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Status and trends of coral reefs and associated coastal habitats in Fiji's Great Sea Reef

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A healthy coral reef patch with lila staghorn corals photographed in 2m depth at the inner reef sites around the RaviRavi passage north of Vanua Levu. Great Sea Reef Survey, Fiji.

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EXECUTIVE SUMMARY

GSR CONTAINS OVER 1,200 km² OF REEF SYSTEMS, INCLUDING THE THIRD LARGEST BARRIER REEF SYSTEM IN THE WORLD

The Great Sea Reef (GSR) region in Fiji stretches across an arc over 450 km long from the western coast of Viti Levu to the north eastern point of Vanua Levu. The GSR contains over 1,200 km² of reef systems, including the third largest barrier reef system in the world. It is exceptionally biodiverse – with over three quarters of known coral species, over half of recorded fish species, and almost half of known endemic species from Fiji. The GSR also plays a crucial role for Fijian livelihoods, food security, and cultural identity. A third of the Fijian population lives within the region, and over three quarters of all inshore fish supplied to urban markets are sourced from the reef. The GSR is also a major hub of international tourism – which generates over FJD 1.1 billion annually and accounts for more than 25% of Fiji's GDP. Marine areas within the reef are divided into *qoliqoli*—customary fishing areas—which are under control of indigenous Fijian communities.

During September-October 2019 the most comprehensive ecological survey of the GSR conducted to date was completed. The survey spanned 74 sites, extending along the full length of the GSR, from the Mamanuca Islands in the south west to Udu point in the north east. Of the sites surveyed, 48 had historic survey data available, allowing trends in coral reef health to be calculated. Survey results are reported for the GSR by province and by individual *qoliqoli*.

Across the GSR hard coral cover was found to be high at 34%, with the highest found in the northern GSR. For example, Bua province had exceptionally high coral cover at 45%, followed by 36% in Macuata province. Reefs in the south of the GSR had lower coral cover; 26% in Ba province and 23% in Nadroga-Navosa province – though this is still high relative to many reefs in the global context. Analysis of survey results suggests it was very

GSR HARD CORAL COVER AVERAGED 34%

unlikely that hard coral cover changed since the early 2000s across much of the reef, with past surveys indicating historic GSR regional coral cover of 31%. Algae cover was low across the GSR, though it was extremely likely there was a small increase – from 4% in historic surveys to 5% in 2019. However, there was evidence of recent disturbance to some reefs, with it virtually certain that rubble increased on reefs across the GSR (from 5% to 17%). These results suggest that while coral reef benthic communities remain generally healthy, there have been some recent disturbance to reefs.

Fish abundance and biomass were generally low across the GSR, with overall abundance of fish on the target family/species list of 2,878 ± 189 ind/ha, while biomass was at 421 ± 60 kg/ha. Reef fish communities were dominated by herbivores, with high abundance and biomass of Acanthuridae (surgeonfish) and Scaridae (parrotfish). It was very likely that key fisheries family abundance (Haemulidae, Lutjanidae, Scaridae, and Serranidae) declined by 33% across the GSR since historic surveys in the early 2000s. It was virtually certain that key fisheries family biomass declined 80%, with historic surveys previously recording biomass of these fish families at 1,198 kg/ha. These results therefore show that there has been a severe decline in fis abundance and biomass for the majority of sites with historical data available across the GSR.

80% DECLINE IN KEY FISHERIES FAMILY BIOMASS WAS OBSERVED ACROSS THE GSR

Rare species showed mixed trends. Serranidae (grouper) abundance and biomass were 28 ind/ha and 9 kg/ha in 2019, with it virtually certain that Serranidae abundance increased since the early 2000s at the coral reef sites with historical data. However, while an increase in grouper abundance was detected, grouper populations in 2019 remained very low across all sites, an some sites experienced declines in grouper abundance. This overall trend also hides variation between different grouper species, and also that very few large-bodied grouper were observed in the survey. Shark abundance and biomass across all species in Carcharhinidae in 2019 was 2.54 ind/ha and 66 kg/ha. The surveys indicated it was extremely likely that shark abundance increased. However, futher analysis is required to identify species-specific patterns, as most shark species remained at very low population levels. In addition to blacktip (*Carcharhinus melanopterus*), whitetip (*Triaenodon obesus*), and grey reef sharks (*Carcharhinus amblyrhynchos*), we also observed several bull sharks (Carcharhinus leucas) and silvertip sharks (*Carcharhinus albimarginatus*). Humphead wrasse (*Cheilinus undulatus*) were recorded at 1.55 ind/ha, suggesting it was unlikely their abundance changed since historic surveys. Only one bumphead parrotfish (*Bolbometopon muricatum*) was recorded during the 2019 survey, though bumphead parrotfish have been exceptionally rare since the early 2000s in the GSR. Work is required to rebuild populations of rare species groups.

Improvements in fisheries management and sustainability practices in the region are urgently needed.

Benthic habitat results are encouraging in the context of global trends in coral reef cover, where many reefs are declining globally. GSR benthic communities in 2019 compare favorably with other remote and protected reef systems in the Indo-Pacific region. Reef fish abundance and biomass were declining and low compared to global reference values for reef fish abundance and biomass required to maintain key ecological functions. Results suggest an urgent need to increase fisheries management and sustainability in the region to reverse these declines. Previous work has indicated that locally managed marine area networks set up within *qoliqoli* can increase fish abundance and biomass while being equitable for local communities. It is suggested these approaches be replicated across the GSR region.

Overall, we make 12 management recommendations to improve the condition of marine ecosystems in the GSR:

1. Expand existing and establish new protected areas and other effective conservation measures (OECMs) across the GSR to form a representative network.
2. Develop specific conservation programs for rare and endangered wildlife such as humphead wrasse (*Cheilinus undulatus*), bumphead parrotfish (*Bolbometopon muricatum*), camouflage grouper (*Epinephelus polyphekadion*), sharks, and other important species.
3. Improve suitable fisheries management within the GSR.
4. Promote economic incentives and community livelihood approaches that support sustainability and conservation.
5. Strengthen customary governance systems and state governance systems for both formal and informal management approaches.
6. Increase cross-institutions coordination.
7. Develop sustainable financing plans and mechanisms to support conservation activities in the GSR region.
8. Initiate legal protection for existing mangrove forests and seagrass beds and restore mangroves and seagrass in places that have been lost.
9. Assess and mitigate environmental impacts of land-based activities.
10. Assess and mitigate environmental impacts from coastal resource extraction and prohibit the most damaging extractive activities.
11. Promote sustainable coastal development practices.
12. Establish more regular monitoring and evaluation that can feed into adaptive management.

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Henry R. Koliniwai, a turtle monitor representative of the Nakawaga village on Mali Island. Macuata Province, Vanua Levu, Fiji.

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PART A

Status and trends in Great Sea Reef ecosystem health and management recommendations.

Fiji's Great Sea Reef region spans 450 km from western Viti Levu to the eastern end of Vanua Levu, representing the third largest barrier reef system in the world. The interlinked coral reefs, mangrove forests, and seagrass beds boast many rare species, including sharks and IUCN-listed bumphead parrotfish and humphead wrasse.

The Great Sea Reef plays a critical role in the lives of Fijians, sustaining many of their fisheries, international tourism ,and other industries - which translates to countless livelihoods in the region.

1 INTRODUCTIONS

The Great Sea Reef is at the foundation of much of Fijian Society, yet remains poorly studied.

44%
OF FIJI'S ENDEMIC SPECIES ARE FOUND IN THE GREAT SEA REEF

Globally coral reefs are under severe threat (Hughs et al. 2017), with both local and global pressures causing widespread degradation in many regions. Major local threats include over- and destructive fishing, pollution from sewage and other waste products, unsustainable land-use practice, or development leading to sedimentation (Dight and Scherl 1997). Since the late 1990s, climate change has also been recognized as a major driver of coral reef loss (Wilkinson 2000). Yet coral reefs provide crucial food security, livelihoods, and cultural value to millions of people worldwide (Teh et al. 2013; Spalding et al. 2017; Lau et al. 2019). This has led to increasing focus on marine management options that can support the resilience of coral reefs and the ecosystem services they provide under climate change (Côté and Darling 2010), including implementation of marine protected areas (MPAs). Yet, many coral reefs are incorporated into customary management and tenure systems that have existed for hundreds to thousands of years, which conservation approaches must reflect (Jupiter et al. 2014).

1.1 Fiji

Fiji is a South Pacific archipelago nation comprised of over 300 islands with a land area of approximately 18,270 km^2 (Mangubhai et al. 2019). The exclusive economic zone of Fiji spans approximately 1.29 million km^2 and contains rich marine habitats. Fiji's marine habitats range from shallow tropical marine systems, e.g. coral reefs, mangrove forests, and seagrass beds, to open ocean pelagic and deep-sea hydrothermal vent systems (Sykes et al. 2018). Over 2,340 species have been recorded from the coral reef systems in Fiji – the majority of which are fishes (Pyle 2019). Over 1,000 marine fish species (Seeto

4,550 KM²
OF CORAL REEFS EXTEND ACROSS THE FIJIAN ARCHIPELAGO

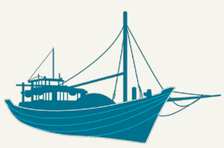
and Baldwin 2010; Mangubhai et al. 2019) and 342 species of scleractinian corals (Lovell and McLardy 2008) are native to Fiji. Shallow coral reefs in Fiji cover approximately 4,550 km^2, mangrove forests cover approximately 425 km^2, and seagrass beds are poorly mapped (Mangubhai et al. 2019).

Fisheries play both an important economic and cultural role in Fijian society. Fisheries were worth over USD 64 million in 2014 (Gillett et al. 2014), with reef fin fish primarily supplied to the domestic market and other marine products such as aquarium fish, seaweed, and beache-de-mer targeted for overseas exports (WWF-Pacific 2014). There are two major fishing sectors in Fiji: oceanic (offshore) and coastal (inshore). Small-scale commercial (or artisanal) and subsistence fishing are performed in coastal fisheries, managed primarily at the village or community level, but within an economic and policy context at a national scale (Gonzalez et al. 2015). There is no fishing quota control for inshore fisheries in Fiji, and overfishing, destructive, and illegal fishing, as well as pollution, are the most significant pressures on inshore reef fisheries. The control of overharvesting relies on communities engaging in some degree of fisheries management and/or conservation; initiatives for sustainable management of resources and conservation have incorporated both traditional and contemporary management methods.

Marine governance and ocean tenure in Fiji can be characterized by legal pluralism with both state and customary ownership recognized, a situation currently unresolved (Rohe et al. 2019). In practice, the Fisheries Act is the main legislation covering coastal areas in Fiji, which grants indigenous communities the right to fish and control access to fisheries within centuries-old customary fishing areas – known as *qoliqoli* (Rohe et al. 2019). Across Fiji, indigenous Fijian communities retain strong links to ancestral tribes (*yavusa*) who have common ancestors (Aswani et al. 2017). These tribes exercise management of the *qoliqoli* that cover the coastal areas of Fiji, under the control of community chiefs (Veitayaki 1998). *Qoliqoli* extend from the coastline to just beyond the outer edge of adjacent coral reefs (Sloan and Chand 2016). The Fijian government considers that *yavusa* have usufructuary rights to control access and manage the *qoliqoli*, but that the government and country of Fiji are the direct owners of these coastal areas.

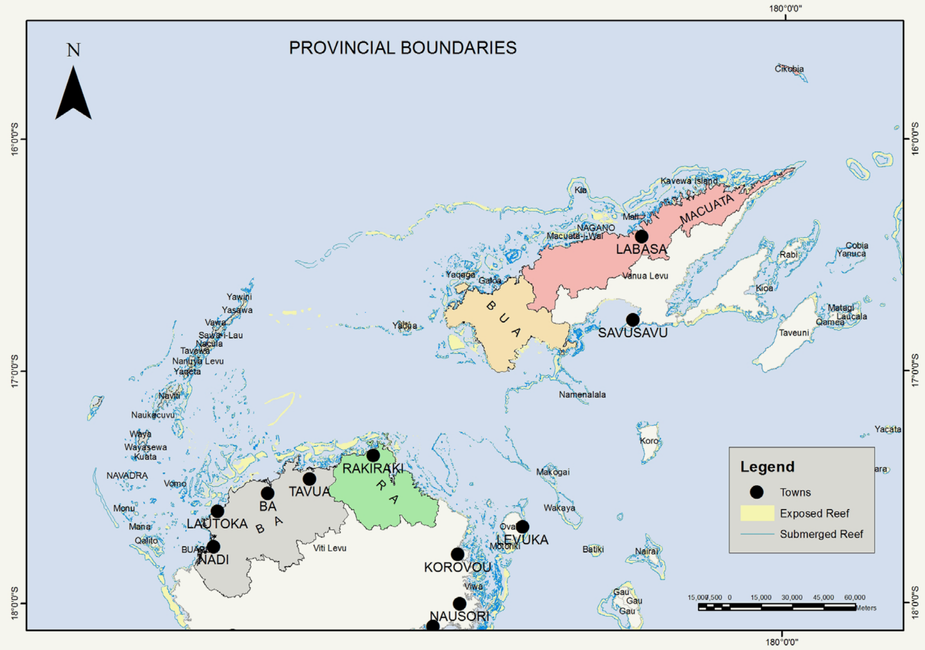
1.2 The Great Sea Reef

The Great Sea Reef (GSR) region stretches in an arc over 450 km long from western Viti Levu in the south to the eastern tip of Vanua Levu (Figure 1.2.1). In the south, the reef system begins in Nadroga-Navosa province, where it splits from the fringing reefs of Viti Levu to pass through the Mamanuca Islands, before extending north into Ba province through the Yasawa Islands. From the northern tip of the Yasawa Islands the reef extends eastward, crossing north of the Vatu-i-ra passage and across the northern edge of Blight Waters before reaching the north coast of Vanua Levu and running offshore of Bua province. The reef continues along Macuata province before merging with the fringing reefs of eastern Vanua Levu on Udu Point. The northern boundary of the GSR is marked by a near-continuous barrier reef from northeast of the Yasawa Islands running westward to Udu Point – over 250 km long. This barrier reef—known locally as Cakaulevu and also referred to as the "northern wall"—is the third largest barrier reef system in the world and includes a 25 km section along the north coast of Macuata province with



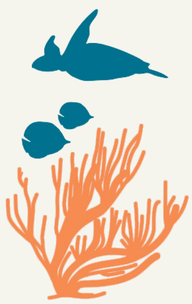
There is no fishing quota control for inshore fisheries in Fiji

Figure 1.2.1. The Great Sea Reef region. Major towns, islands, and provinces are labelled.



a double barrier reef system. The broader GSR region covers approximately 25,800 km^2 (Figure 1.2.2), and in addition to the seaward facing barrier reefs and islands also includes many inner reefs and other marine ecosystems within the lagoons and other marine areas of the provinces on Viti Levu (Nadroga-Navosa, Ba, and Ra) and Vanua Levu (Bua and Macuata).

