant, number of trees within a quadrant, number of rows within the quadrant, number of propagules per row, origin, wall height in cm, wall length in meters, elevation and GPS coordinates.

Maintenance should include regularly clearing any debris, garbage, filamentous algae or marine life attached to the mangroves. Algae and other debris weigh down the plant, which can choke and break the mangroves (PTFCF and ZSL 2015).

Characteristics of the rehabilitated mangrove area can be monitored such as fauna, flora, and physical environment in comparison to the reference forest. Routine sampling of biota such as fish, invertebrates or birds is not recommended by MAP Indonesia. Observational monitoring can on the other hand be useful such as snorkel surveys or benthic walks during low tides ("Ecological mangrove rehabilitation, a field manual for practitioners"). While rehabilitation is progressing, a visual presentation of data should be developed in an understandable format for the local communities ("Ecological mangrove rehabilitation, a field manual for practitioners").

**Statistical Analysis**

All statistical analysis will be undertaken using the statistical program R (Team 2017) through the R studio interface (Team 2017). The data sheet setup will be made in excel in a compatible format with R studio. Growth rate: Use height of mangroves and number of leaves to measure the growth of the mangroves over time. Preferably compare species separately since *R. stylosa* propagules are longer than *R. samoensis*. Compare height and number of leaves between monitoring events using a t-test to see if there has been any real change in the data or if the change is simply caused by sampling variation. A paired sample t-test can be used to analyse trends over time. ("Ecological mangrove rehabilitation, a field manual for practitioners"). Survivability/density: Use the number of mangroves over time within a quadrant to evaluate the survivability of the propagules. The same tests can be used as for analysing growth rates ("Ecological mangrove rehabilitation, a field manual for practitioners"). All confidence levels should be 95% or $p \leq 0.05$ ("Ecological mangrove rehabilitation, a field manual for practitioners"). Presentation of data: Data will be presented using line graphs to show trends over time either using R or excel.
Summary

- Understand the hydrology of the reference forest and the rehabilitation site.
- If mangroves are not naturally occurring, find out why.
- Correct conditions so they are suitable for mangroves.
- Mangroves should be planted above neap tide or above mean sea level.
- Monitor planted mangroves to detect issues and make corrections (PTFCF and ZSL 2015).

3.2.3 Results

Pictures show current visual status of rehabilitation area in Naiseuseu for future reference (figure 10). The height, species and number of leaves of every sapling in the Naiseuseu area was recorded once in phase 183.

![Figure 10: Pictures of the rehabilitation area showing visual status](image)

Survivability

The survivability of planted mangroves reveals a declining trend between phases 182 and 183 (figure 11). In total there was a 63% survival rate across all zones, however the losses were concentrated in zones 2B and 4B. Both were planted in phase 182 and mark the current boundaries of the Naiseuseu rehabilitation area as the land past this is deemed unsuitable for planting. No effort was made to replant as, especially in zone 4B, the tidal current was noted as likely too strong for propagule survival.

Mangrove growth

The average height of the planted mangroves shows an increasing trend between phase 181 and 182 (figure 12). Quadrant 1A, 2A and 3A show a similar increase in mangrove growth (17%, 19% and 12% respectively) while 4A heights stay more or less steady (-1%) and 2B grows more rapidly (45%). 3B and 4B show markedly anomalous growth rates, due to the lack of survivors in 4B and small number of saplings in 3B.

The average number of leaves show an increasing trend between phase 182 and 183 (figure 13). Quadrants 1A, 2A, 3A and 4A show a similar increase in the average number of leaves (1.3, 1.5, 0.7 and 0.8 respectively) while quadrant 2B had a greater increase (4.6). Again, due to the small/non-existent nature of saplings in 3B and 4B they remain anomalous.
Figure 11: Survivability of mangroves planted in phase 181 and 182 at the Noseuseu rehabilitation site. Zone A mangroves were planted in 181, B in 182. This includes both species, samoensis and stylosa.

Figure 12: Average height development between phase 182 and 183 according to quadrants, split according to species.

