Fiji Marine Conservation Programme

Literature Review of Long-Term Studies
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Beqa Island, FIji

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1 Introduction

1.1 Frontier

Established in 1989, Frontier is a UK-based non-profit NGO with the following mission:

“To conserve the world’s most endangered wildlife and threatened habitats and to build sustainable livelihoods for marginalized and under resourced communities in the world’s 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’s marine projects give non-specialist volunteers, or Research Assistants (RA’s) environmental science species identification training at the beginning of their placement, to enable them to collect data on local fish, benthic and invertebrate species. Frontier’s 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 (Figure 1) composed of approximately 330 islands and 500 islets and cays, with an associated landmass of 18,333 km$^2$ (Cumming et al., 2002; Berthold et al., 2016). Approximately one third of Fiji’s islands are inhabited and of these, the two largest islands, Viti Levu and Vanua Levu, contain approximately 90% of Fiji’s population (Fiji Bureau of Statistics, 2018).

![Figure 1: Map of all the islands that make up the Republic of Fiji.](image)

The relatively high proportional representation of sea to land mass area, (the land area is 70 times smaller than its Exclusive economic zone), means that for much of Fiji’s population subsistence fishing on and near coral reefs is a way of life (Berthold, 2016). Beqa is a large island and lies within the Beqa Lagoon, 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; Waisomo, Lalati, Soliyaga, Dakuni, Dakuibeqa, Naceva, Naieuseu, Rukua and Raviravi. Frontier Research camp lies between Naieuseu and Rukua.

Fiji is world renowned as the ‘Soft Coral Capital of the World’ and is also home to Beqa Lagoon (BL), 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, 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
1.3.1 Coastal Governance and Fisheries Management

Beqa’s inhabitants, along with most of Fiji’s 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. This dual system means that fishers are required to obtain a license from centralized, government systems. However, this must be signed by chiefs in their local communities (Sloan & Chand, 2015). 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, they broadly utilize tools such as: seasonal bans and temporary no-take areas, or “tabu” areas (Tawake & 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. Studies have repeatedly shown that traditional methods are an effective way to control and sustainably manage harvest rates of marine resources, with documented overflow restocking non Tabu areas (Hoffmann, 2002; Cakacaka, 2007). FJM’s work aims to provide evidence on the effectiveness of Beqa’s 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 invertivore and algivorous fish (Jennings & Polunin, 1996; Cakacaka, 2007). 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. Figure 3 below denotes the qoliqoli areas in existence around Beqa and the presence of tabu areas around these areas.

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 (Berthold et al., 2016). 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.

1.4 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 (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.

Similar 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 (IPCC, 2007). 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).
1.4.1 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 (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 & 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 et al., 2004). 2015 reports indicate a steady decrease in ornamental reef exports with 205,000 kg live inhabitants plus 85,236 pieces of rock and coral. Though difficult to determine trend causation, general consensus indicates habitat destruction and limited fish availability have contributed to the decline of ornamental exports. (Gillett & Tauati, 2018). Though previously unseen in Beqa waters, divers during Phase 193 reported witnessing live fish capture and coral harvesting on the reef fringe. Communications with surrounding villages revealed Rukua chiefs have given permission to local harvesters to recruit within their qoliqoli. It is currently unclear if the village understands the extent of their harvesting, and there is potential for continued future harvesting to have devastating effects on the reef system.

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 (Ginsberg, 1994; Mosley & Aalbersberg, 2003; Yang et al., 2008). Coral reefs are unique as they thrive in 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 foreign nutrients, the result is excessive plant growth in the form of macroalgae (Shantz & Burkepile, 2014). Such algae are detrimental to the health of the reef as they use all available oxygen within the water column, depriving fish populations. 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). Once coral death occurs, the available space is filled by opportunistic sessile organisms and more algae, reducing coral recruitment (Haas et al., 2014).

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 & Aalbersberg, 2003; Tamata & Thaman, 2001; Zann & Lovell, 1992).