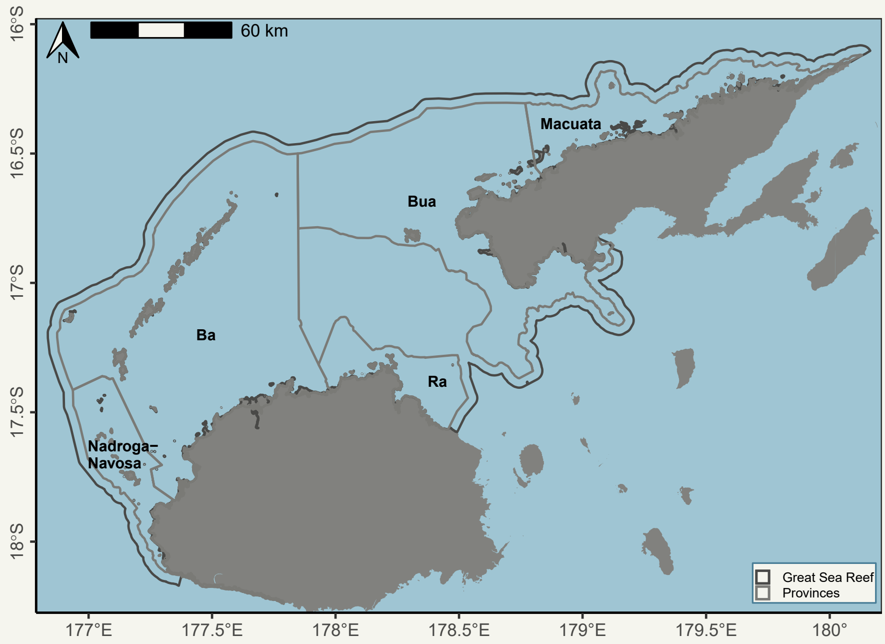
The GSR is very poorly studied biologically. The first systematic scientific assessment was conducted by WWF and partners in 2004 but was restricted to the northern section of the reef (Jenkins et al. 2005). The survey found that the GSR contained 55% of known fish species, 74% of known scleractinian coral species, and 40% of known marine algae in Fiji (Jenkins et al. 2005). In addition, 44% of reef species endemic to Fiji were also found on the GSR. IUCN rare species were also observed, including several endangered species such as humphead wrasse (*Cheilinus undulatus*), bumphead parrotfish (*Bolbometopon muricatum*), and several shark and turtle species. While a systematic survey, the number of sites visited in 2004 were limited and all surveys were limited to reef habitats, so these biodiversity numbers should be considered conservative, with the true marine species richness of the GSR likely much greater. Since 2004, there have been few biodiversity studies on the GSR, with those conducted restricted to small sections of the reef or individual *qoliqoli*, though there have been several fisheries monitoring assessments (Prince 2017).



Over 1,000 marine fish species and 342 species of scleractinian corals are native to Fiji

There have been multiple environmental and biological stressors affecting GSR coral reefs over the past few decades. Most of Fiji was impacted by high levels of coral bleaching in 2000 and moderate bleaching in 2002 and 2006, though reefs had high levels of recovery (Sykes 2007; Sykes and Whippy-Morris 2009). However, there was limited data available at this time for the GSR. Bleaching surveys conducted during 2000 around the islands and barrier reef north of Labasa in the northern GSR, and on the reefs of west Viti Levu on the south of the GSR found little bleaching evidence (Lovell

Figure 1.2.2. GSR region boundaries and provincial waters.

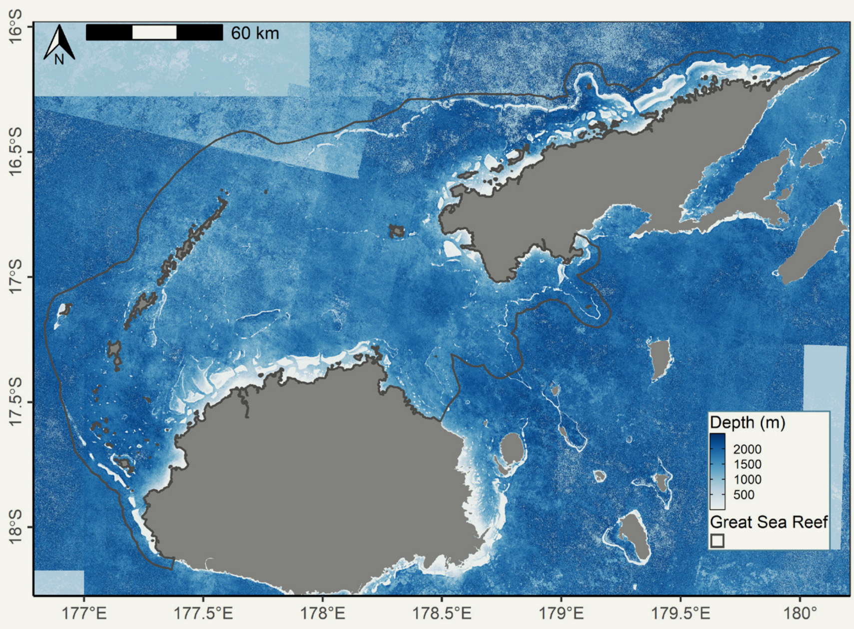


around 10%
OF FIJIAN PEOPLE ARE DIRECTLY DEPENDENT ON THE GSR FOR FOOD AND LIVELIHOODS

2000; Cummings et al. 2002). However, sites within the Vatu-i-Ra Passage and Yasawa Islands exhibited severe bleaching (Cummings et al. 2002; Sykes and Whippy-Morris 2009). Since 2006 there have not been any widespread bleaching events recording in Fiji (Mangubhai et al. 2019), however, some bleaching was observed in 2015 (F. Areki, personal communication, October 2020). Cyclones have also caused impacts to Fijian coral reefs in the past, with the main season between November and April (Mangubhai et al. 2019). In 2016 Cyclone Winston (Category 5) caused severe damage across the country and was the strongest cyclone on record for the region. However, there have not been any surveys of the GSR since this cyclone hit, so its impact on the reef is unknown. Elsewhere in Fiji, Cyclone Winston caused significant reef damage down to 20-30 m depth (Mangubhai 2016). The eye of Cyclone Winston passed over the coral reefs of Ra province and the southern GSR (west Viti Levu), and so there is potential for significant damage. Other threats that have been identified include semi-regular outbreaks of crown-of-thorns starfish (COTs; *Acanthaster planci*)—with several outbreaks recoded in the southern GSR in the early 2000s (Mangubhai et al. 2019)—and increased sedimentation from unsustainable land use practices (Figure 1.2.4).

The GSR is crucial for Fijian livelihoods and food security. Roughly one third (800,000 people) of Fiji's population lives in proximity, with approximately one tenth of the Fijian population directly reliant on the GSR for subsistence and livelihoods (WWF-Pacific 2014). Possibly over three quarters of all inshore fish supplied to urban markets within the country is primarily sourced from fishing grounds falling within the GSR boundaries (WWF-Pacific 2014). It has been estimated that the ecosystem services provided by coral reefs within the GSR are valued at approximately FJD 47.5 million annually, while mangrove-related fisheries production within the GSR is worth FJD 19.2 million annually (WWF-Pacific 2014). The inshore fisheries sector within the GSR is worth FJD 12-16 million annually. The GSR is also

Figure 1.2.3. Bathymetry of the GSR. The GSR contains a diversity of shallow water and deep sea ecosystems.



47,500,000
FIJIAN DOLLAR PER YEAR IS THE ESTIMATED VALUE OF FIJI'S REEF ECOSYSTEM SERVICES

a major hub of international tourism – which generates over FJD 1.1 billion annually and accounts for more than 25% of Fiji's GDP (FBS 2012).

Marine areas in the GSR region are divided into 33 distinct *qoliqoli* that are recognized by indigenous Fijian communities and registered with the government. These are distributed across the five provinces that comprise the GSR (Figure 1.2.5), with one *qoliqoli* in northern Nadroga-Navosa within the GSR region covering 1,298 km², 14 in Ba province covering 8,989 km², two in Ra province covering 1,235 km², nine in Bua province covering 6,191 km², and seven in Macuata province covering 2,038 km². Some marine areas within the GSR region are outside the *qoliqoli* and so are under direct government control. These areas, however, are deep water areas that do not contain shallow water tropical marine ecosystems and so are areas for pelagic fisheries rather than shallow reef artisanal fishing.

Formal marine protection in the GSR has been limited to date, though there is a rich history of customary management within *qoliqoli* to improve fisheries sustainability and increase food security (Jupiter et al. 2014). These customary management structures include permanent closures—tabu areas—that are no-take, as well as areas with conditional closures and rotational closures (Govan and Jupiter 2013). In recent times, with increasing coastal threats, there has been increased interest in building off this customary management to support conservation efforts leading to the establishment of the Fiji Locally Managed Marine Area (FLMMA) Network (Techera 2010; Jupiter et al. 2014). In 2005, local community chiefs working with FLMMA, WWF, and the University of the South Pacific established five new permanent tabu areas in Qoliqoli Cokovata, located in Macuata province (MPA News 2005). In addition, there were multiple areas established as open-close systems with scheduled monitored openings every five to ten years (WWF-Pacific 2017). Qoliqoli Cokovata is the combined *qoliqoli* areas of Dreketi, Macuata, Sasa, and Mali within Macuata province (WWF-Pacific 2017). This required bringing together community leaders, traditional fishermen

16,586 ha
OF MARINE HABITATS ARE PROTECTED WITHIN 18 TABU (NO-TAKE) RESERVES

Qoliqoli span from the coastline to the edges of nearby reefs, and are managed by indigenous communities based on ancestral tribes - the *yavusa*.

(Gonedau), traditional heralds (Matanivanua), traditional religious advisors (Bete), traditional warriors (Bati), village headmen (Turaga ni Koro), tribal leaders (Turaga ni Mataqali), and other members of the community in a workshop coordinated by FLMMA.

Today, these protected areas have expanded to include 18 tabu areas (totaling 16,586 ha), four mangrove reserves (740 ha), and five turtle nesting areas (0.7 ha) (WWF-Pacific 2019). In 2018, Qoliqoli Cokovata was declared a Ramsar site – the second Ramsar site in Fiji (WWF-Pacific 2019).

Partnerships between tourism businesses and local communities have also led to marine protection on the GSR. For example, several hotels are actively protecting marine areas and key species. In the Mamanuca Islands, around Tokoriki Island there is a giant clam (*Tridacna gigas*) nursery maintained by Tokoriki Diving at the Tokoriki Island Resort. Here, this historically overharvested species is grown to maturity in cages on the reef to protect them from predators before they are placed back onto the reef in an area protected from harvesting (Tokoriki Diving 2020). Many tourism operators in the GSR have marine conservation agreements with indigenous communities (Mangubhai et al. 2020). For example, the Botaira Resort in the Yasawa Islands has a no-take tabu area (approximately 53 ha) that is used for scuba diving and snorkeling. This was negotiated with local communities on the basis of employing local villagers in the resort (Mangubhai et al. 2020). Also in the Yasawas Group, several marine conservation agreements have been set up to protect areas between Drawaqa and Naviti Islands where manta rays (*Mobula alfredi*), spinner dolphins (*Stenella longirostris*), and sharks are commonly found. Here, tourists visiting to snorkel with manta rays pay a fee that goes to indigenous rights holders (Mangubhai et al. 2020). The resorts also report observations of fishing in tabu areas to community leaders.

With growing global threats to coral reefs, and increasing fisheries pressures facing Fiji, there is an urgent need to ensure adequate marine protection is in place. Given the different governance contexts of marine areas between *qoliqoli* and areas under the direct management of the Fijian government, such marine protection will need to be proposed, designated,

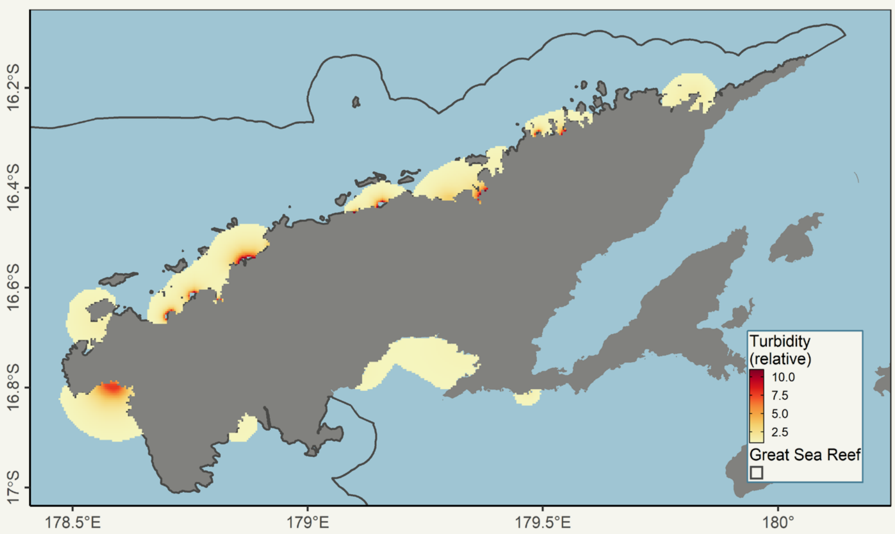
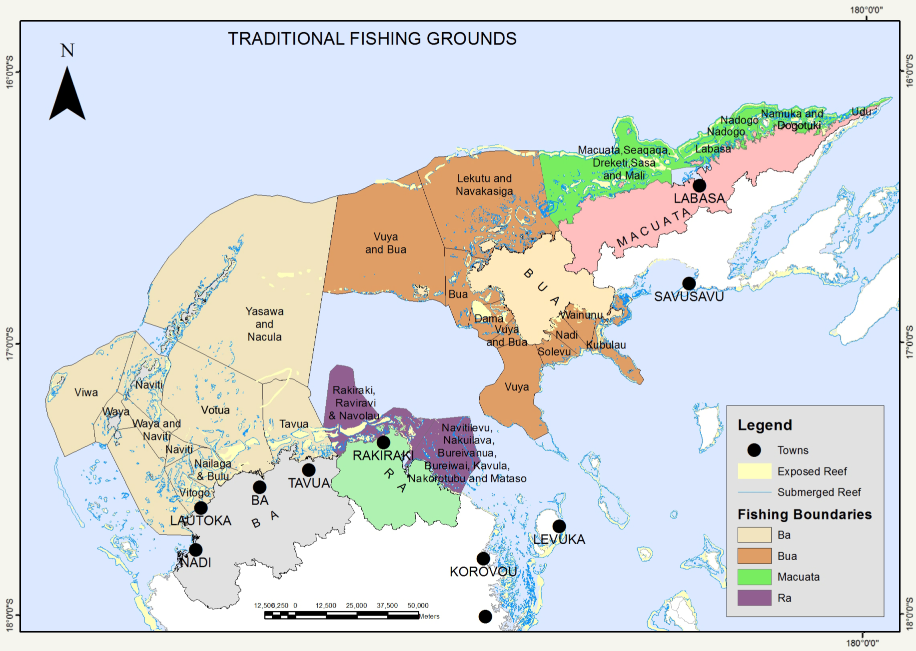