3.2.4 Discussion

Survivability
Results show that mangroves were lost between 182 and 183. This decline is probably due to propagules being washed away or rough seas that bring in drift wood that damage propagules during tide changes. The deterioration of the sea wall over time may also affect mangrove survivability. The mangroves planted in phase 181 (those in zones A) had better survival rates, probably due to older, more established root systems. Of those planted in phase 182 (zones B), one was completely lost (4B), one had eight survivors (3B) and the largest, 2B, had only a 30% survival rate. These zones are more exposed than the A zones were, and mark the limit of the land thought suitable for rehabilitation, indeed it seems that the areas 3B and 4B themselves were unsuitable, and as such are not being reseeded. Mangroves are highly affected by microclimates that determine their survivability. The low survivability demonstrates the importance to plant a considerable number of mangroves to account for the natural decrease in the early stages. After a longer time period, mangroves are expected to decline. In a successful rehabilitation area 90% of the mangroves planted will have died off because of competition for nutrients and sunlight ("Ecological mangrove rehabilitation, a field manual for practitioners"). In the start phase on the other hand a 50% survivability between phases is preferable. The survival of those mangroves planted in zones 1A, 2A, 3A and 4A since phase 182 means that reseeding is unnecessary, and attention should be better focused to new rehabilitation areas. Mangroves planted in phase 181 and 182 are currently dominated by *Rhizophora samoensis* because of the propagule deficiency of *Rhizophora stylosa*.

The Naiseuseu rehabilitation site is located approximately 500m from Naiseuseu village. The village had a meeting about the mangroves and has requested a wish for us to plant mangroves closer to their village in front of their sea wall. Phase 183 witnessed the beginning of this attempt. Approximately 120 propagules were planted in three zones, each with a sea wall and a gap of six meters between each zone at the behest of the villagers. Survival rates, as well as the appropriateness of the chosen area will need to be monitored in coming phases. Successful saplings from the Nursery areas will be transferred to this area in front of the village as well, where they provide most benefit to the community.

**Mangrove growth**

Results show that mangrove height increased between phase 182 and 183. The growth rate of the mangroves shows similar trends as the 181 report measuring plants in the nursery. Some of the mangroves planted would have been more developed than others since the quadrants were re-stocked at different times when the first quadrants were set up. Preferably the mangrove height should be compared according to species as well as over time. Species should be separated because the length of the species propagules varies largely, with *Rhizophora stylosa* having longer propagules than *Rhizophora samoensis*.

During measure events it was obvious that plants can be largely affected by algae which limit the growth of the mangrove. Regular maintenance at the rehabilitation site and nursery site is important.

**Future work**

- Continue monitoring of the rehabilitation site and take up monitoring again of the nursery site.
• Evaluate the nursery mangroves as suitable for relocation.
• Continue rehabilitation close to Naiseuseu.
• Mangrove rehabilitation with the Dakuni village.
• Pictures should be continued to be taken in the future for a visual development of the rehabilitation area over a longer period of time.
3.3 Assessing Black Tip reef shark (*Carcharhinus melanopterus*) nursery areas in Beqa Lagoon

3.3.1 Introduction

Globally, the trophic importance of sharks is high, as they are classed as ecosystem engineers that is, they have an above average effect on ecosystem processes (Killam and Parsons 1989), since as top predators in reef ecosystems, their removal can result in major trophic collapse. As predators, they shift their prey’s spatial habitat, which alters the feeding strategy and diets of other species. If sharks were to be removed from the coral reef ecosystem, large predatory fish, including groupers (ReefCheck species), will increase in abundance and feed on herbivores. Less herbivores will eventually result in macroalgae expanding and coral will no longer be able to compete. Coastal elasmobranchs represent an important component of marine ecosystems, but their populations have become increasingly threatened due to overfishing through both industrial and artisanal fishing (J. et al. 2015). This makes it imperative to protect them to help further preserve the health of reefs around the world and their associated species.