Many families on Beqa lay claim to 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. 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 (Kathiresan & Rajendran, 2005). 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 (FAO, 2007; Giri et al., 2010). According to local reports, the areas of mangroves have significantly decreased and with the added impact of slash and burn techniques this is likely to continue. 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 years and some suggest that this represents the greatest anthropogenic impact aside from climate change. In 2008, a study by Teh et al. (2009) 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 with rising domestic consumption and the growing export market to blame for such dramatic expansion. (Gillett et al., 2014) For example, resources of invertebrates such as Bêche-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 (MRIS, 2012). These new reports are revealing subsistence-based fisheries may be dwindling, as communities understandably progress to the commercialisation of their traditional resources.

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 (MRIS, 2012). Commercial fishing does not occur within Beqa Lagoon, however, overfishing in other areas may have reduced population numbers to such an extent that Emperor species (Lethrinidae) are not present or very rarely encountered. Species such as the Bumphead parrotfish (Bolbometopon muricatum), have now become almost completely extinct in Fijian waters (Cumming 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 programs and infrequent 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., (2009) produced an overview of the
socio-economic and ecological perspectives of Fiji’s 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.

1.5 Project Aims & Objectives

FJM have been conducting research in Beqa Island for over five years, producing cumulative datasets which are used for long-term analyses. The methodologies are in constant reform, with the aim to optimise resources and reliability of results. Simultaneously, standardized protocols of data collection such as the Reef Check system allow for comparative analysis throughout the years. FJM also aims to participate in completing data deficient information, such as estimates of the current Fijian mangrove population size. Our short-term objectives unite science and community and will:

- Evaluate the 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 logs.
- Feed into the international databases of both Reef Check and the Global Coral Reef Monitoring Network, using globally recognized methodologies.
- Investigate the effects of the Bêche-de-mer restrictions through a monitoring program specifically focused on commercially important invertebrate fisheries around Beqa.
- Examine both the ecological and 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 Beqa’s villages and increase the island’s 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 behaviors 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.
2 Survey Areas

Table 1: A total of fifteen survey sites were used for Reef Check data collection. The names and GPS coordinates are listed in Table 1. Anecdotal information is unavailable for some of the sites.

<table>
<thead>
<tr>
<th>Site name</th>
<th>GPS coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milky Bar</td>
<td>S 18°23'46.3&quot; E 178°05'53.2&quot;</td>
</tr>
<tr>
<td>House Reef</td>
<td>S 18°24'167&quot; E 178°06'184&quot;</td>
</tr>
<tr>
<td>Mala's</td>
<td>S 18°24'171&quot; E 178°05'988&quot;</td>
</tr>
<tr>
<td>Rabbit</td>
<td>S 18°24'07.5&quot; E 178°06'09.9&quot;</td>
</tr>
<tr>
<td>Vuvale</td>
<td>S 18°24'07.6&quot; E 178°03'54.9&quot;</td>
</tr>
<tr>
<td>Kobe</td>
<td>S 18°24'811&quot; E 178°03'877&quot;</td>
</tr>
<tr>
<td>Twins</td>
<td>S 18°24'376&quot; E 178°06'547&quot;</td>
</tr>
<tr>
<td>Bikini</td>
<td>S 18°23'40.1&quot; E 178°05'26.0&quot;</td>
</tr>
<tr>
<td>Heaven</td>
<td>S 18°25'26.5&quot; E 178°04'42.4&quot;</td>
</tr>
<tr>
<td>Snapper</td>
<td>S 18°24'56.7&quot; E 178°04'04.4&quot;</td>
</tr>
<tr>
<td>Sici</td>
<td>S 18°26'383&quot; E 178°06'707&quot;</td>
</tr>
<tr>
<td>Crabbie</td>
<td>S 18°24'412&quot; E 178°03'950&quot;</td>
</tr>
<tr>
<td>Wreck Reef</td>
<td>S 18°22'48.22&quot; E 178°05'18.3&quot;</td>
</tr>
<tr>
<td>Sese</td>
<td>S 18°25'272&quot; E 178°07'629&quot;</td>
</tr>
<tr>
<td>Sandbar</td>
<td>S 18°28'876&quot; E 178°03'387&quot;</td>
</tr>
</tbody>
</table>

**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 20m 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 frequently visited by locals for fishing and rubbish dumping.

**House Reef** - An inshore site (0.2 nautical miles from camp) located in the centre on Vaga Bay. The side is mostly shallow with a reef sloping gently to 10m where it becomes a flat silty bottom.