Figure 1.2.4. Modelled turbidity around Vanua Levu in the northern GSR. Most turbidity is caused by sediment from riverine input into coastal water. Data from Brown et al. 2017.

implemented, and then actively managed using a wide range of contextspecific approaches. However, given that the last systematic GSR survey was in 2004, a key first step is the reassessment of GSR ecosystem health. Here, is reported the 2019 GSR survey, jointly led by WWF and Ministry of Fisheries, Fiji, with the support and participation of the University of the South Pacific, University College London, the Zoological Society of London, and National Geographic Society. The 2019 survey represents the largest survey undertaken to date on the GSR, and the first to span the full arc of the reef. In this report are analyzed the extent of critical habitats, benthic habitat health, reef fish biomass, and the presence of rare species.

Figure 1.2.5 Qoliqoli boundaries in the GSR.



Portrait of Api Asenaca Lovoma (Secretary of the Woman's Group) with one of the products created with the kuta grass. Navakasobu village. Northern Vanua Levu, Fiji.

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2 SURVEY OVERVIEW

The survey incorporates 74 sites overall in 13 *qoliqoli* across four provinces, gauging diverse ecosystems and fisheries, and involving collaborations with multiple stakeholders.

The primary objective was to complete the first status assessment of GSR health across the full length of the reef system.

2.1 Survey aims

There were multiple broad aims for the GSR survey:

- Document current coral reef health for benthic habitats and fish communities at a representative set of sites across the full arc of the GSR.
- Identify changes in coral reef health for sites where historic data was available.
- Provide detailed surveys of reefs around the Ba River estuary and Qoliqoli Cokovata as priority areas where WWF-Pacific is working.
- Gather survey data that can inform marine spatial planning in the GSR region.
- Use the information generated to raise awareness nationally and internationally on the importance of the GSR for biodiversity conservation and local livelihoods.
- Provide a platform for additional survey methods to be deployed to support partner projects that can provide additional insights on the biodiversity and support conservation of the GSR.

2.2 Survey route overview

The 2019 GSR survey took place from 24 September – 13 October, with a pre-departure workshop taking place in Lautoka on 23 and 24 September. The survey used the Ministry of Fisheries vessel Bai Ni Takali (whose name means "protecting the ocean" in Fijian), departing from Lautoka, pulling into port in Labasa during the survey, before finishing in Suva (Figure 2.2.1). Table 2.2.1 provides an overview of the survey activities.

Survey participants included representatives of WWF, Fiji's Ministry of Fisheries, University of the South Pacific, Griffith University, and the Biome Health Project (Table 2.2.2). Also present as part of the team was a professional photographer tasked with documenting the survey.

Figure 2.2.1 GSR survey route overview.

The survey was supported by multiple institutions, including Fiji's Ministry of Fisheries, WWF, National Geographic Society, University of South Pacific, University College London, and Zoological Society of London.

Table 2.2.1. GSR survey activities overview.

Date	Location	District and Province	Activity	Number of sites surveyed
24 September	Lautoka	Vitogo, Ba	Survey	1
25 September	Tokoriki Island	Malolo, Nadroga-Navosa	Depart Lautoka Port for survey start early am. Survey	4
	Samu's Reef	Vuda and Waya, Ba	Survey	2
26 September	Ba Estuary	Nailaga and Bulu, Ba	Survey	1
	Ba Estuary	Nailaga, Ba	Survey	3
27 September	Central Nailaga	Nailaga, Ba	Survey	4
28 September	Ba Estuary	Nailaga, Ba	Survey	4
29 September	Navotua Village	Yasawa and Nacula, Ba	Rest day and village visit	
30 September	West coast of Matacawa Levu Island	Nacula, Ba	Survey	2
	West coast of Tavewa and Malakati Islands	Yasawa and Nacula, Ba	Survey	4
1 October	East coast of Yanggeta Island	Nacula, Ba	Survey	4
2 October	Yandua Island	Vuya and Bua, Bua	Survey	6
3 October	Inner islands, eastern Bua	Lekutu and Navakasiga, Bua	Survey	3
4 October	Inner islands, eastern Bua	Lekutu and Navakasiga, Bua	Survey	1
	Inner islands, western Macuata	Qoliqoli Cokovata, Macuata	Survey	5
5 October	Mali Channel & Mali Island, central Macuata	Qoliqoli Cokovata, Macuata	Survey	6
6 October	Labasa Port		Rest day and visit to Mali Island	
7 October	Kia Island and Outer Barrier Reef, central Macuata	Qoliqoli Cokovata, Macuata	Survey	6
8 October	Outer Barrier Reef, eastern Bua	Vuya and Bua, Bua	Survey	2
	Outer Barrier Reef, eastern Bua	Lekutu and Navakasiga, Bua	Survey	4
9 October	RaviRavi Passage and western Macuata Outer Barrier Reef	Qoliqoli Cokovata, Macuata	Survey	4
10 October	Labasa Port, then Inner Islands, eastern Macuata	Nadogo, Macuata	Fiji Day (public holiday), and Survey	1
11 October	Outer Barrier Reef, eastern Macuata	Nadogo, Macuata	Survey	1
	Channel and Inner Islands, eastern Macuata	Namuka and Dogotuki, Macuata	Survey	2
	Outer fringing reef, eastern Macuata	Udu, Macuata	Survey	2
12 October	Inner islands, western Macuata	Qoliqoli Cokovata, Macuata	Survey	2
13 October	Suva Port		Disembark for survey end	

Table 2.2.2. Survey team for the 2019 GSR survey.

Participant Name	Survey Role	Organization
Dr. Dominic Andradi-Brown	Lead Scientist, fish surveys	WWF-US
Metui Tokece	Fish surveys	WWF-Pacific Programme
Apolosa Robaigau	Benthic and big fish surveys	WWF-Pacific Programme
Lusiana Daletuicama	Benthic and big fish surveys	Ministry of Fisheries
Pitila Waqainabete	Benthic and big fish surveys	Ministry of Fisheries
Viliame Salabogi	Benthic and big fish surveys	Ministry of Fisheries
Apolosi Cokanasiga	Benthic and big fish surveys	Ministry of Fisheries
Rosemary Dautei	Fish surveys	University of the South Pacific
Tomasi Tikoibua	Benthic surveys	University of the South Pacific
Alyssa Giffin	Benthic surveys	Griffith University
Janice Taga	National Geographic Society - Allen Coral Atlas surveys	University of the South Pacific
George Naboutuiloma	National Geographic Society - Allen Coral Atlas surveys	University of the South Pacific
Moses Mataika	National Geographic Society - Allen Coral Atlas surveys	University of the South Pacific
Dr. Daniel Bayley	3D reef modelling	Biome Health Project – University College London
Olivia Hewitt	3D reef modelling	Biome Health Project – University College London
Nicholas Dunn	Stereo-video fish surveys	Biome Health Project – Zoological Society of London
Jonathan Greenslade	Stereo-video fish surveys	Biome Health Project – Zoological Society of London

2.3 Survey site selection

Survey sites were selected to optimize the survey objectives. The primary objective was to complete the first status assessment of GSR health across the full length of the reef system, and so sites were selected along the full arc of this system, including sites that had not previously been surveyed. To maximize insight, survey locations with historic data available were prioritized, including sites from the 2004 WWF GSR survey.

74 sites, 13 qoliqoli, 4 provinces - SITES REPRESENT THE FULL ARC OF THE WHOLE GREAT SEA REEF SYSTEM

74 sites in 2019 were surveyed (Figure 2.3.1; Table 2.3.1) with benthic surveys completed at 72 sites and fish surveys completed at 71 sites. Sites were located in four provinces and 13 *qoliqoli*. Full details of all sites, including surveys completed and GPS coordinates, are available in Table 2.3.2. Survey permits were issued by the Ministry of Fisheries, Fiji for this work to be conducted. Prior to surveys being conducted WWF-Pacific field staff visited *qoliqoli* leaders across the region to explain the purpose of the survey, the broad assessment methods that would be used, and sought permission for survey participants to enter each *qoliqoli* to conduct the survey.

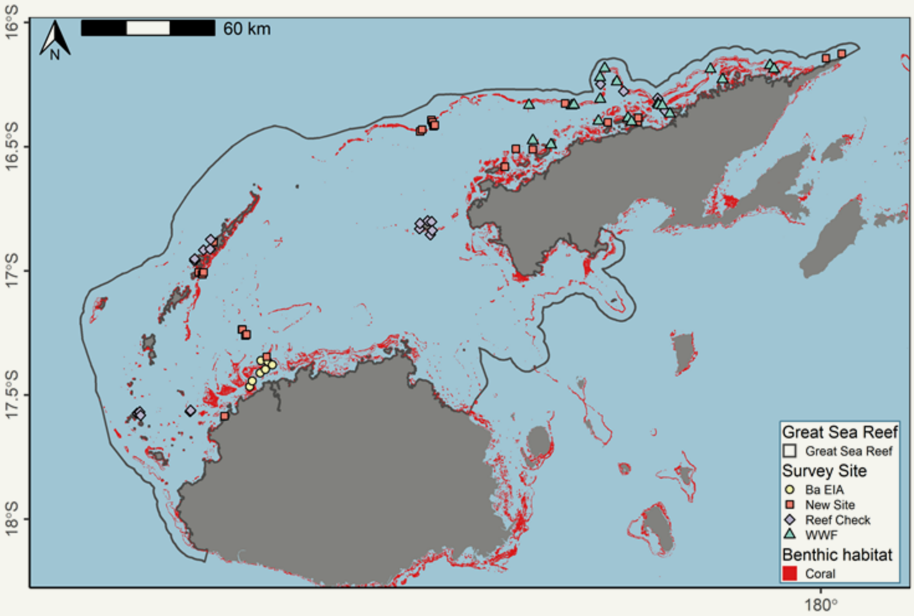

Figure 2.3.1 GSR survey sites in 2019. Sites are plotted over GSR coral reef extent and identified based on whether historic survey data is available. 'Ba EIA' indicates sites surveyed by the Ba province Environmental Impact Assessment (EIA); 'New Site' indicates a new site surveyed in 2019 with no historical data available to us; 'Reef Check' indicates a site with historic Reef Check surveys; 'WWF' indicates sites that were surveyed by the 2004 WWF GSR survey.

Table 2.3.1. Number of sites surveyed in 2019 by province and *qoliqoli*.

Province	Qoliqoli	Number of survey sites
Nadroga-Navosa		4
	Malolo	4
Ba		25
	Vuda & Waya	2
	Vitogo	1
	Nailaga & Bulu	1
	Nailaga	11
	Nacula	6
	Yasawa & Nacula	4
Bua		17
	Vuya & Bua	8
	Lekutu & Navakasiga	9
Macuata		28
	Cokovata	22
	Nadogo	2
	Namuka & Dogotuki	2
	Udu	2

Table 2.3.2. Sites surveyed in 2019 for benthic and fish communities. Subgroups indicate site groupings based on geography and reef types for analysis. Historic data available indicates whether there is past data available for the site. All latitude and longitude coordinates are given in WGS84 format. Site ID codes for sites with historic data match existing codes used by Lovell (2000), Jenkins et al. (2005), and GREENPAC (2011). Historic sites from the Reef Check database were given new Site ID codes.