There are approximately 440 species of shark globally, and Fijian waters play host to a wide variety of elasmobranch species. They range from large, highly migratory sharks to coastal dwelling rays and reef sharks. Beqa Island is known globally due to the presence of several baited shark dives at areas located around the island and in the marine protected area Shark Reef Marine Reserve, which was established in 2003 (Brunnschweiler 2009). These baited dives attract tourists due to the presence of up to 8 different shark species, including bull sharks (*Carcharhinus leucas*), however outside of scientific research conducted during these dives there is a paucity of inventories that detail the elasmobranch species observed around Beqa. Elasmobranch species counts and inventories serve as a vital baseline for future studies and can be used to estimate the impact of changing fisheries and protected area management.

Capturing data about elasmobranch species is vital since they exhibit a k-selected life-history. K-selection is one of two evolutionary strategies and is characterized by long gestation periods and slow maturity rates. Having this life-history pattern makes them highly vulnerable to over-exploitation. Globally, sharks are threatened by targeted fisheries and through high by-catch in other industrial and small-scale fisheries. Within Fiji there is limited information on artisanal and subsistence shark fisheries, with mixed communications on whether Fijians would actively target shark species or whether they are considered tabu e.g. a restricted species that is forbidden to catch through traditional culture.

During scientific survey activities FJM regularly encounter two species of reef sharks, blacktip (*Carcharhinus melanopterus*) and whitetips (*Trianodon obesus*). Both represent coastal species found in tropical and sub-tropical reef systems. Blacktip adults can reach a maximum length of 1.8m and are easily recognized by the black tip and white sub-marginal band on their first dorsal fin (Castro 1996) and whitetips can grow larger, to approximately 2.3 meters (although they are predominantly never seen over 1.6m). Both species favour reef flats and shallow lagoons, such as those around Beqa, using reef systems as primary hunting grounds and represent important apex predators.

With so little known worldwide about the dispersion of juvenile sharks from pupping grounds (Chapman et al. 2009) it is increasingly important for worldwide conservation and protection of coastal species to study their movements. Coastal reef shark species are recognised as having strong nursery habitats circumglobally (Chapman et al. 2009). This includes *C. limbatus*, the Caribbean species of blacktip reef shark, which have been recorded in nursery aggregations as juveniles (Heupel and Simpfendorfer 2004). Here in Fiji, *C. melanopterus* are known to have nursery grounds in the Beqa Lagoon waters (FJM science report 162). The seasonal patterns of pupping and aggregations for local *C. melanopterus* around Beqa Lagoon are important to understand. As a highly mobile species, recording visual census data on their movement patterns and overall abundance is essential to further understand the impact they may be having on the surrounding reef ecosystems that FJM surveys regularly.

Here we studied visual census to assess abundances of blacktip and whitetip sharks in Beqa, Fiji in order to better understand dispersion of juvenile individuals as well as distribution and movement patterns of adult individuals.

3.3.2 Materials and Methods

Using snorkel survey methods, visual surveys were completed at the two sites correlated with blacktip breeding and birthing grounds. These sites are sandbar and lighthouse (figure 14); two low profile sandy reefs which are protected by a barrier reef. The emphasis on shallow and sandy bottom is important for the blacktip nursery sites (i.e. sandbar). Visual shark surveys are completed on a weekly basis in the early morning when sharks are more active. Surveys are conducted for an hour (60 minutes) at a time.
Upon viewing an individual, the species, estimated size, sex (if mature adults), group size, and time of day are recorded. If unusual or unique markings are visible that is noted for further identification of individuals. Through the collection of this data we can improve our understanding of resident individuals and mating/pupping schedules.

3.3.3 Results

During phases 173, 174, 182, and 183 8, 3, 5, and 3 trips were made respectively. The total number of individual sightings were 45, 14, 13, and 5 respectively. During phase 181 there were no trips made to nursery and mating sites due to lack of funding and cyclone season. The average size of recorded individuals was varied throughout the year with a lowest average size in September 2018, and highest in April 2018. From July 2017 September 2018, with a gap for phase 181, the average sizes are seen in figure 15. The highest number of sightings per trip was during 173 at around 6 per trip and down to about 1 per trip in phase 183. From phase 173-183, Lighthouse C. melanopterus sightings were an average size of 1.2m, while the sightings from Sandbar averaged only 0.7m (figure 16).
Figure 15: The average size of *C. melanopterus* per month from phase 173-183 as recorded at both survey sites (Lighthouse and Sandbar).