**Mala’s** - 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 of the reef is around 8m deep, whereas the outer reef is around 18m deep. 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.

**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 bommies. The average depth is around 8 m dropping down to 16 m at the reef’s 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.

**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.

**Twins** - An offshore site (2 nautical miles from camp) made of two large bommies. The reef is a wall which slopes steeply down to around 20m. The site has a high abundance of megafauna and it is often used for visual shark surveys.

**Snapper** - An offshore site (2.5 nautical miles from camp) relatively protected from South 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 Snapper, hence the name.

**Bikini** - An offshore site (0.99 nautical miles from camp) with an average depth of 7.2m, dropping off to approximately 20m towards the Southern side of the reef. It is comprised of several bommies, containing an abundance of fish, hard coral, and soft coral. Frequently visited by Beqa Lagoon Resort divers.

**Heaven** - An offshore site (2.2 nautical miles from camp) and approximately 500m from Royal Davui Resort. A shallow site with lots of hard coral and sandy bottom. Ideal for shark dives, as it is frequented by White Tip Reef Sharks and the occasional Black Tip.

**Redtooth** - A fringing reef (5.04 nautical miles from camp) offshore. Known for its abundance of piscivorous fish and sharks, this site is frequented by tourist divers and evidently exploited by aquarists.

**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 current are rare. This site was historically fished for Beche de-Mere, however this is no longer the case.

**Wreck Reef** - An offshore site (1.97 nautical miles from camp) very exposed with a purpose sunk wreck is located on the seabed just off the reef at a depth of 22m. The reef has an average depth of 8m, however, the edge of the reef has a steep drop off down to a depth of 22m. There can be strong currents present, however, the site is far enough away from freshwater sources to not be affected by dissipation. The site is rarely visited by Beqa Lagoon Resort for tourism or fishing by the locals (so is classed by tabu).
3 Research Work Program

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 have 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 & 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 1.3.1, 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 Fiji’s reefs, particularly those around Beqa.

Beqa Island lies within Beqa Lagoon, 10km South of the main island of Viti Levu. The majority of Beqa’s 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 Beqa’s fisheries and resources was conducted in 2012 by the Marine Resource Inventory Survey (MRIS) team (MRIS, 2012). This survey fed into a management plan for Beqa and was conducted in Yauca and Rukua villages. Methodologies utilized included an underwater visual census and socio-economic surveys. It was reported that the main source of income for villages was fishing and that over 90% of villagers “always” or “sometimes” consumed fresh fish in a week. As a result, 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, overfishing, 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 reefs 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 & Semmens, 1998).

3.1.2 Materials and Methods

Full Reef Check surveys were conducted to gather valuable data on benthic cover, fish biodiversity, and invertebrate biodiversity. These surveys consist 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 09:00-10:00 or 14:00-15:00, 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.

Figure 4: Layout of Reef Check 200m$^2$ transect, set at a depth of 4-6m and 10-12m.

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 wide 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 800m$^2$ is surveyed in one transect (Figure 4).

- **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.

Figure 5: Figure showing the belt-transect methodology for recording both fish and invertebrate data (Reef Check, 2018).
3.1.3 Results and Discussion

The abundance of different species of coral has varied between the sites recorded over the years. Since benthic cover surveys have been introduced in Phase 172, every report has shown hard coral to be the most prevalent of all the coral species (Figures 6 & 7).

![Substrate cover (% frequency on PITs)](image)

**Figure 6: A pie chart showing the percentage frequencies of different benthic covers for Phase 172. RB = Rubble, HC = Hard Coral (FJM Science Report 172)**

Furthermore, over the years, a significant decrease in hard coral cover has been recorded across all sites (9%). This is accompanied by an increased rock presence (7.9%) and Nutrient Indicator Algae (2.1%) (FJM Science Report 193). Despite the lack of experimental evidence, algal cover increase has been found to coincide with outbreaks of coral disease (Nugues 2004, Edmunds 2002). This factor, amongst others, could be a potential threat to the health of the reef communities. Furthermore, it was found that NIA negatively correlates with certain fish species. The decreasing number of fish feeding on the algae could be contributing to their growing presence on the benthic zone.