Province / Site ID	Latitude	Longitude	Subgroup	Qoliqoli	Benthic	Fish	Historic data available
Nadroga-Navosa							
LW11	-17.57027	177.0869	Southern GSR	Malolo	Y	Y	Y
LW12	-17.575778	177.075833	Southern GSR	Malolo	Y	Y	Y
LW13	-17.57275	177.085111	Southern GSR	Malolo	Y	Y	Y
LW14	-17.583833	177.0905	Southern GSR	Malolo	Y	Y	Y
Ba							
BA02	-17.379581	177.650742	Ba Estuary	Nailaga	Y	Y	Y
BA03	-17.398367	177.621112	Ba Estuary	Nailaga	Y	Y	Y
BA04	-17.41175	177.59908	Ba Estuary	Nailaga	Y	Y	Y
BA05	-17.445179	177.565322	Ba Estuary	Nailaga	Y	Y	Y
BA08	-17.362855	177.602369	Ba Estuary	Nailaga	Y	Y	Y
BA09	-17.366208	177.632463	Ba Estuary	Nailaga	Y	Y	Y
BA10	-17.347054	177.626654	Ba Estuary	Nailaga	Y	Y	
BA07	-17.467203	177.555348	Ba Estuary	Nailaga & Bulu	Y	Y	Y
BA11	-17.257225	177.541657	Central Ba	Nailaga	Y	Y	
BA12	-17.261478	177.535525	Central Ba	Nailaga	Y	Y	
BA15	-17.23774	177.52339	Central Ba	Nailaga	Y	Y	
BA16	-17.236976	177.5209	Central Ba	Nailaga	Y	Y	
LW07	-17.586279	177.448437	Southern GSR	Vitogo	Y	Y	
LW03	-17.568944	177.301778	Southern GSR	Vuda & Waya	Y	Y	Y
LW04	-17.56387	177.30389	Southern GSR	Vuda & Waya	Y	Y	Y
YA01	-16.96129	177.31938	Yasawa Islands	Nacula	Y	Y	Y
YA02	-16.953694	177.319972	Yasawa Islands	Nacula	Y	Y	Y
YA07	-17.007427	177.358101	Yasawa Islands	Nacula	Y	Y	
YA08	-17.015995	177.352197	Yasawa Islands	Nacula	Y		
YA09	-17.014933	177.350759	Yasawa Islands	Nacula	Y	Y	
YA10	-17.007162	177.337232	Yasawa Islands	Nacula	Y	Y	
YA03	-16.918	177.357667	Yasawa Islands	Yasawa & Nacula	Y	Y	Y
YA04	-16.914056	177.385417	Yasawa Islands	Yasawa & Nacula	Y	Y	Y
YA05	-16.875722	177.387278	Yasawa Islands	Yasawa & Nacula	Y	Y	Y
YA06	-16.885161	177.400219	Yasawa Islands	Yasawa & Nacula	Y	Y	
Bua							
IB1	-16.469517	178.751517	Inner Reef	Lekutu & Navakasiga	Y	Y	Y
YQ01	-16.50346	178.67955	Inner Reef	Lekutu & Navakasiga	Y		
YQ02	-16.57648	178.63327	Inner Reef	Lekutu & Navakasiga	Y	Y	
YQ04	-16.505479	178.751384	Inner Reef	Lekutu & Navakasiga	Y	Y	
CH1	-16.327467	178.7336	Seaward Barrier Reef	Lekutu & Navakasiga	Y	Y	Y
GS01	-16.39027	178.320863	Seaward Barrier Reef	Lekutu & Navakasiga	Y	Y	

GS02	-16.399878	178.32556	Seaward Barrier Reef	Lekutu & Navakasiga		Y	
GS03	-16.411183	178.335652	Seaward Barrier Reef	Lekutu & Navakasiga	Y	Y	
GS04	-16.415195	178.33055	Seaward Barrier Reef	Lekutu & Navakasiga	Y	Y	
GS05	-16.428833	178.281872	Seaward Barrier Reef	Vuya & Bua	Y	Y	
GS06	-16.43682	178.27373	Seaward Barrier Reef	Vuya & Bua	Y	Y	
YD01	-16.800117	178.324889	Yadua Island	Vuya & Bua	Y	Y	Y
YD02	-16.796583	178.308611	Yadua Island	Vuya & Bua	Y	Y	Y
YD03	-16.807389	178.275611	Yadua Island	Vuya & Bua	Y	Y	Y
YD04	-16.829139	178.274	Yadua Island	Vuya & Bua	Y	Y	Y
YD05	-16.835083	178.327778	Yadua Island	Vuya & Bua	Y	Y	Y
YD06	-16.852333	178.319667	Yadua Island	Vuya & Bua	Y	Y	Y
Macuata							
IP1	-16.48624	178.828214	Inner Reef	Macuata Seaqaqa Dreketi Sasa & Mali	Y	Y	Y
IP2	-16.35655	179.330067	Inner Reef	Macuata Seaqaqa Dreketi Sasa & Mali	Y	Y	Y
IP3	-16.390467	179.168	Inner Reef	Macuata Seaqaqa Dreketi Sasa & Mali	Y	Y	Y
IP3.5	-16.375133	179.153617	Inner Reef	Macuata Seaqaqa Dreketi Sasa & Mali	Y	Y	Y
IP4	-16.3885	179.027667	Inner Reef	Macuata Seaqaqa Dreketi Sasa & Mali	Y	Y	Y
IP5	-16.393909	179.067801	Inner Reef	Macuata Seaqaqa Dreketi Sasa & Mali	Y	Y	
IP6	-16.373951	179.19535	Inner Reef	Macuata Seaqaqa Dreketi Sasa & Mali	Y	Y	
IP7	-16.390431	179.194997	Inner Reef	Macuata Seaqaqa Dreketi Sasa & Mali	Y	Y	
Site 1	-16.344039	179.308722	Inner Reef	Macuata Seaqaqa Dreketi Sasa & Mali	Y		Y
IP4.5	-16.215217	179.550667	Inner Reef	Nadogo	Y	Y	Y
IB4	-16.1715	179.768017	Inner Reef	Namuka & Dogotuki	Y	Y	Y
CH4A	-16.32829	178.91351	Leeward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y
GS07	-16.31936	178.88593	Leeward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	
IB3	-16.230117	179.104617	Leeward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y
Site 3A	-16.268417	179.133472	Leeward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y
IB5	-16.174517	179.499233	Leeward Barrier Reef	Nadogo	Y	Y	Y
CH2A	-16.3154	179.278717	Seaward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y
CH2B	-16.320883	179.28155	Seaward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y
CH4B	-16.324833	178.92305	Seaward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y
IB2	-16.324367	179.297667	Seaward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y
OB1A	-16.300117	179.034167	Seaward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y

OB1B	-16.213	179.032683	Seaward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y
OB3	-16.176233	179.051933	Seaward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali		Y	Y
Site 2	-16.295139	179.277861	Seaward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y
Site 4	-16.240417	179.035083	Seaward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y
CH5	-16.15627	179.75037	Seaward Barrier Reef	Namuka & Dogotuki	Y	Y	Y
UP01	-16.12494	179.98643	Seaward Barrier Reef	Udu	Y	Y	
UP02	-16.1057	-179.94705	Seaward Barrier Reef	Udu	Y	Y	

2.4 Other supported projects

In addition to the primary GSR survey, two additional projects were supported from key partners during the survey. The first was the Allen Coral Atlas, with involvement coordinated by National Geographic Society with University of the South Pacific students collecting field data. This team conducted snorkel surveys to support new remote-sensed shallow marine habitat maps. Given that large sections of the GSR had been missed from past global coral reef datasets, generating new maps that document the full extent of the reef is key to informing and supporting ongoing conservation efforts. We use these Allen Coral Atlas data layers to quantify coral reef and seagrass extent within the GSR.

The Biome Health Project, a WWF-UK funded project led by University College London and the Zoological Society of London, was also supported. This team was interested in understanding how human pressure gradients on the GSR affected biodiversity – with a particular focus on fisheries and sedimentation. They used video- and audio-based survey techniques to capture permanent records of reef benthic condition in 3D models (Box 1), reef fish communities including fish size and biomass (Box 2), and reef soundscapes. These allowed new insights to be generated beyond those that traditional reef survey methods enable.

Box 1 - Using the Latest Underwater Imaging Technology

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Structure from motion photogrammetry is an emerging monitoring tool in marine science, being used to digitally recreate reefs in 3D (Bayley and Mogg 2020; Bayley et al. 2019). This technique stitches together many hundreds of overlapping camera images, taken from multiple angles around the reef, in order to recreate its complex shape. It is then possible to overlay a mosaic of these images on top of the reconstructed 3D surface to make an accurate, color representation of all the corals, molluscs, sponges, and algae that make up the reef. Researchers can then use this data to record and quantitatively analyze the reef in a range of ways.

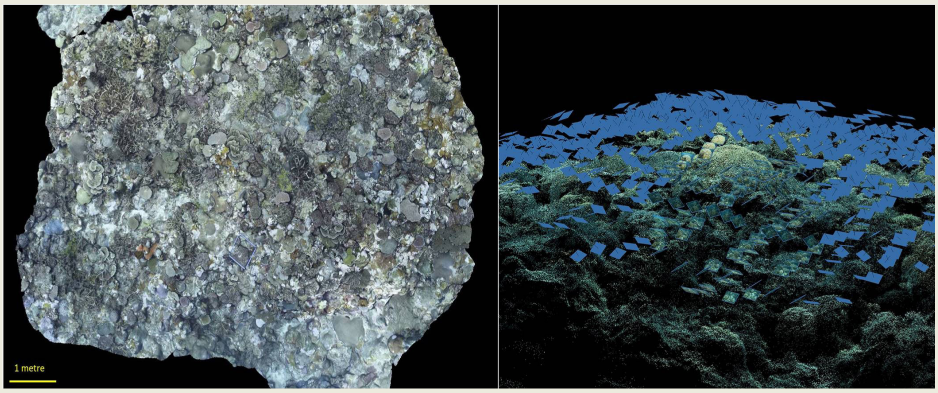

Figure B1.1. A photo-mosaic of approximately 100 m2 of reef, imaged north of Vanua Levu, Fiji (left). A 3D recreation of the surface of the reef, and individual camera positions shown in blue (right).

Reef 3D complexity is an important measure of reef health and resilience, which also governs fish diversity and abundance (Graham and Nash 2013). Sadly many reefs are now becoming degraded and less complex over large areas due to human and environmental damage (Alvarez-Filip et al. 2009). Therefore, during the 2019 Great Sea Reef (GSR) survey, researchers on the WWF-UK-funded ‘Biome Health Project’ used this new technology at 29 sites to survey the reef’s structure in detail. The Project aims to develop a system that provides new evidence on how biodiversity responds to human pressures and how conservation interventions can be used to reduce the impacts of those pressures: coral reefs are one of four biomes of study for the Project. The outputs from analysis will be used to help answer questions about the effects of varying levels of disturbance on physical structure and community composition of Fiji’s reefs. These datasets can then also be used to refer back to in the future, allowing researchers to see any changes occurring on the reefs following disturbance events like coral bleaching.

Box 2 - Diver Operated Stereo-Video Surveys

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Diver operated stereo-video (Stereo-DOV) systems are an increasingly used tool for monitoring fish communities (e.g. Andradi-Brown et al., 2016). The method uses two video cameras mounted on a horizontal bar with overlapping fields of view. The system is carried by a SCUBA diver along a predetermined transect, with both cameras independently filming. Videos are then analyzed to estimate species richness, the relative abundance of fishes, overall diversity metrics, the length (and subsequently biomass) for individual fish, and the distance fish are away from the cameras. The major benefits of this method compared to traditional Underwater Visual Census (UVC) methods is that it allows the more rapid collection of data (Goetze et al., 2015; 2017). Additionally, it is not as influenced by observer bias as UVC (Thompson & Mapstone, 1997; Harvey et al., 2004).

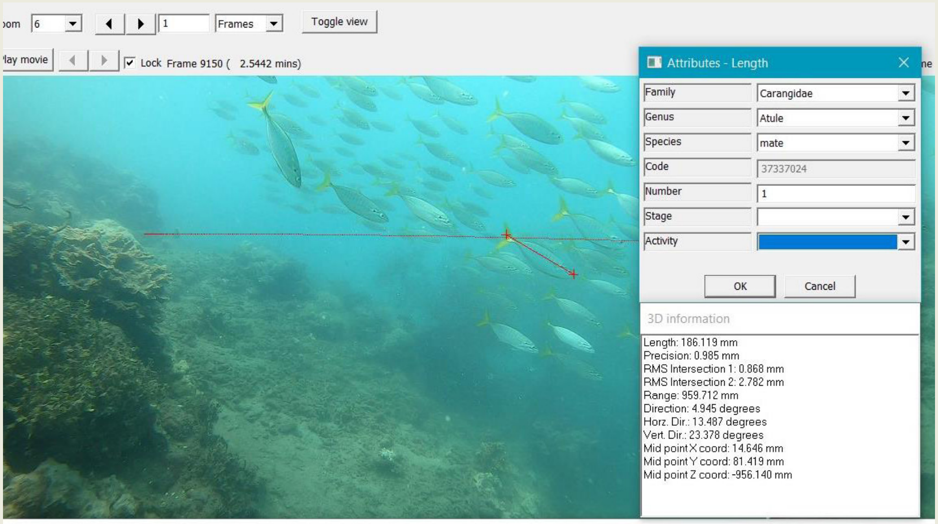


Figure B2.1. The interface of the EventMeasure software used to analyse the stereo DOV videos collected during the Great Sea Reef survey. Red crosses are placed on the tip of the snout and the fork in the tail of each individual fish within each overlapping stereo image (left and right). The linear distance between crosses gives the fork length (mm). In this example, a yellowtail scad (*Atule mate*) is measured as having a fork length of 186mm.

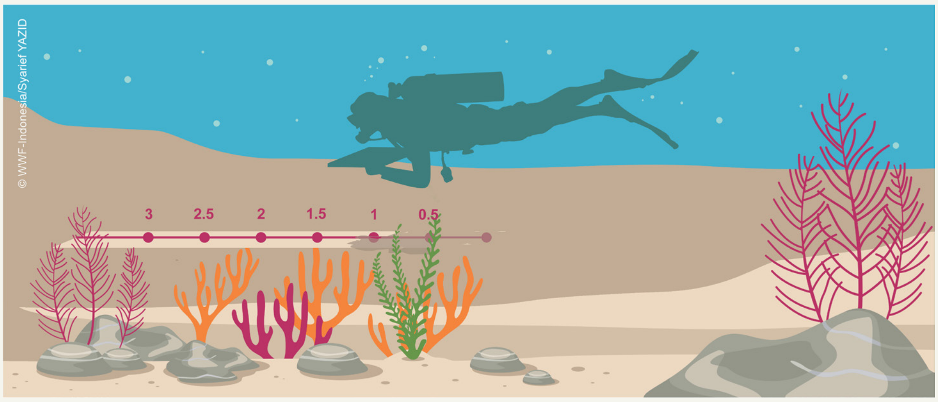
During the 2019 Great Sea Reef (GSR) survey, Biome Health researchers conducted 117 stereo-DOVs across 31 sites. These data are currently being analysed to assess the health of reef fish communities across the Great Sea Reef. Video transect data will also be archived and will act as a permanent record of the GSR that can be cross-checked in the future, resampled for additional data, or reanalyzed by other researchers.

2.5 Survey methods overview

Here survey results are reported based on underwater visual transects conducted at each site. Surveys targeted 10 m depth at each site, though some cases varied based on local reef conditions. Three broad survey types were conducted: (i) benthic habitats monitoring, (ii) fish community monitoring, and (iii) invertebrate community monitoring. In this report we focus on analyzing the benthic and fish community data. Three transects were conducted at each site, with each transect 50 m long and placed parallel to the reef crest following the depth contour. More detailed survey methods are provided in Chapter 9 – Survey protocol.