Figure 16: Average size of *C. melanopterus* surveyed at Lighthouse and Sandbar during phase 173-183.
3.3.4 Discussion

When including the data from past phases, with slightly different methodology, it is shown that the average size of individuals has shifted, and they were on average the smallest during phase 174 (October-December). Individuals sighted were largest during phase 182 from April-June. The end of phase 183 exhibited a major decline in average size from the previous months. Patruition (pupping) may be responsible for this which takes place annually from October to November (Lyle 1987). The lowest average sizes of *C. melanopterus* sighted were during phase 174 which also coincides with patruition. As FJM continues to gather data on this species throughout the next phases, this hypothesis will be analysed further. On average, individuals sighted at Sandbar through all four phases were smaller than individuals sighted at Lighthouse. This data follows trends found in previous years given that Sandbar has been noted as a nursery site for *C. melanopterus* (FJM Science Report 162). The overall lack of sightings of juveniles at Lighthouse, which is just up the barrier reef from Sandbar, supports this finding.

However, there was a large decrease in sightings per trip during phase 182 and 183. A potential for this decrease could be due to the three cyclones which passed nearby Beqa in February and March. There was a major shift in reef shape, and visible damage to the reef likely caused by these storms. The reef is now much shallower at low tide where the coral nearly breaks the surface, which may not allow for juvenile blacktip activity over the reefs as seen in previous phases. While there have been worse cyclone seasons in the past such as cyclone Winston in 2016 (Terry and Lau 2018), there is not data for the blacktip populations from before that time. Since this data set is new, in the future storm action and swells should be taken into account. It has been shown that juvenile coastal sharks stay near their nursery site until reaching sub-adult size, and if displaced can return to site within the year (J. and Planes 2012). That being said there is potential for the individuals that may have been displaced from this years cyclones to return to the sites now that the disturbance has passed.
3.4 Assessing the abundance of coastal megafauna versus general reef health in Beqa Lagoon

3.4.1 Introduction

Coastal elasmobranchs and sea turtles play a vital role in sustaining a coral reefs natural functionality. Sharks remain at the top of the reefs food web as apex predators and consistently, through top-down control, help balance mesopredator populations (i.e. grouper, sweetlips, etc.) to further sustain primary consumer populations. For this reason, changes in their abundance or their removal from reefs can have detrimental effects on these ecosystems such as causing trophic cascades down the foodweb (Baum and Worm 2009). An example of a trophic cascade caused by the removal of sharks from an ecosystem is an increase in herbivorous fish species due to the removal of predation, causing a decrease in algal cover due to overgrazing by herbivores. Rays and turtles prove as important intermediaries in the food web that assist greatly in nutrient cycling (Roff et al. 2016), exposing food for other marine species, and helping to control the distribution of direct coral competitors, such as algae and sponges (Meylan 1988; Len and Bjorndal 2002). Worldwide, coastal shark species have shown a major decline in population that predates any fishing records available (Nance et al. 2011). Studies also suggest that elasmobranch species around the Indo-Pacific are very vulnerable, have declined, and some species that greatly rely on coastal habitats have all but disappeared, leaving them particularly vulnerable to climate change and anthropogenic effects on reef systems (Espinoza et al. 2014; Chin et al. 2010). The shark finning industry is responsible for the death of 100 million sharks each year (Topelko and Dearden 2005), with the average exploitation rate exceeding the recovery rate for many shark populations (Worm et al. 2013). This means catch rates are unsustainable and inevitably will have detrimental effects on the ecosystems they are a part of. Sea turtles have also been noted to be on the decline due to fishing demands, incidental bycatch, anthropogenic pressures (i.e. coastal development on nesting beaches, poaching), and increasing sea temperatures (Carr and Stancyk 1975).