Originally, FJM was not conducting benthic cover surveys. In the earlier phases during 2016, the information collected was the abundance of fish found in different sites, their size group and species richness of transects. In more recent times, key species were identified, their abundance was recorded, and long-term data is currently being collected to assess changes in the reef health. It has consistently been found that Butterfly, Parrot and Surgeon fish were more abundant at sites populated by hard coral, suggesting a relationship between them. One hypothesis is that the presence of hard coral offers protection from predators or fishers, something that other benthic cover types would not allow so effectively. No correlations between the decrease in hard coral and abundance of these species of fish have been noted, interestingly, perhaps because the decrease of predator abundance due to overfishing could compensate for the benefits that the coral provide to their safety. This is speculation, and continued research may
Figure 7: A bar chart showing the percentage abundance of different benthic covers for Phase 193. (FJM Science Report 193).

identify solid trends in the future.

The Crown of Thorns were recorded to have been low in numbers throughout the phases, thus no removal efforts have been carried out so far. Conversely, Sea Cucumbers were reported to have been seen commonly throughout sites. Sea Cucumbers are important members of the community as they function as bioeroders. Their presence helps to balance CaCO₃ levels in the reef (Schneider, 2011), which increases the alkalinity of the environment (Jansen and Ahrens, 2004), dampening the effects of ocean acidification due to climate change, and is essential for reef building (Goreau, 1963).

3.1.4 Depth Differences

Shallow depths hosted a higher average percent hard coral cover for all sites considered. Corals display depth zonation due to the effect of increased 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). Depth’s 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). All five corals exposed to algal exudates, were bleached and suffered complete mortality. However, if the seawater was treated with the antibiotic ampicillin, the corals remained healthy. Therefore, the author’s postulate that dissolved organic carbon (DOC) derived from algal polysaccharides caused anoxic regions to develop as a result of enhanced bacterial growth on the coral’s 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 Mala’s may have been due to a difference in algal abundance, and/or different corals with varying susceptibility to algal effects.
3.1.5 Corals as Determination of Fish Assemblages

As previously mentioned, it was discovered that the number of Butterfly, Parrot, and Surgeon fish were generally higher at reefs more populated by hard coral. 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 has decreased (Komyakova, Jones & Munday, 2018). Therefore, as structural heterogeneity increases, fish diversity and numbers generally increase as well (Darling et al., 2017; Komyakova, Jones & Munday, 2018). Increasing coral size can also equate to a larger, more diverse fish community, which is presumably due to increased availability of living space makes niche partitioning possible (Komyakova, Jones & Munday, 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 fish greater than 8cm 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 consortiums, 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, Jones & Munday, 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 water’s potentially damaging effects (boulder, encrusting). With increasing in 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).

3.1.6 Crown of Thorns

Crown of thorns (COT; Acanthaster planci) are starfish that predate on the polyps of scleractinian corals, although they exhibit an affinity for Acropora species (Bos et al., 2013). Porites spp. are the least palatable to COT (Pratchett et al., 2009), and perhaps other reefs had a higher prevalence of these particular coral species. Although endemic to the Pacific Ocean (Pratchett et al., 2009), COT is of great concern for reef vitality, as outbreaks of these species (defined as ¿1500 individuals/km²) can have significant repercussions on coral populations and by extension, reef ecosystems. By initiating widespread coral mortality that can lead to extensive algal overgrowth, COT may trigger an ecological shift for affected reefs. There are several hypotheses concerning the rise in COT populations, one of the oldest being the predator removal effect (Endean, 1977). In other words, the reduction of the COT’s natural predators allows them to survive and reproduce more easily. More recent evidence suggests that nutrient discharges from rivers cause phyto-plankton blooms, along with shifting their species composition to a larger quantity of nano and micro-plankton, all substantial nutrient sources for the COT larvae (Brodie et al., 2005). This would lead to an increased survivability rate of COT into adulthood, resulting in more outbreaks. Damage caused by outbreaks can be ameliorated by removal efforts, the methods of which include spearing with poles and/or inoculation with lethal chemicals. Cutting individuals into
several fragments was previously utilized, although this is no longer practiced due to COT’s regenerative capacity. Coral may also be damaged during the removal process and their venomous spines must be taken into consideration. Removal success is compounded by the fact that adjacent reefs can harbour COT, thereby functioning as a seedbank that can re-populate the reef upon which they were previously removed. Yet success may be bolstered by removing COT before they reproduce by spawning and by focusing efforts on remote reefs (Bos et al., 2013). The observed populations of the COT across the sites has been low, and no outbreaks have been reported thus far. The numbers of COT will continue to be monitored and if deemed necessary, physical removal tactics will be employed prior to breeding events.