To survey benthic habitats a point-intercept transect (PIT) method was used. PIT is a fast, efficient method that provides reliable estimates of the cover of corals and other sessile benthic invertebrates, algae, and substrate type (Hill and Wilkinson 2004). Along each of the three 50 m long transect lines, the benthic habitat cover was recorded at 0.5 m intervals directly under the transect line starting at 0.5 m and finishing at 50 m (Figure 2.5.1) This resulted in 100 benthic survey points per transect, with three transects per site, generating a total of 300 benthic survey points per site. Broad benthic categories were identified, including bare substrate, crustose coralline algae, hard coral, macroalgae, rubble, sand, soft coral, sponge, turf algae, and other invertebrate groups. For hard corals we recorded the growth form and the genus where possible. See Chapter 9.4 for more detailed classifications of benthic categories recorded.

Figure 2.5.1. Benthic point intercept transect. Benthic cover was recorded at 0.5 m intervals along the 50 m length transect. Adapted from Amkieltiela and Wijonarno (2015), based on Wilson and Green (2009).



Underwater visual census (UVC) along fish belt transects was used for assessing coral reef fish abundance and length. Fish belt transects provide a high degree of precision for most fisheries species and herbivores and are suitable for monitoring for multiple objectives (fisheries and resilience). Reef fishes were surveyed using three 50 m long transects at each site. Each transect consisted of two fish observers swimming along transects who counted and estimated the size—total length (TL)—of individual fish of the target fish species based on two different transect widths (Figure 2.5.2). The first observer swam 1-2 m above the substratum along the transect, counting and estimating the size of small to medium sized individuals (0 - 40 cm TL) using a transect width of 5 m (2.5 m either side of the transect tape). The second observer swam slightly behind and above the first observer to provide a better view of the larger area and to minimize disturbance to small fishes

48 sites

ON THE GSR HAVE HISTORIC DATA - ALLOWING TRENDS TO BE ESTIMATED.

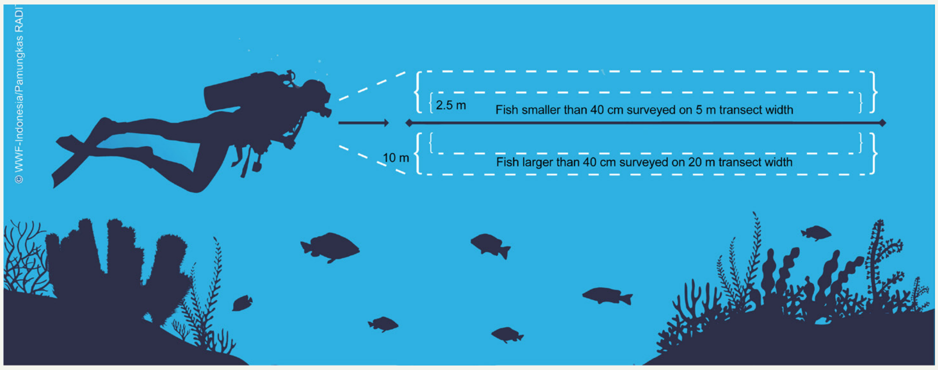


Figure 2.5.2. Fish belt transect. Fish less than 40 cm total length were recorded on a 5 m transect width – which equates to 2.5 m on either side of the observer. Fish greater than 40 cm total length were recorded on a 20 m transect width – which equates to 10 m on either side of the observer. Transects were 50 m long. Adapted from Amkieltiela and Wijonarno (2015).

by the passage of the divers. The second observer counted and estimated the size of all large individuals (>40 cm TL) using a wider transect width of 20 m (10 m either side of the transect tape). For fish in the 0-40 cm TL size range, individuals were assigned to one of four size categories: 0-10 cm, 10-20 cm, 20-30 cm, or 30-40 cm. For fish larger than 40 cm, the total length of each individual was estimated to the nearest 10 cm. Fish identification was done at the most accurate taxonomic level possible for the observer – either species or family level. Only target fish families/species were recorded on the transects (see Table 2.5.1); these broadly represent important herbivores, fisheries species, and key indicator species.

2.6 Historic data

Historic benthic and fish data were incorporated to allow trends in ecosystem condition to be calculated for 48 sites on the GSR. The majority of historic data comes from the early 2000s (Table 2.6.1), with 24 sites surveyed in 2004, seven in 2003, one in 2001, and four in 2000. Though some more recent data was included, with three sites surveyed in 2006, one in 2007, seven in 2010, and one in 2011. Given the large temporal gap between all historic data and the 2019 survey, for this report all historic data were grouped together to compare to 2019 to identify change.

2.6.1 2004 WWF Great Sea Reef Survey

Benthic and fish data from the 2004 WWF Great Sea Reef Survey were incorporated (Jenkins et al. 2005). This survey was conducted from 6-15 December 2004 and was restricted to the north coast of Vanua Levu. During the 2019 survey, we resurveyed 20 of the historic 2004 WWF GSR survey sites (Table 2.6.1). Benthic data in the 2004 survey followed the Global Coral Reef Monitoring Network protocol, with four point intercept transects of 20 m length each using 0.5 m intercept intervals. These benthic transects identified benthic habitat cover into broadly similar benthic habitat types. Fish data was by UVC, conducted as two 50 m long by 5 m wide transects per site recording all observed fish species and estimating their lengths using the following size categories: (i) <2 cm, (ii) 2-5 cm, (iii) 5-10 cm, (iv) 10-15 cm, (v) 15-20 cm, (vi) 20-25 cm, (vii) 25-30 cm, (viii) 30-35 cm, (ix) 35-40 cm, and (x) >40 cm. For fish >40 cm length, no record of the actual fish lengths is available. The same site identification labels for these sites as the 2004 survey were used to enable easy site comparisons between this historic data and the recent survey data. For more information see the 2004 WWF Great Sea Survey Report (Jenkins et al. 2005).

2.6.2 Other Historic Surveys

Other historic coral reef data from 2000–2011 were used to increase the range of sites that we could calculate trends for. This additional historic data was taken from three sources: (i) Reef Check data directly from the Reef Check database (Reef Check Foundation 2019), (ii) benthic surveys from a report that followed reef check methodology (Lovell 2000), and (iii) fish surveys from an environmental impact assessment (EIA) associated with the Ba River estuary (GREENPAC 2011).

Reef Check monitoring comprised of both benthic cover and fish abundance surveys. Data were sourced from 17 sites from the Reef Check database (Reef Check Foundation 2019). For benthic surveys, Reef Check conducts four 20 m long point intercept transects with the benthic cover recorded at 0.5 m intervals. Reef check fish surveys are conducted by UVC along the same four 20 m transects using a 5 m transect width. Fish abundance on the transects is recorded and archived in the database for the following target families: Chaetodontidae, Haemulidae, Lutjanidae, Muraenidae, Scaridae, and Serranidae, and the following species: Bolbometopon muricatum, Cheilinus undulatus, and Cromileptes altivelis. In addition, rare species (e.g. sharks and turtles) observed at the site are recorded as additional observations.

Additional historic benthic data came from a report that followed reef check methodology (Lovell 2000). Lovell (2000) surveyed sites in central Macuata province in 2000 to assess the presence and severity of coral bleaching – identifying little bleaching at these four sites. Four of these sites were resurveyed in 2019.

Historic Ba Estuary fish surveys were conducted in 2010 as part of an environmental impact assessment (EIA) to initiative sand dredging from the Ba River delta (GREENPAC 2011). The EIA followed the same fish assessment protocol as outlined for the 2004 WWF fish surveys. In brief: two 50 m by 5 m transects per site, recording all individual fish observed within the transect area to species level and into the following ten length class groups; (i) <2 cm, (ii) 2-5 cm, (iii) 5-10 cm, (iv) 10-15 cm, (v) 15-20 cm, (vi) 20-25 cm, (vii) 25-30 cm, (viii) 30-35 cm, (ix) 35-40 cm, and (x) >40 cm. For fish >40 cm length, no record of the actual fish length is available. The same site identification labels for the Ba Estuary as used in the EIA (GREENPAC 2011) were used to enable easy site comparisons between this historic data and the recent survey data.

Table 2.6.1. Historic survey data availability and sources. Fish abundance indicates that fish surveys recording counts of fish families/species are available from transects at the site, while fish biomass indicates whether these fish surveys included length estimates for individual fish allowing biomass to be calculated. Historic data sources: 'Ba EIA' indicates sites surveyed by the Ba Estuary Environmental Impact Assessment (GREENPAC 2011); 'Reef Check' indicates a site with historic survey data in the Reef Check database (Reef Check Foundation 2019); 'Lovell' indicates benthic surveys from Lovell (2000) that followed Reef Check methodologies; 'WWF' indicates sites that were surveyed by the 2004 WWF GSR survey (Jenkins et al. 2005).

Site Identification	Historic survey year	Subgroup	Qoliqoli	Benthic Cover	Fish Abundance	Fish biomass	Data Source
Nadroga-Navosa							
LW11	2004	Southern GSR	Malolo	Y	Y		Reef Check
LW12	2004	Southern GSR	Malolo	Y	Y		Reef Check
LW13	2004	Southern GSR	Malolo	Y	Y		Reef Check
LW14	2004	Southern GSR	Malolo	Y	Y		Reef Check
Ba							
BA02	2010	Ba Estuary	Nailaga		Y	Y	Ba EIA
BA03	2010	Ba Estuary	Nailaga		Y	Y	Ba EIA
BA04	2010	Ba Estuary	Nailaga		Y	Y	Ba EIA
BA05	2010	Ba Estuary	Nailaga		Y	Y	Ba EIA
BA08	2010	Ba Estuary	Nailaga		Y	Y	Ba EIA
BA09	2010	Ba Estuary	Nailaga		Y	Y	Ba EIA
BA07	2010	Ba Estuary	Nailaga & Bulu		Y	Y	Ba EIA
LW03	2011	Southern GSR	Vuda & Waya	Y	Y		Reef Check
LW04	2007	Southern GSR	Vuda & Waya	Y	Y		Reef Check
YA01	2003	Yasawa Islands	Nacula	Y	Y		Reef Check
YA02	2006	Yasawa Islands	Nacula	Y	Y		Reef Check
YA03	2003	Yasawa Islands	Yasawa & Nacula	Y	Y		Reef Check
YA04	2006	Yasawa Islands	Yasawa & Nacula	Y	Y		Reef Check
YA05	2006	Yasawa Islands	Yasawa & Nacula	Y	Y		Reef Check
Bua							
IB1	2004	Inner Reef	Lekutu & Navakasiga	Y	Y	Y	WWF
CH1	2004	Seaward Barrier Reef	Lekutu & Navakasiga	Y	Y	Y	WWF
YD01	2003	Yadua Island	Vuya & Bua	Y	Y		Reef Check
YD02	2003	Yadua Island	Vuya & Bua	Y	Y		Reef Check
YD03	2003	Yadua Island	Vuya & Bua	Y	Y		Reef Check
YD04	2003	Yadua Island	Vuya & Bua	Y	Y		Reef Check
YD05	2003	Yadua Island	Vuya & Bua	Y	Y		Reef Check
YD06	2001	Yadua Island	Vuya & Bua	Y	Y		Reef Check
Macuata							
IP1	2004	Inner Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y	WWF
IP2	2004	Inner Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y	WWF

IP3	2004	Inner Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y	WWF
IP3.5	2004	Inner Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y	WWF
IP4	2004	Inner Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y	WWF
Site 1	2000	Inner Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y			Lovell
IP4.5	2004	Inner Reef	Nadogo	Y	Y	Y	WWF
IB4	2004	Inner Reef	Namuka & Dogotuki	Y	Y	Y	WWF
CH4A	2004	Leeward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y	WWF
IB3	2004	Leeward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y	WWF
Site 3A	2000	Leeward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y			Lovell
IB5	2004	Leeward Barrier Reef	Nadogo	Y	Y	Y	WWF
CH2A	2004	Seaward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y	WWF
CH2B	2004	Seaward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y	WWF
CH4B	2004	Seaward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y	WWF
IB2	2004	Seaward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y	WWF
OB1A	2004	Seaward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y	WWF
OB1B	2004	Seaward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y	WWF
OB3	2004	Seaward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y	Y	Y	WWF
Site 2	2000	Seaward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y			Lovell
Site 4	2000	Seaward Barrier Reef	Macuata, Seaqaqa, Dreketi, Sasa, & Mali	Y			Lovell
CH5	2004	Seaward Barrier Reef	Namuka & Dogotuki	Y	Y	Y	WWF

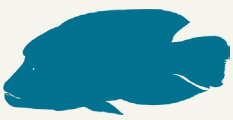
2.7 Habitat and ecological indicators

2.7.1 Benthic

To evaluate benthic habitat cover at sites, broad benthic indicators as recommended by the International Coral Reef Initiative were used (ICRI 2020). Two broad indicators for reef status based on 2019 data were also used: (i) hard (scleractinian) coral cover, and (ii) macroalgae cover. High hard coral cover is generally associated with healthy reefs and limited levels of disturbance. For example, both coral bleaching events that cause mortality and cyclone impacts have reduced hard coral cover in Fiji (Mangubhai et al 2019). Direct anthropogenic impacts, such as destructive fishing and pollution can also lead to reduced hard coral cover (Dight and Scherl 1997). Macroalgae cover is also an indicator of reef health, with high coverage of macroalgae generally associated with degraded reefs (Green and Bellwood 2009). Macroalgae cover can increase in the presence of nutrient pollution or the overharvesting of herbivorous reef species such as Acanthuridae (surgeonfish) or Scaridae (parrotfish).To evaluate trends through time changes in percentage hard coral cover were compared. As not all historic data sources separated macroalgae cover from other algae types (e.g. algal turfs), for comparisons through time changes in percentage cover of all algal types grouped were compared.

2.7.2 Fish

The 2019 fish community data by abundance and biomass were analyzed at the family level to identify dominant families. A single fisheries indicator group was used to summarize surveys per site and allow comparisons through time – key fisheries families. This was comprised of the families Haemulidae (sweetlips), Lutjanidae (snapper), Scaridae (parrotfish), and Serranidae (grouper). These families were chosen as focus species as they are important fisheries and functional species as well as Reef Check indicator species for the Pacific region, and so are consistently available in the historic fish datasets. All sites with historic fish data available included abundance of key fisheries families, allowing comparisons through time. Fish biomass comparisons through time were limited to a subset of historic sites (WWF 2004 survey sites, Ba EIA sites) that had historic fish length data available, enabling biomass to be calculated. In addition to the key fisheries family indicator, changes in rare species were also evaluated. Rare species groups were: (i) humphead wrasse (*Cheilinus undulatus*), (ii) bumphead parrotfish (*Bolbometopon muricatum*), (iii) grouper (Serranidae), and (iv) sharks of the family Carcharhinidae.