The reefs of Vaga Bay and the surrounding waters of Beqa Lagoon are internally managed in a variety of ways: Marine Protected Areas (MPA), tabu fishing reefs, and non-tabu fishing reefs (figure 3). This affects not only the fish that are actively sought after and consistently removed, but subsequently the predators further up the food chain and the general health of the reefs. It is general knowledge in the villages of Beqa that the fishing of elasmobranchs and sea turtles is prohibited, so shark sightings have remained generally stable, and sea turtle sightings, while still infrequent, have seen an increase. Ray sightings, however, have decreased, suggesting that populations in the area may be dwindling, or perhaps individuals are becoming more cryptic.

The shark species sighted most frequently on FJM survey dives are white tip reef sharks (*Triaenodon obesus*) and black tip reef sharks (*Carcharhinus melanopterus*), and both are listed as near threatened on the IUCN red list. These species utilize the reef flats and lagoons around Beqa as hunting grounds, and some, particularly the black tips, tend to show long-term fidelity to these reefs as a home range (Chin et al. 2013). Both species of sea turtles that frequent Beqa Lagoon, green (*Chelonia mydas*) and hawksbill (*Eretmochelys imbricata*) are on the IUCN Red List as endangered and critically endangered, respectively. Once matured, *C. mydas* and *E. imbricata* spend the majority of their lives in and around shallow lagoons and inshore reefs, as found in Beqa Lagoon, working as vital macroherbivores tending to algal blooms in the reef system. The rays seen on FJM surveys, blue-spotted ribbontail ray (*Taeniura lymma*) and Kuhls Ray (*Dasyatida kuhli*), are both listed as data deficient, and thus are vital to survey in order to gain a better understanding of their distribution as nutrient cyclers of the reefs.

The aims of this relationship study will help to monitor the abundance of these ecologically important species while also assessing their relationship to habitat type and general health. This can contribute to community relations with the nearby villages to help create a better understanding of the impacts of nightly fishing on these different reefs and megafauna, and potentially assist in future management strategies.

3.4.2 Materials and Methods

The first step in analysing this relationship was to obtain a general baseline idea of general reef health of the different survey sites. This included all of FJMs current coral reef monitoring project survey sites, all of FJMs current shark population assessment project sites, as well as the introduction of a few new sites. On these reefs, research staff and trained RAs performed the standardized Reef Check survey methodology (outlined in 3.1), which were completed at least two times per calendar year, preferably six months apart for sites that are not regularly surveyed on the reef monitoring project. This provided
baseline data on the overall health of the surveyed sites that could then be compared with megafauna observation abundance.

Megafauna exploratory visual surveys (shark population surveys included) were completed at one to two sites per week using SCUBA or snorkel for 60 minutes. Start and end time of each survey was recorded for further analysis of general species activity. The reef habitat type (table 5) was also noted for each dive/snorkel site. Following each survey, individual divers/snorkelers recorded the species of megafauna spotted and the number of sightings that occurred per species, taking into account that non-sightings were still recorded to better assist in monitoring abundance trends. This general site exploration methodology is preferred over transect methodology because it gives the surveyors the opportunity to roam the sites freely to further increase the possibility of a sighting (Ward-Paige and Lotze 2011). In addition to the specified megafauna surveys, sightings and non-sightings of megafauna on reef health surveys were recorded to build a broader data set.

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<thead>
<tr>
<th>Habitat</th>
<th>Description</th>
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<tbody>
<tr>
<td>High Profile</td>
<td>Most coral heads rise 1.5m + off bottom</td>
</tr>
<tr>
<td>Low Profile</td>
<td>Most coral heads average 1.5m off bottom</td>
</tr>
<tr>
<td>Wall</td>
<td>Sheer drop-off over 9m that faces open water</td>
</tr>
<tr>
<td>Sand</td>
<td>Mostly sandy bottom</td>
</tr>
<tr>
<td>Artificial</td>
<td>Ship wrecks, dumped debris, or other manmade habitats</td>
</tr>
</tbody>
</table>