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 the 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 & Levin, 1995; Armitage, 2014). 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 (Armitage, 2014). Mangrove species show unique reproductive strategies and many mangroves develop viviparous seeds called propagules (Kathiresan & Bingham, 2001). 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 the conditions are right, will develop into adult trees (Kathiresan & Bingham, 2001).

Mangrove conservation and restoration will provide a multitude of benefits to the local ecosystem and human populations alike. Studies show that mangroves are able to defend the coastline from storm surges and reduce flooding levels (Koch et al., 2009; Zhang et al., 2012), as well as potentially reduce the effects of small tsunamis (Tanaka 2009). Properly established and healthy mangrove communities could protect the livelihoods of many of the island’s inhabitants and is a practical, inexpensive solution to the increasing threats posed by climate change and overfishing. In addition, they provide nursery habitats to many crustacean, fish and mollusc species (Ley 2002), some of which will leave the area and become part of other ecosystems, such as coral reefs (Laegdsgaard & Johnson, 2001). Mangroves are also a natural way to maintain the quality of coastal water by cycling nutrients, filtering material coming from land and stopping pollutants from reaching the water (Gilman 2006). There is recent research that suggests mangroves are the most carbon-rich forests in the tropics, holding an average of 1, 023 Mg per hectare (Donato, 2011). This fact illustrates the importance of mangroves outside of their local habitat, as less land per carbon unit stored is an optimal focal point for some factors of the reforestation efforts.

Figure 8 (Ellison 2010) shows all the mangrove site locations in Fiji (taken from the Fiji Mangrove Committee 1986). Beqa appears to contain 72 hectares of mangrove forest.

However, recent literature surrounding Fiji’s mangrove population size is ambiguous. The FAO claims the most reliable, recent estimate equates to 424.6 km$^2$ in 1991 (FAO Forestry Paper 153, FAO, 2007). On their list of countries in Oceania, Fiji’s report is among the most dated. FJM’s research can, among other things, provide much needed current information that can be used to map and assist in the creation of mangrove conservation programmes.

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, Rhizophora samoensis, and Rhizophora 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 asiatica), 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 *Rhizophora 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 (FAO, 2007; Spalding, 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, 1992). 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, sewage, pesticide runoff, animal waste, introduced species, logging, and bio-prospecting for natural products (Ellison & Fiu, 2010).

Besides anthropogenic destruction, the reasoning behind mangrove degradation is often multifaceted with a combination of several factors including hydrological change, subsidence, climate variability and storm events (Lewis et al., 2016). Often stressors that cause only slight changes will manifest over a few years and gradually the loss of percentage canopy cover will alter the physical environment until it becomes such that no individuals can survive (Lewis 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 (Kathiresan & Bingham, 2001).

Mangrove ecosystems are sensitive to climate change impacts, particularly associated to 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 IPCC’s 4th
Assessment Report 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 (IPCC, 2007; Gillman et al., 2008). Rise in temperature and the effects of increased CO\textsuperscript{2} 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 being exploited for firewood and materials for building, reclaimed for urban development, new settlements and agriculture and being impacted by local pollution (Agrawala et al., 2003). 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 with human settlements. Together with the added impact of land clearing using slash and burn techniques, the current decline in mangrove forests is likely to continue. 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 (FAO, 2019). 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 the world wildlife fund (WWF) (Ellison & Duke, 2010), with Beqa only currently having 72 hectares of mangrove forest on the island (Ellison & Fui, 2010). In light of Cop23 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