Rare species included in the survey include humphead wrasse, bumphead parrotfish, groupers, and sharks

2.8 Data analysis

2.8.1 Ecological data analysis

For analysis sites were grouped in four ways: (i) GSR region, (ii) province, (iii) subgroup, and (iv) *qoliqoli*. The GSR region analysis included all sites, while the province analysis included sites grouped by provincial waters. Subgroups represented groupings of sites based on a combination of geographic location in the GSR region and reef type (e.g. separate sites on the seaward side of the outer barrier reef from sites on the inshore sheltered fringing reef). *Qoliqoli* level analysis provides the status and trends grouped by sites within each customary fishing ground.

All data was entered into the Marine Ecological Research Management Aid (MERMAID; MERMAID 2018) by the surveyors while in the field and in the immediate week following the survey. MERMAID supports rapid data cleaning and analysis, and we used default MERMAID lengthweight conversions based on Fishbase (Froese and Pauly 2019) to convert fish lengths to biomass estimates. All survey data was then output and analyzed in R (R Core Team 2020) for analysis. Multiple transects at each site were averaged together to create overall site means for each indicator, and analysis was then conducted at the site level (i.e. site as the level of replicate). Fish biomass values were calculated in two ways: (i) when 2019 biomass values for individual fish families, key fisheries families, or rare species are presented to indicate current status, they are calculated using the recorded 2019 fish lengths and (ii) when 2019 fish biomass is compared with historic fish biomass for key fisheries families or for rare species these biomass values are calculated based on all fish >40 cm TL being 45 cm length. This is necessary because the historic fish biomass data does not provide any length estimates for individual fish >40 cm TL.

Comparisons between historic data and the 2019 survey used Mann-Whitney U tests. The Mann-Whitney U test is a nonparametric test that allows comparisons between two groups without making assumptions about the distribution of the values. This is appropriate for ecological field surveys where data are unlikely to meet the assumptions of parametric statistics. For comparisons of fish length distributions through time we used nonparametric Kolmogorov–Smirnov tests based on standardizing the data into 10 cm length classes.

2.9 Communicating uncertainty and graph interpretation

Uncertainty in scientific monitoring is unavoidable and may occur at many steps during the monitoring process. The extent of the uncertainty can be quantitatively observed through statistical analysis (Glew et al. 2015). In this report, the standard classification used by Intergovernmental Panel on Climate Change (IPCC 2014) is adopted to describe the level of uncertainty found in comparisons between historic monitoring data and the 2019 survey (Table 2.9.1). For each finding in this report, the likelihood term is provided in italicized font (e.g., extremely likely) and the exact probabilistic likelihood (p value) in parentheses. For example, if there is less than a 5% chance that the trends documented for a specific indicator would arise by chance, the trend is described as ‘extremely likely (p=0.05)’. Here, the p value expresses the probability of obtaining a result equal to, or more extreme than was actually observed in the data (Glew et al. 2015). Often the p value will be accompanied by a summary statistic based on the specific statistical test used. All summary statistics presented in this report text are presented as the mean ± 1 standard error of the mean unless otherwise stated. This report also presents data in a standard graphical format. Figure 2.9.1 provides an overview of how to interpret data presented in this format (Glew et al. 2015).

2.9.1 Spatial data

To provide additional contextual data at the GSR regional, provincial, and *qoliqoli* level data is presented here on critical marine habitats and other biophysical components from recently published data sources. This analysis required dividing existing spatial data layers into discreet provincial and *qoliqoli* areas.

Figure 2.9.1. Interpreting data from standardized bar graphs used in this report. Colors represent different groups of data to be compared (e.g. historic surveys vs. 2019 survey results). Bar heights represent mean values for indicators unless otherwise stated. All error bars on figures in this report represent 1 standard error above and below the mean unless otherwise stated. Figure adapted from Glew et al. (2015).

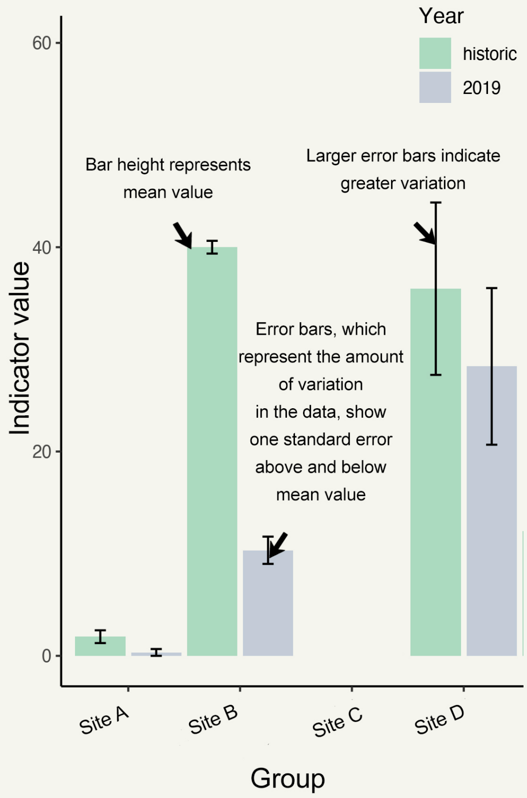
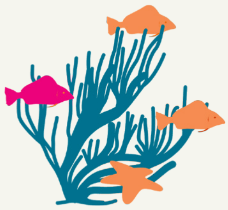


Table 2.9.1. The Intergovernmental Panel on Climate Change standard classification for describing quantified measures of uncertainty (IPCC 2014).

Terms	Likelihood of the observed outcome or an outcome of greater magnitude	Associated probabilistic likelihood (P value)
Virtually certain	99–100% probability	p < 0.01
Extremely likely	95–99% probability	0.01 < p ≤ 0.05
Very likely	90–95% probability	0.05 < p ≤ 0.10
Likely	66–90% probability	0.10 < p ≤ 0.33
About as likely as not	33–66% probability	0.33 < p ≤ 0.66
Unlikely	10–33% probability	0.66 < p ≤ 0.90
Very unlikely	1–10% probability	0.90 < p ≤ 0.99
Exceptionally unlikely	0–1% probability	0.99 < p

2.9.1.1 Defining spatial boundaries

The Fiji landmass and land provincial data were obtained from the Global Database on Administrative Boundaries (GDAM 2020). The Ministry of Lands and Mineral Resources provided the *qoliqoli* boundary data (Figure 1.2.5; LMR 2020). These *qoliqoli* data were used to derive the marine boundary data for each province by dissolving the data by the stated province field (Figure 1.2.2). The GSR boundary was then produced using these marine province boundaries with an added 4 km buffer (Figure 1.2.2). In some areas, *qoliqoli* boundaries overlapped with the GDAM Fiji landmass coastal boundaries. In these cases, the GSR region boundaries were clipped to follow the coastline. The southern end of the GSR region was defined by southern boundaries of Malomalo *qoliqoli*. Therefore, spatial data for Nadroga-Navosa province represent only Malomalo *qoliqoli* as the only part of the province within the GSR boundary. Area calculations for critical habitats for Macuata province and Udu *qoliqoli* are likely underestimates, as the current Allen Coral Atlas spatial data layers do not extend past the antimeridian (180° longitude), which passes through Udu point. This underestimation also affects values for the GSR region as a whole, but given the small unmapped area relative to the whole GSR region, this is unlikely to result in major changes.



The high connectivity between coral reefs, mangroves and seagrass beds are critical for many fisheries species included in the study.

2.9.1.2 Critical marine habitats

The extent of three critical marine habitats were evaluated: (i) coral reefs, (ii) mangrove forests, and (iii) seagrass beds. These three ecosystems play a large role in supporting coastal biodiversity, ecological function, and ecosystem services. Local Fijian communities have traditional fishing rights over and depend heavily on fisheries from these three ecosystems for livelihoods and food security. Coral reefs, mangrove forests, and seagrass beds are highly connected, with fisheries species often moving between them either during tidal cycles or with life stage (Moberg and Folke 1999; Nagelkerken et al. 2000; Mumby et al. 2004). For coral reefs, in addition to identifying the spatial extent of reef, the extent of different geomorphic reef types are summarized. Also provided are bathymetric maps for the GSR region and modelled sedimentation values for Vanua Levu.

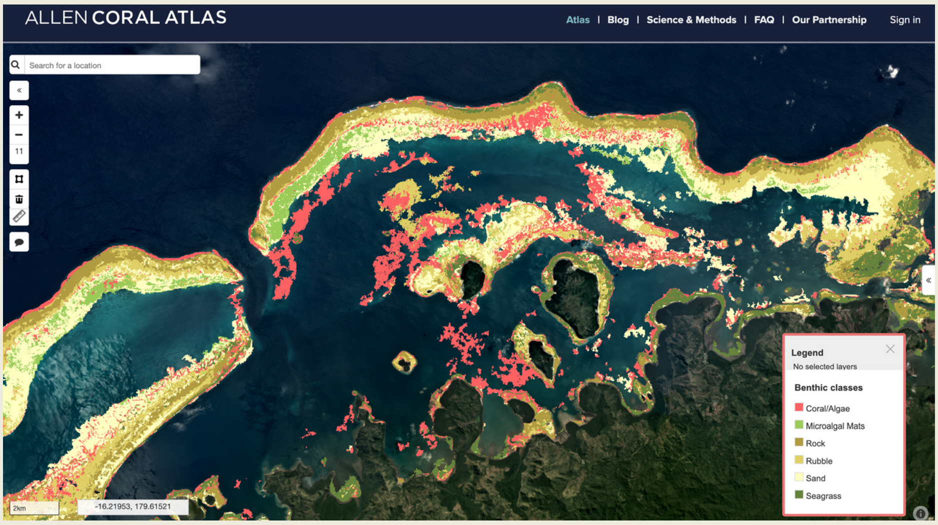
Coral reef and seagrass bed extent data and coral reef geomorphic type and bathymetry data were sourced from the Allen Coral Atlas (Allen Coral Atlas 2020). These data layers represent the May 2020 updated habitat classification maps following the Allen Coral Atlas field team collecting field data for satellite verification on the GSR survey (see Box 3). The Allen Coral Atlas uses a five layer classification system for benthic habitats (Figure 2.9.2). In Fiji, benthic zone data have six unique classes: coral/algae, seagrass, microalgal mats, sand, rubble, and rock (Figure 2.9.2; Table 2.9.2) while the geomorphic data have nine zones, or reef types. These are: Inner Reef Flat, Outer Reef Flat, Plateau, Reef Crest, Reef Slope, Shallow Lagoon, Sheltered Reef Slope, Terrestrial Reef Flat, and Unknown and are based on the criteria of water depth, neighborhood relationship, slope, and brightness level of individual bands (Figure 2.9.2; Table 2.9.3). For example, all areas identified as coral reefs (Level 1 in Figure 2.9.2) are then spatially classified into a broad reef type (Level 2 in Figure 2.9.2). These broad reef types are then spatially classified into the geomorphic zones, with each geomorphic zone then subdivided spatially based on benthic zones (Figure 2.9.2).

Box 3 - The Allen Coral Atlas: a new management and monitoring tool

Zoe Lieb[1] and Brianna Bambic[1]

[1]Allen Coral Atlas Field Engagement team, National Geographic Society

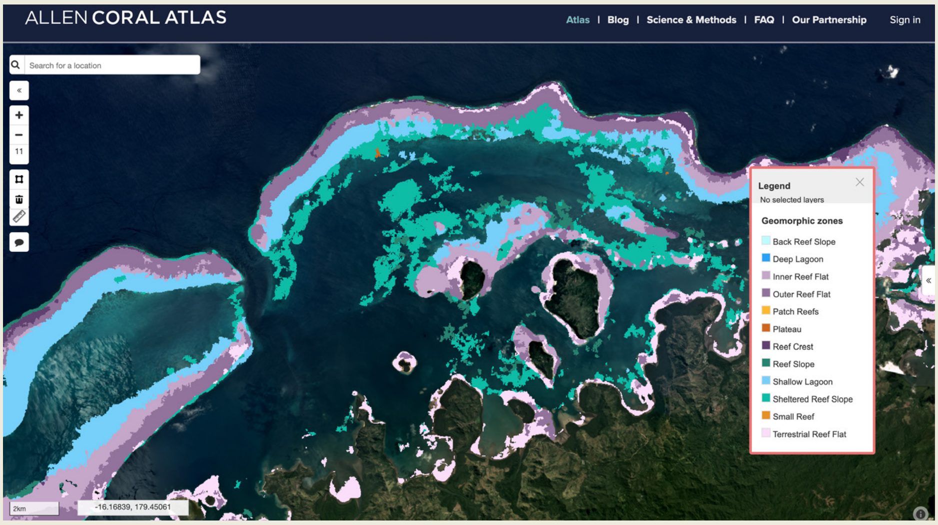
Maps provide a baseline for planning, analysis, and evaluation of the diversity of marine habitats in Fiji. Presently, spatial and temporal gaps in knowledge exist for corals, seagrass, and other benthic habitats in the Southwest Pacific region. The Allen Coral Atlas combines high resolution satellite imagery, machine learning, and field data to produce the very first globally consistent benthic and geomorphic maps of the world's coral reefs. The Atlas substantially increases the scale and coverage of Fijian coral reef maps to support better Marine Spatial Planning (MSP).



In order to produce the Atlas, field photo transect data are critical. These data fulfill two purposes. First, they train the machine learning algorithm that generates the benthic data layer from satellite imagery. Second, they support map validation, by testing for accuracy once the data layer is produced (Roelfsema et al. 2020). WWF-Pacific's GSR expedition team invited University of the South Pacific students to collect georeferenced transect data for the Allen Coral Atlas. The GSR photo transect data in turn helped create the Southwest Pacific region maps! Other students are integrating the Atlas as a planning tool to view the context and location of suitable sites for experimental studies on the effects of macro-plastics and identify coral reef composition that may be shaped by hydrodynamic patterns.

Even before the expedition, the Atlas satellite imagery and bathymetry data were also useful to the WWF team in its early planning stages to select remote reef areas of the GSR (Li et al. 2017).