Table 6: Reef habitat type and description

### 3.4.3 Results

During this phase megafauna data was recorded on 137 dives by 745 divers/snorkelers, for a total of 137 survey hours. FJM recorded 399 total megafauna sightings at 13 different survey sites, with an average of 0.55 megafauna sightings per diver per dive. Out of the 137 dives used for 182-183 data collection, megafauna were sighted on 70. The most common megafauna recorded on dives and snorkels was the whitetip reef shark, with a total of 225 total sightings documented, followed by the blue-spotted ribbontail with 69 total sightings, and the hawksbill turtle with 43 total sightings. On average per FJM survey dive, 1.64 whitetip reef sharks were sighted, followed by 0.50 blue-spotted ribbontails, and 0.31 hawksbill turtles (figure 17). The majority of FJM megafauna sightings occurred on low profile reefs (184) and high-profile reefs (81), followed by sand habitat (38), with wall reefs (26) and artificial reefs (4) providing the least overall sightings (figure 18).

Vuvale had the most recorded FJM megafauna sightings this phase with 100 total megafauna sightings, followed by Sici with 53 sightings, and Lighthouse and Crabbie with 34 sightings each. Lighthouse had the highest average amount of megafauna sighted per diver per survey (2.3), followed by Sici (2.03), 008 (1.67), Vuvale (1.3) as. House Reef and Lighthouse had the greatest diversity of megafauna species recorded. On thirteen dives at House Reef during these phases, FJM recorded sightings of hawksbill turtles, green turtles, Kuhls rays, and blue-spotted ribbontails. On the two snorkels at Lighthouse during phase 182 and 183, FJM recorded sightings of blacktip reef sharks, whitetip reef sharks, green turtles, blue-spotted ribbontails, and kuhls rays.

The majority of the sites surveyed revealed rock as the predominant benthic cover. Rabbit, House Reef, and Sese exhibited the highest amounts of silt, with it covering 31%, 30%, and 24% respectively of each sites overall benthic composition. Sici, Vuvale, Crabbie, and Sese showed to have the highest average hard coral cover, while Sandbar and Sici exhibited the highest percentages of sand cover (figure 19).
3.4.4 Discussion

This general megafauna abundance data is vital towards gaining a reliable understanding of overall reef health in and around Vaga Bay in Beqa Lagoon. Megafauna were observed and recorded on roughly half of the overall survey dives/snorkels. As expected, based on local knowledge and previous FJM data collection, whitetip reef sharks were the most commonly sighted megafauna around Beqa Lagoon this phase. Their substantial presence on the low-profile reefs FJM surveys may indicate that the whitetips in the lagoon prefer the steadier sloping reefs than those with more abrupt drop-offs and massive coral heads. The blacktip reef sharks were only found on the shallow (1-2m) sandy outer reefs that can only be surveyed through snorkeling which suggests they may prefer the sandier and much shallower environments that the barrier reef provides. Other research shows similar findings (Mourier et al. 2013).

On House Reef, there is a noted lack of reef sharks, where we could theoretically expect to find them at certain times of the year, given some reef shark species utilize mangroves as safe nursery sites for their juveniles to learn to hunt after pupping season from October to November (Chapman et al. 2009). The diversity and abundance of ray and turtle species sighted there, may be due to the nutrient levels of these waters. Given House Reefs close proximity to Vaga Bays mangrove forest and the local village of Naiseuseu, the sediment around House Reef is mainly silt. This is supported by the high abundance
of silt (nutrient rich sediment) noted in FJM ReefCheck surveys for House Reef (see figure 20), so it is possible sea turtles and rays frequent this reef for the increased nutrient availability. Rays are known nutrient cyclers, so their presence on this reef is particularly important for the removal and relocation of these nutrients so the corals can develop properly. Sea turtle diets consist mainly of seagrass, algae (C. mydas), and sponges (E. imbricata), so it is possible these species frequent this site given the accessibility of these prey species that are more prosperous in nutrient rich areas. Sea turtles are essential in the nutrient cycle process as they can transfer nutrients and energy from nutrient rich grounds to less nutrient high areas (Pawlik et al. 2012).