At the start of 2016, during Phase 161, mangrove monitoring and mapping at Vaga Bay began. Level 1 monitoring protocol was used following the Manual for Mangrove Monitoring in Pacific Island Regions (Ellison et al., 2012). Firstly, we determined the extent of the mangrove forest using the most recent aerial photographs at the time. Vegetation zones were marked based on the photograph and were taken into the field to accurately check the types and positions of the zones, called ground truthing. On the aerial photograph, six transects perpendicular to the coastline were marked. The transects were numbered from one to six from North to South. Using major features visible on the aerial photograph, we determined the starting point of each transect. The transect start position was identified using the GPS and marked using flagging tape. A new data form for each vegetation zone along the transect was used and notes were taken that will help re-locate this position if without a GPS, such as marking the point with flagging tape. The transect lines are laid into the forest using a 50 m fibreglass tape, using a hand compass to ensure the transect is perpendicular to the shoreline and stays straight. Species are
noted and zone recorded, with a measure of abundance taken and the width measurement of each zone (mm). At each observation point the degree of impact in an area with a 15 m radius around is assessed. Impact is assessed on a scale from 0 to 5 where 0 is no impact and 5 is severely impacted (Table 4). The surrounding area is then inspected visually to determine the cause of Impact. Impact may be direct, indirect, or both, anthropogenic activities such as piggeries, garbage, illegal cutting, storm damage, etc was recorded. The GPS position on the mangrove edge is recorded and condition of the seaward edge is noted, such as any recruitments, or signs of erosion.

During Phase 163, a restoration area was planned on 1,032 m$^2$ of bare wetland on the north side of present mangroves at the time. The area was divided into 4 zones, in which zones 1 -3 are restoration areas and zone 4 is a nursery area where we grew propagules up to transplantable size. The zones were further divided into seaward and landward zones. Red mangroves (Rhizophora spp.) were planted on the seaward zones while black mangroves (Bruguiera spp.) were planted on the landward zones following the pattern of present mangroves. Walls were built to protect propagules from wave action and to retain nutrients from land, with gaps to allow circulation. Freshwater is provided by a creek on the north side of the mudflat. Regular rainfall also helps provide freshwater necessary for the propagule to grow.

### 3.2.3 Wall Building

The walls were originally built by stacking rocks in a chicken wire frame, however it was discovered that the chicken wire was susceptible to degradation over time. Therefore, to prevent the wall from losing its functionality, monthly maintenances were scheduled, and the wire was removed. The structures are approximately 75cm in width each, with gaps left in between them to allow for nutrient and water flow.

### 3.2.4 Propagule Collection

RAs are deployed in groups of 4 on mid tide and comb the tideline for viable red and black mangroves propagules (Figure 9). Viable propagules have visible budding and form root nubs, the body of the propagules should be whole without cuts or gouges.

![Figure 9: Viable and non-viable mangroves propagules.](image)
together than blacks, which were planted more than 1m apart. However, after 1 year of development the propagules will be “spaced” out in order to replicate growing conditions in the wild. This will occur as part of the replanting and rehabilitation project. In order to space out 50% of the individuals will be removed and replanted elsewhere. This will only be done once the propagules have reached 1m in height as they are deemed suitable for relocation. It was aimed that *Rhizophora spp.* (red) would be planted on the seaward areas, and *Bruguiera spp.* (black) would be planted in the landward areas, however there has been some mixing through both human error and natural propagule settlement. The survival rate of these propagules is measured at the beginning and end of each phase in order to identify the following factors, which will allow us to understand ideal physical and environmental variables imperative for restoration:

- Species-specific survival rates based upon planting location.
- Seasonal differences in propagule survival rate.
- Difference in growth rates depending on anthropogenic alterations to the physical environment.

The location of the nursery area is right of the FJM camp in Vaga Bay and is in a tidally influenced creek area next to a mangrove forest that continues towards the camp. There is only one residence located in the area and therefore the area is considered to be relatively unaffected by anthropogenic activity, namely nutrient run-off from the villages and associated piggeries which are located around Beqa.

### 3.2.5 How the Nurseries Have Progressed Over Time

Following the creation of the nursery in Phase 163, planting efforts were improved as the areas were being assessed, new ones being created, and walls were being built. Planting in Zone 1 began in Phase 163, Zone 2 in Phase 164, Zone 3 in Phase 171 and Zone N in Phase 173. The zones were re-arranged in Phase 173, shown in Figure 10, along with all the replanted areas. During that Phase, 14 new propagules were replanted in Zone 2, 16 in Zone 1 and 50 in Zone N. This period proved to be extremely productive for FJM and the development of the nursery advanced steadily with each phase.