"Prior to the Atlas we would have had to buy a ton of admiralty charts/expensive electronic access to commercial shipping charts to get useful bathymetry data like that. I know the bathymetry isn't super accurate on the Atlas, but for the sort of general conversations we were having it was really useful." - Dominic Andradi-Brown, Ph.D., Oceans Team, World Wildlife Fund



The Atlas can be accessed on the online platform - AllenCoralAtlas.org. Users can also download the Atlas data layers to use on other platforms for more complex analyses. It serves as the first comprehensive map of the Fiji region and will aid WWF-Pacific, Government of Fiji, and other NGOs to reach their conservation goals.

Note: The Allen Coral Atlas combines high resolution satellite imagery, machine learning and field data to produce globally consistent benthic and geomorphic maps of the world's coral reefs. By providing timely maps and monitoring technology, the initiative's goal is to help stakeholders ranging from local communities to regional and national governments reach their conservation targets and improve management and monitoring of coral reefs. The Atlas program is led by Vulcan Inc. (founded by the late Microsoft co-founder and philanthropist Paul G. Allen), and is aided by a consortium of implementing partners: Arizona State University's Center for Global Discovery and Conservation Science corrects the satellite imagery from Planet; the University of Queensland's Remote Sensing Research Center (RSRC) creates maps of benthic habitat and reef geomorphology; and the field engagement team at the National Geographic Society facilitates use and uptake of the Atlas to achieve conservation results.

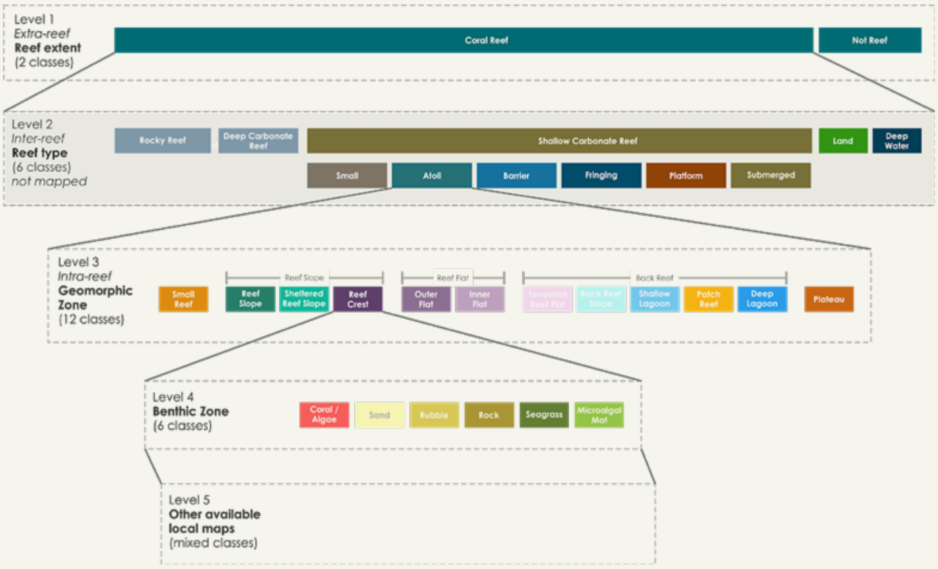


Figure 2.9.2. Allen Coral Atlas mapped classes. Colored boxes represent map classes used in the hierarchical classification scheme applied for the survey. Source: Allen Coral Atlas 2020.

Table 2.9.2. Allen Coral Atlas global benthic zone classes. These classes represent Level 4 on Figure 2.9.2. Source: Allen Coral Atlas 2020.

Class	Definition
Coral/Algae	**Coral/Algae** is any hardbottom area supporting living coral and/or algae.
Seagrass	**Seagrass** is any habitat where seagrass is the dominant biota.
Microalgal Mats	**Microalgal Mats** are any visible accumulations of microscopic algae in sandy sediments.
Sand	**Sand** is any soft-bottom area dominated by fine unconsolidated sediments.
Rubble	**Rubble** is any habitat featuring loose, rough fragments of broken reef material.
Rock	**Rock** is any exposed area of hard bare substrate, with uncommon to scarce corals and fleshy macroalgae.

Table 2.9.3. Allen Coral Atlas global geomorphic map classes. These classes represent Level 3 on Figure 2.9.2. Source: Allen Coral Atlas 2020.

Class	Definition
Reef Slope	**Reef slope** is a submerged, sloping area extending seaward from the reef crest (or flat) towards the shelf break. Windward facing, or any direction if no dominant prevailing wind or current exists.
Sheltered Reef Slope	**Sheltered Reef Slope** is any submerged, sloping area extending into deep water but protected from strong directional prevailing wind or current, either by land or by opposing reef structures.
Reef Crest	**Reef Crest** is a zone marking the boundary between the flat and the reef slope, generally shallow and characterized by highest wave energy absorbance.
Outer Reef Flat	Adjacent to the seaward edge of the reef, **Outer Reef Flat** is a level (near horizontal), broad and shallow platform that displays strong wave-driven zonation.
Inner Reef Flat	**Inner Reef Flat** is a low energy, sediment-dominated, horizontal to gently sloping platform behind outer reef flat.

Terrestrial Reef Flat	**Terrestrial Reef Flat** is a broad, flat, shallow to semi-exposed area fringing reef found directly attached to one side, and subject to freshwater run-off, nutrients, and sediment.
Shallow Lagoon	**Shallow Lagoon** is any fully to semi-enclosed, sheltered, flat-bottomed sediment/ dominated lagoon area, shallower than 5 m approx.
Plateau	**Plateau** is any deeper submerged (>5 m approx.), hard-bottomed, horizontal to gently sloping (angle shallower than 10° approx.), seaward-facing reef platform.
Unknown	**Unknown** is when some factor makes classification difficult or impossible, such as when an area is too deep for an analysis or there is cloud interference.

Mangrove 1996 and 2016 extent was sourced from Global Mangrove Watch (Bunting et al. 2018). The 2016 layer (the most recent available) was used for current mangrove extent within the GSR. Differences between the 1996 and 2016 layers were used to identify overall net mangrove change, as well as areas of gain and loss within the GSR. Sedimentation data for Vanua Levu are visualizations of the turbidity layer by Brown et al. (2017).

2.9.1.3 Spatial calculations and mapping

All spatial calculations were performed in ArcGIS Pro 2.5.1 (ESRI 2020) and reported in km^2 or ha at three different scales: (1) GSR, (2) provincial, and (3) *qoliqoli* in the projected coordinate system UTM Zone 60S. Each dataset of interest was clipped by the appropriate boundary for the area of interest. All maps were produced in R (R Core Team 2020). For plotting, all critical habitat layers were rasterized to 25 m resolution. A 100 m buffer was added to the mangrove extent, mangrove gain, and mangrove loss data to improve visibility on the maps. Bathymetric visualizations maintain the 2 m data resolution. The sedimentation layer was plotted following native resolution and recommendations from Brown et al. (2017).

© TOM VIERUS / WWF-US

A young mangrove plant growing in between mature mangrove roots on northern Mali Island. Macuata Province, Vanua Levu, Fiji.

3 STATE OF THE GREAT SEA REEF

Although trends in hard coral cover and shark populations compared favorably to systems elsewhere, fish biomass and abundance as well as mangrove forests declined significantly, while some rare species such as the bumphead parrotfish remained difficult to find.

1,228 km^2 OF SHALLOW REEF-RELATED ECOSYSTEMS ARE PRESENT WITHIN THE GSR

3.1 Critical habitat coverage

Coral reefs span 588 km^2 in the GSR region (Figure 3.1.1), though summing all Allen Coral Atlas benthic categories that likely contribute to broader coral reef ecosystem composition (i.e. coral/algae, microalgal mats, rock, and rubble) suggests a coverage of 1,228 km^2 of shallow reef-related ecosystems within the GSR. The greatest extent of coral reefs is in Bua province at 177 km^2, followed closely by Ba province at 176 km^2 (Table 3.1.1). Macuata province also has extensive reefs at 154 km2. Across the GSR there are 2,995 km^2 of shallow water reef habitats (Figure 3.1.2). The most extensive reef habitat type is inner reef flats covering 420 km^2, followed by outer reef flats at 366 km^2. Full reef geomorphic types are in Table 3.1.2.

Mangrove forests covered 341 km^2 across the GSR in 2016 (Figure 3.1.3). The greatest cover was in Macuata province at 123 km^2, followed by Ba province at 104 km^2 (Table 3.1.1). Across the GSR, mangrove cover declined by 3.88 km^2 between 1996-2016. All provinces lost mangrove cover between 1996-2016, with the greatest loss in Ba province (2.96 km^2 loss of mangrove forest; Table 3.1.3). Net mangrove loss was lowest in Macuata province at 0.04 km^2. These changes in mangrove cover hide the fact that mangrove loss was actually higher due to counterbalance against gains in mangrove cover within each province (Table 3.1.3). Seagrass cover was 172 km^2 in the GSR (Figure 3.1.4). The greatest province cover was in Ba (58 km^2), followed by Macuata (51 km^2; Table 3.1.1).

Figure 3.1.1 Coral reef extent in the GSR.

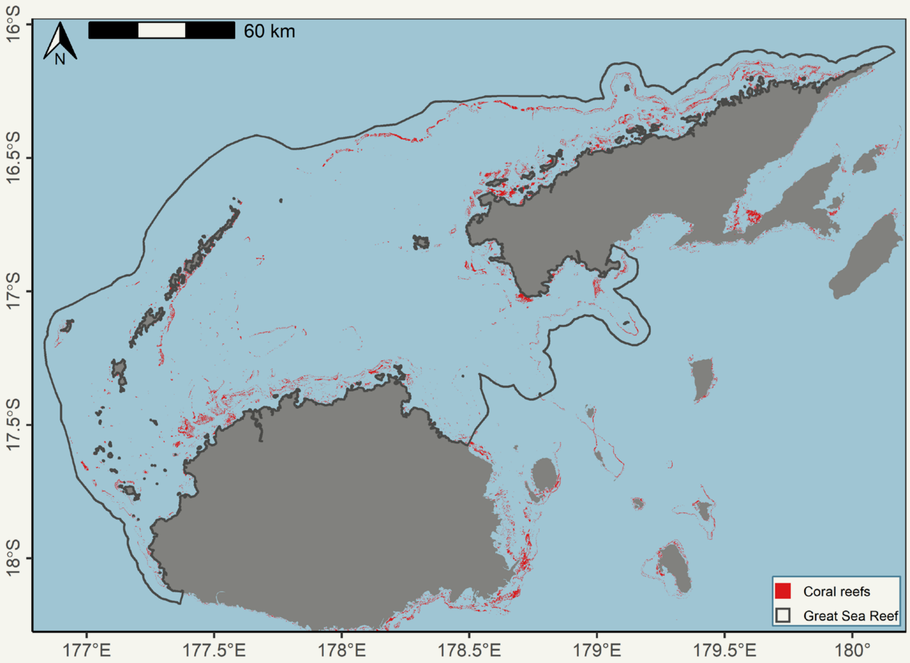


Figure 3.1.2 Coral reef geomorphic types in the GSR.

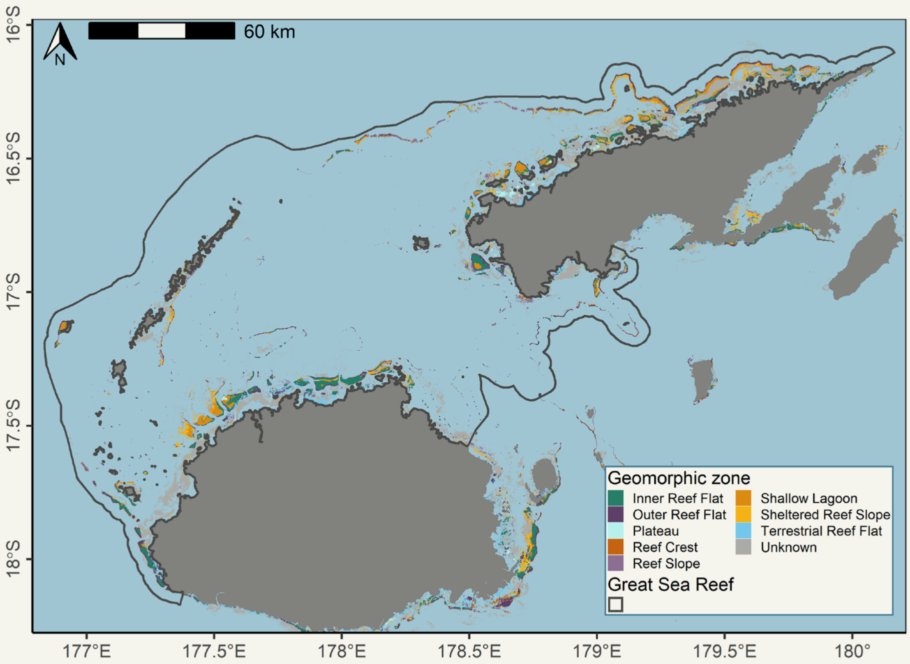


Figure 3.1.3 GSR Mangrove cover in 2016.

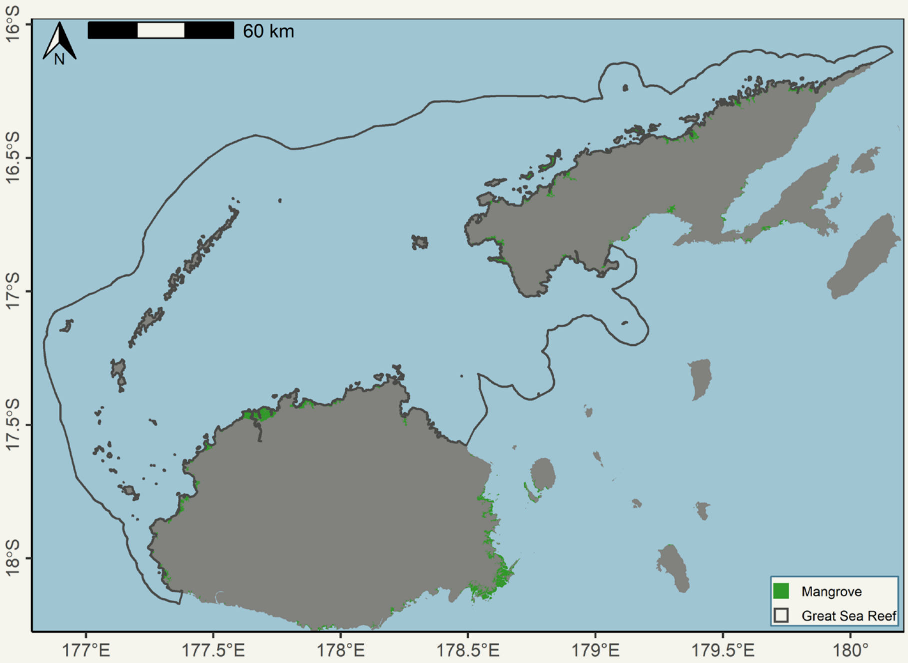


Figure 3.1.4 Change in mangrove cover from 1996 – 2016 in the GSR.