It is also intriguing that the reefs located in nearby non-tabu areas that are heavily fished by locals (specifically Vuvale) produced some of the greatest number of megafauna sightings this phase. The non-tabu reefs further out on Beqa Lagoons barrier reef (Lighthouse and Sandbar) also showed a greater amount of megafauna sightings. Considering the regularity that these reefs are fished, the frequency of sightings recorded could be more due to the actual structural health and integrity of these reefs than the amount of fish that are being removed. This was tested by investigating the overall benthic composition of each surveyed site with a theory that higher coral cover, suggestive of a healthier reef, would result in a higher frequency of megafauna sightings. The high hard coral cover at Sici and Vuvale and the relatively high frequency of megafauna sightings at these sites (refer to figure 27) could potentially support this theory. However, when analysing the rest of the sites surveyed, this trend does not match. Crabbie, for instance, has a similar hard coral cover as Vuvale, so one could infer that Crabbie should have a similar average abundance of megafauna sightings, especially given the sites close proximity to one another and non-Tabu distinction. However, there are almost three times fewer megafauna sightings at Crabbie than found at Vuvale. Other factors, such as fish biomass, or fish diversity, come into play when it comes to megafauna abundance. A study from the Indian ocean suggests that benthic composition doesn’t impact reef shark abundance as much as the presence of planktivorous fish such as fusiliers, wrasse, cardinalfish, squirrelfish and soldierfish (Tickler et al. 2017). These fish families are not currently recorded while we are following the ReefCheck methodology, however, it may be beneficial to assess these fish in the future.

FJM was unable to do a ReefCheck survey for Lighthouse during either phase 182 or 183. This site will need to be surveyed during phase 184 in order to obtain better information about megafauna abundance along the Beqa Barrier Reef. Since Lighthouse is a non-Tabu reef, in the future it would be particularly interesting to assess the reefs healthy hard coral cover and fish abundance relative to average megafauna abundance compared to what FJM has found at Tabu Sici and non-Tabu Sandbar.

It is important to note that this sort of investigation requires a more long-term data collection process to produce results of any major significance. The assessment of these relationships can be continued

![Figure 19: The average benthic composition of each ReefCheck surveyed site versus the average megafauna sightings per diver per dive at each site recorded during Phase 182 and Phase 183](image-url)
during phase 184 to produce a larger dataset, and potentially produce more concrete findings about 
megafauna abundance in Beqa Lagoons reefs. The data can then be used to work with local villages 
on instilling improved fishing management practices to further sustain these ecologically significant and 
locally sacred animals.
3.5 Assessing Crown-of-Thorns (COTs) outbreaks around Beqa Lagoon

3.5.1 Introduction

Crown of Thorns Starfish (*Acanthaster planci*) are coral-eating invertebrates that feed solely on polyps of reef building corals, preferably those of *Acropora* species (Pratchett et al. 2009). They leave behind only coral skeletons which causes widespread damage to many coral reefs in the Indo-Pacific. Crown of Thorns outbreaks are becoming increasingly commonplace and can decimate coral reefs. On the Great Barrier Reef, the first COT outbreak was observed in 1966, and since 1985 around 42% of the GBRs decline in coral cover is due to COT outbreaks (Uthicke et al. 2015). A third observed outbreak cycle is now in progress (Brodie et al. 2005). There are various hypotheses surrounding the cause of COT outbreaks; Souter et al. 1997 (1997) suggested that outbreaks could be attributed to the removal of adult predators, in particular, fish and gastropods. Whereas many other studies suggest that outbreaks could be a result of enhancement of larval food supply as a result of nutrient enriched terrestrial run-off (Lucas 1982; Brodie 1992). In order to combat such outbreaks, FJM have been implementing COT removals upon the reefs within Beqa Lagoon. Removals of Crown of Thorns are crucial initiatives in limiting the damage to coral reefs during outbreaks (Bos et al. 2013). When conducting removals, it is imperative that local spawning season is recognized, and no removals are conducted during this time period given that COT are known to release their gametes when put under stress, which is often synchronized throughout populations during the spawning period (Beach et al. 1975; Dumas et al. 2016). The largest possible spawning period for COTs in Fiji is from November to February (Pers Comms: Dr. Antoine D’Nyeurt 2017); to prevent unnatural levels of spawning, FJM does not conduct removals during this time period.