![Figure 10](image.png)

**Figure 10: Fig. 10: Diagram of the nursery area in Vega Bay (Phase 173).**

A new zone was created in Phase 174 adjacent to Naisenseu village after consultation with the local community and local elders. This is an area known to previously (approximately 50 years ago) have been inhabited by mangrove species. These forests are believed to have disappeared through natural activity, such as tree death from storms. Due to the physical properties of the site, it is submerged 15-19 hours a day, it was determined that only red mangroves should be planted. The propagules were planted by RAs, staff and the local community, and local children were taught how to collect and plant the propagules correctly.

During this phase, there was an even larger quantity of propagules planted (504) split amongst the 6 zones established at the time. Figure 12 illustrates the differences between Phases 173 and 174, with a substantial increase in plantations across all zones except Zone 3.
During phase 191, a new site was developed: “Sulu Rock”. The new site is located 400m from the village of Naiseuseu and is in a relatively sheltered area of the bay. After an initial struggle to keep the propagules from being washed away, three walls were built at the end of that January to help shelter propagules better (Figure 13). When propagules were planted behind wall 2 and wall 3, they did not have a root structure or any leaves. This could be a plausible cause as to why the propagules did not survive.
3.2.6 Results and Discussion

Approximately 12,600 m$^2$ of Mangroves wetland was mapped throughout the 161 and 162 quarters, and it was found that the most prevalent species (47% cover) in that area was the *Bruguiera gymnorhiza* (FJM Science Report 163). With the number of nurseries now in place, more recent monitoring efforts have been focused on those. Planted mangroves must be monitored for a minimum of three years, preferably five. With the current nurseries roughly one year old, there is still much to do before they can be relocated and left to grow unchecked.

Overall, the initial nurseries started in Phase 163 were successful. A total of 792 propagules have been planted between Phases 163 and 174, and according to our most recent data, 332 of those have survived. The survival rate of the newly planted propagules over time is expressed in the graph below (Figure 14), illustrating an overall rate of 32%.

This result was heavily altered by the survival rate of propagules in Zone 3, which is lower than 6%, indicating that it is probably not a suitable zone for a mangrove nursery. Zones 1 and 2, on the other hand, have a survivability of 44% and 50% respectively, for an average of 47%. The average survival in the wild within the first 2 months is 15% (Smith 1992, Sheue *et al.*, 2005), and the national average in Fiji ranges from 30% to 55% (Molony & Sheaves, 1995; Krauss *et al.*, 2014), meaning FJM’s nurseries have been built and maintained successfully.

In more recent times, since the creation of the “Sulu Rock” nursery at the beginning of 2019, there has been less focus on the mangrove project. However, there is currently a plan to measure the mangroves between “Sunset Rock” and “Sulu Rock” to record any new mangroves growing in the area and plans to re-establish the now damaged Sulu Rock nursery.
3.3 Assessing the abundance of coastal megafauna and general reef health in Beqa Lagoon

3.3.1 Introduction

Coastal elasmobranchs and sea turtles play a vital role in sustaining a coral reef’s natural functionality. Sharks remain at the top of the reef’s 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 food web (Baum and Worm, 2009).

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). 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, accidental 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. 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 (Sykes, 2017), or perhaps individuals are becoming more cryptic.
Consistently in the past years, the shark species sighted most frequently on FJM survey dives are white tip reef sharks (*Triaenodon obesus*) and black tip reef sharks (*Carcharhinus melanopterus*), both listed as near threatened on the IUCN red list (Smale, 2009; Heupel, 2009). 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 (Seminoff, 2004; Mortimer and Donnelly, 2008). 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 are the blue-spotted ribbontail ray (*Taeniura lymma*) and Kuhl’s Ray (*Dasyatis kuhlii*), which are listed as near threatened and data deficient respectively. These species are vital to survey as there is currently a poor understanding of their numbers and distribution.

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.

### 3.3.2 Local Fisheries and their Relationship with Sharks

Predominately subsistent and artisanal, Fiji’s in-shore fisheries remained undocumented until recently (Glaus *et al*., 2015). Focus on Industrial fish landings and economically valuable fish exports has facilitated our reduced understanding of underdeveloped fishing industries (Teh *et al*., 2009). Perpetual recommendations for further research from most Fiji based fisheries reports have gone relatively unanswered (Sadovy & Batibasaga, 2006; Teh *et al*., 2009).