3.5.2 Materials and Methods

Removal teams comprise of two groups, a diving group and a snorkel group. Both groups go out onto a reef together, and both teams begin searching for COTs, searching in crevices and under rocks as these nocturnal species are often hiding during the day. Once an individual has been found, a member of the diving team will remove the individual from the reef carefully using tongs; ensuring as low amount of disturbance and damage to the animal, the surrounding reef, and diver themselves as possible as they can be harmful to humans. Agitation can also cause COT to spawn so extra care has to be taken when removing them off the reef. Once removed, a member of the snorkel team free-dives down to the diver with a bucket and the COT is placed in the bucket and swam back to the boat. Once the removal is completed, the COTs are taken back to shore and buried on land, this is one of the most efficient small scale, community-based methods for ensuring minimal reef disturbance and effective disposal (Dumas et al. 2016).

3.5.3 Results

A total of four removals were conducted in Vaga Bay during Phase 183. While the average size of the COTs collected from House Reef this phase has increased (figure 20), there has not been any notable increase in COTs impact on the reef. The average amount of COTs removed from Milky Bar this Phase was 12 per removal, with the highest amount being 15 individuals removed on one dive. The average weight of COTs removed has increased from 182, which may suggest that the specimens collected this phase have outgrown their old hiding spots that kept them concealed. Based on GCRMN (Global Coral Reef Monitoring Network) surveys of these two reefs, the *Acropora sp.* cover reached 10% at Milky Bar, and 0% at House Reef (figure 21).
3.5.4 Discussion

Milky Bar Reef had considerably more individuals collected, with the maximum collected on a 1-hour dive of 15 individuals, and an overall average of 12 individuals per removal dive. The first removal dive on House Reef only resulted in two individuals collected. This suggests that the abundance of these invertebrates was not at a level detrimental to the ecosystem. Visual surveys on House Reef throughout the remainder of the Phase echoed this result, thus no further removals were conducted upon House Reef during 183. This is a substantial difference in abundance between two geographically close together reefs; it is possible that there are different ecological factors affecting both reefs that are influencing this
difference in abundance.

COTs are known to prefer feeding upon Acropora corals (Patchett et al. 2009). Our data support this conclusion, for example, only two COTs were found on House Reef, which subsequently has a 0% benthic cover of Acropora corals (figure 21). Given House Reefs close proximity to Vaga Bays mangrove forest and the village of Naiseuseu, it is possible that sedimentation, which is known to slow Acropora corals growth rates (Rogers, 1990), may contribute to lower Acropora cover than at Milky Bar Reef. Milky Bar is also located closer to Rukua Reef, around the corner of the bay, which has historically had numerous COTs outbreaks (Pers Comms, 2017), which may be attributed to high nutrient input from Rukua village. This close proximity, alongside potential larval disposal through the lagoons current may be influencing factors effecting the great variance of COT abundance between the two sites. Looking into nutrient indicator algae populations and overall coverage and distribution of litter at these sites next phase could provide FJM with valuable insight into possible explanations for each site’s respective COT abundance. Continuing to conduct removals and monitor these sites regularly is vital for producing early warning systems and improve response times should any COT outbreaks occur.
3.6 Future Research

All future endeavors are contingent upon funding. If given the necessary resources, we would like to:

- Continue with Reef Check

- While continuing with Reef Check, I'd like to increase the amount of data we collect when we take surveys. I would like to note coral morphology and add crustose coralline algae, silt on rock, sand on rock, Halimeda, bleached coral, and diseased coral as benthic categories. Furthermore, I'd like the point at which these categories start and end on the transect recorded rather than take point counts every 0.5 m. I'd like to record depth every 10 m along the transect as well as temperature.

- We are in the process of installing permanent transects so that we can take monthly photos of the same spot on the reef each time to document change over time. Along with quadrats, we will be conducting monthly surveys of these transects as well.

- To study cleaner wrasse behavior.

- In the middle of a proposal to conduct algal contact experiments.

- Cataloging the species and distribution of nudibranchs at each of the sites.
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