A recent study has seen 253 interviews to members of artisanal fisheries in Fiji (Glaus *et al*., 2015). It was found that 81.4% of fishers reported catching sharks, and only 18.4% of those were targeting them (Glaus *et al*., 2015), meaning the majority of shark catches are bycatch. Furthermore, of all the fishers who reported catching sharks, 73.8% of them mentioned coral reefs (Glaus *et al*., 2015). This means coral reefs are the locations with the largest number of shark catches. Monitoring shark numbers at their most vulnerable location will provide the most reliable representation of their population status whilst being able to compare how any population changes affect the reef system.

### 3.3.3 Materials and Methods

Megafauna exploratory visual surveys (shark population surveys included) were originally conducted at approximately two sites per week using SCUBA or snorkel. The number and frequency of surveys usually varies between phases. Following each survey, individual divers/snorkelers recorded the species of megafauna spotted and the number of sightings that occurred per species, non-sightings were still recorded to better assist in monitoring abundance trends (Ward-Paige, Westell & Sing, 2018). 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 & 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.

Phase 193 saw the implementation of Baited Remote Underwater Video (BRUV) technology into the surveys. This was done in order to reduce the impact of divers on sightings and improve the accuracy of the surveys. Each day from 10am to 12pm, BRUVs were deployed using a weight 1m tall PVC Pyramid. Mounted with a Yi 4k+ Underwater camera and baited with 500 grams of fresh sardines, the BRUV was deployed for 1 hour at randomly selected reef sites within Beqa Lagoon. The drops were between 10-30m and were always during daytime hours.
3.3.4 Results and Discussion

Long term cross-phase analysis resulted implausible due to changing methodologies. Over time, however, efficiency and productivity have improved drastically, as have the size of the acquired datasets. Since Phase 172, shark surveys became a regular part of the field staff schedule.

During Phase 162, FJM identified a Blacktip Reef Shark nursery in “Sandbar”, and subsequently another at “Lighthouse”. A nursery is defined as ‘an area where young are born and reside as they grow towards maturity’ (Heupel, 2007), and at present there are no strict identification criteria for them. However, there are three characteristics proposed by Heupel et al., (2007) to classify a nursery area:

- Sharks are more commonly encountered in the area than other areas.
- Sharks have a tendency to remain or return for extended periods.
- The area or habitat is repeatedly used across the years.

Blacktip Reef Sharks are known to have very small ranges and high site fidelity (Papastamatiou et al., 2009). As a result of this, there is genetic heterogeneity between sub-populations of Blacktips (Hueter et al., 2005), so protecting the nursery grounds will aid in the preservation of species genetic diversity. Currently, sharks are at relatively low risk in Fiji, as they are considered sacred by the local inhabitants and catching them is prohibited in many villages (Rasalato et al., 2010). However, pressure from international demand for shark fins and foreign fishers may place them at risk. Focusing conservation efforts on areas of key ecological significance such as nursery grounds may prove the most effective way of protecting the species (Hueter et al., 2005), and FJM have identified areas where this can be done, if needs will arise in the future.

Following the discoveries of the nursery areas, snorkel surveys were conducted to monitor the shark population around the island, and to assess Blacktip Reef Shark nurseries in Lighthouse and Sandbar. Between phases 173 and 183, 19 trips to the nurseries were made with 77 total sightings, after which the trips to the nurseries ended. The average sizes across the phases were compared (Figure 15).

![Figure 15: A bar graph showing the average size of Blacktip Reef Sharks found at Lighthouse and Sandbar from Phase 173 to Phase 183 (FJM Science Report 183).](image-url)
During Phase 173 the number of shark population surveys was increased, and more survey sites were introduced. During this phase, 22 dives took place and 70 sharks were recorded for all the surveys. By Phase 184, 88 dives took place with a total 326 sightings. In addition, other megafauna was incorporated into the survey, such as Green Turtles and Kuhl’s Ray.

During Phase 193, 18 BRUV drops were conducted, 15 of those filming at least 1 hour of successful footage. The size of the BRUVs was reduced by 67% after some consideration, as it was suspected that its size was a potential cause of avoidance behaviours from sharks. Future datasets from the BRUV surveys are expected to produce more concrete results.
4 References


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