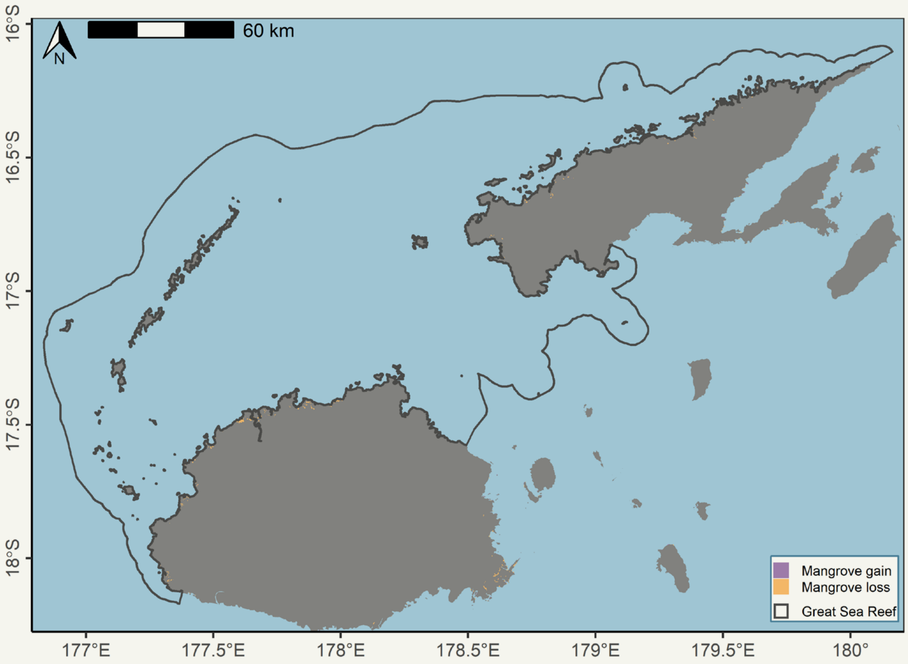


Figure 3.1.5 GSR Seagrass cover.

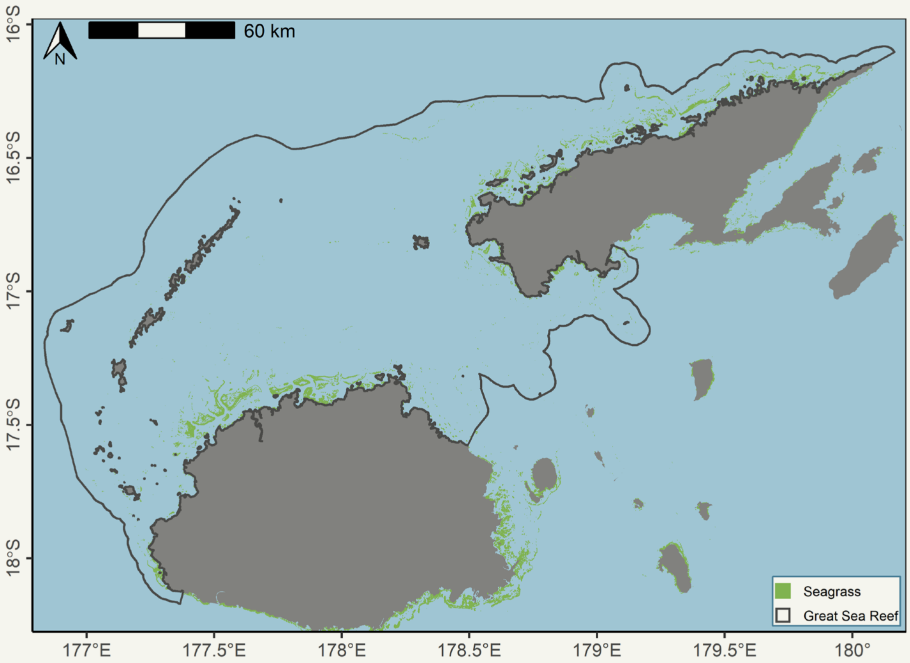


Table 3.1.1 Marine and benthic habitat extent in the GSR. [1]Coral/algae, microalgal mats, rock, and rubble categories from the Allen Coral Atlas. [2]Mangrove cover only represents mangrove areas within *qoliqoli* marine boundaries and so excludes mangroves that may be on land areas outside *qoliqoli* areas. [3]Represents only the area of Nadroga-Navosa within the GSR boundary.

Province / Region	Marine area (km^2)	Coral/ Algae (km^2)	All reef related ecosystems[1] (km^2)	2016 Mangrove cover[2] (km^2)	Seagrass (km^2)
Ba	8,989	176	347	104	58
Bua	6,191	177	312	79	46
Macuata	2,038	154	349	123	51
Nadroga-Navosa[3]	1,298	26	107	20	8
Ra	1,235	32	85	13	9
GSR Region	25,817	588	1,228	341	172

Table 3.1.2 Reef geomorphic types in the GSR. [1]Represents only the area of Nadroga-Navosa within the GSR boundary.

Province / Region	Inner Reef Flat (km^2)	Outer Reef Flat (km^2)	Plateau (km^2)	Reef Crest (km^2)	Reef Slope (km^2)	Shallow Lagoon (km^2)	Sheltered Reef Slope (km^2)	Terrestrial Reef Flat (km^2)	Unknown (km^2)	Total Geomorphic Extent (km^2)
Ba	109.1	99.0	7.9	8.3	51.3	72.6	68.3	70.0	352.6	839.1
Bua	90.0	86.3	18.8	3.7	64.4	48.0	40.4	71.9	248.4	671.8
Macuata	111.4	104.5	9.9	12.4	18.1	100.9	87.0	68.2	457.7	970.1
Nadroga-Navosa[1]	50.9	44.1	0.1	8.0	8.6	7.4	6.3	12.2	71.8	209.4
Ra	58.1	25.6	0.8	0.5	6.0	11.9	11.1	9.9	113.9	237.8
GSR Region	420.1	366.4	37.5	33.2	165.6	246.1	218.6	229.7	1,278.2	2,995.3

Table 3.1.3 Mangrove extent and change in the GSR. [1]Represents only the area of Nadroga-Navosa within the GSR boundary.

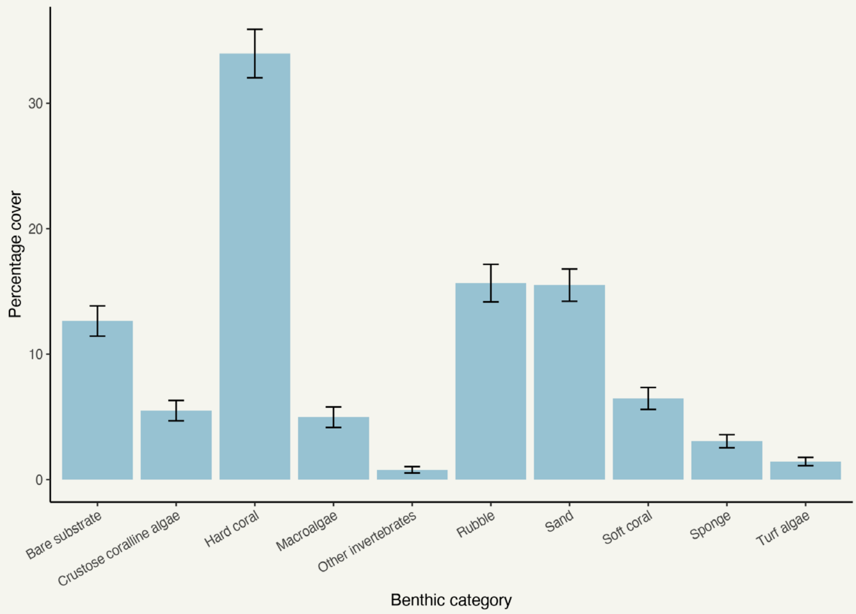
Province / Region	1996 Mangrove cover (km^2)	2016 Mangrove cover (km^2)	Mangrove loss (km^2)	Mangrove gain (km^2)	1996-2016 Net mangrove cover change (km^2)
Ba	107.01	104.05	3.25	0.29	-2.96
Bua	79.07	78.66	0.49	0.09	-0.41
Macuata	123.53	123.49	0.86	0.82	-0.04
Nadroga-Navosa[1]	20.47	20.14	0.35	0.01	-0.33
Ra	13.24	13.11	0.16	0.04	-0.12
GSR Region	344.65	340.77	5.12	1.24	-3.88

3.2 Benthic cover

3.2.1 Current benthic habitat cover

Across the 72 survey sites with benthic data in 2019, hard coral cover was the dominant benthic habitat type – covering 34 ± 2% (mean ± standard error) of the reef surface (Figure 3.2.1). Rubble and sand were both the second and third most common benthic habitat cover, at 16 ± 2% and 16 ± 1% cover, respectively. Soft coral (6 ± 1%) and macroalgae (5 ± 1%) cover were both low (Figure 3.2.1). At the provincial level, Bua province had the greatest hard coral cover at 45 ± 3% (Figure 3.2.2A), followed by Macuata province (36 ± 3%), Ba province (26 ± 3%), and then Nadroga-Navosa province (23 ± 4%). Macroalgae showed a different pattern, with Ba province having the greatest cover at 7 ± 2% (Figure 3.2.2B), followed by Bua province (5 ± 1%), Macuata province (2 ± 1%), and Nadroga-Navosa province with the lowest at <1%. Dividing the provinces into distinct subgroups based on reef type and geographical location showed that the greatest hard coral cover was surrounding Yadua Island – where coral cover was 45 ± 3% (Figure 3.2.3A). The northern GSR subgroups in general had high coral cover – with all groups >35% coral cover. The lowest hard coral cover was for the southern GSR where sites had cover of 17 ± 3%. The greatest cover of macroalgae was in the south, with the Yasawa Islands at 11 ± 2% and Ba Estuary at 11 ± 4% (Figure 3.2.3B). This contrasted with sites in southern GSR which had <1% macroalgal cover.

Figure 3.2.1. Benthic habitat cover across the GSR in 2019.



3.2.2 Trends in benthic cover

The 40 survey sites across the GSR that had past benthic data available had historic hard coral cover of 33 ± 3% compared to 31 ± 2% in 2019 – suggesting it is *very unlikely* that overall hard coral cover changed through time (W=842.5, p=0.69; Figure 3.2.4). It was *extremely likely* that algal cover increased from a historic level of 4 ± 1% to 5 ± 1% in 2019 (W=548, p=0.01), though this represents a small increase. Other biotic habitats had limited change; for example it was *unlikely* that soft coral cover (W=763, p=0.73) and sponge (W=815, p=0.89) cover significantly changed. There were large changes in abiotic habitat cover types. For example, it was *virtually certain* that cover of bare rock declined (W=1,133, p<0.01) from 31 ± 2% to 21 ± 2% in the recent surveys, while it was *virtually certain* that rubble cover increased (W=241, p<0.01) from 5 ± 2% to 17 ± 2%. It was *extremely likely* that sand cover increased (W=542, p=0.01) from 10 ± 2% historically to 15 ± 2% in 2019.

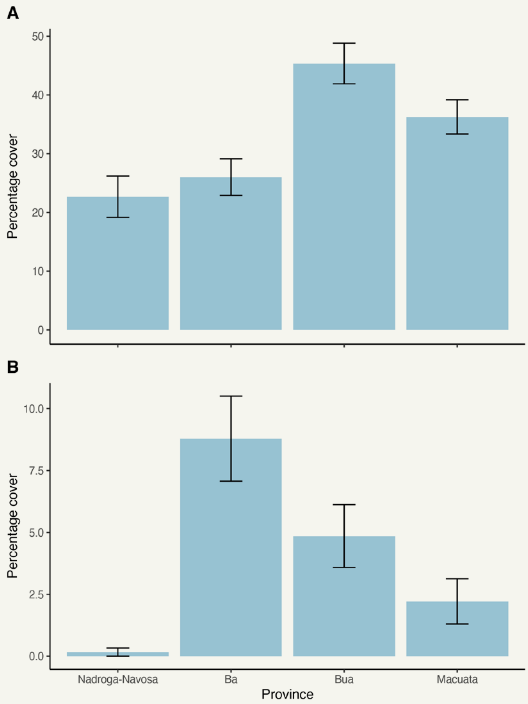
Provincial hard coral cover showed differing trends, with one province increasing, one stable, and two provinces showing declines (Figure 3.2.5A). It is *extremely likely* (W=13, p<0.05) that hard coral cover has increased in Bua province – from 27 ± 5% to 41 ± 4%. In Macuata province it is *unlikely* (W=203, p=0.67) that hard coral cover changed – with the 2019 surveys indicating 32 ± 2% cover compared to 31 ± 3% in the historic surveys. It is *extremely likely* (W=16, p=0.03) that hard coral decline occurred in Nadroga-Navosa province, which historically had 50 ± 5% cover, declining to 23 ± 4%. It is also *very likely* (W=40, p=0.06) that declines have occurred in Ba province – where hard coral cover decreased from 36 ± 4% to 23 ± 4%.

At the subgroup level several subgroups showed changes (Figure 3.2.6A). It was *virtually certain* (W=36, p<0.01) that hard coral cover declined at sites in the Southern GSR from 46 ± 4% to 19 ± 4%. Two subgroups showed increases in hard coral cover. It was *very likely* (W=7, p=0.09) that hard coral cover increased around Yadua Island from 31 ± 6% to 45 ± 3%. It was also *likely* (W=31, p=0.17) that hard coral cover increased at inner reef sites in the northern GSR, from 25 ± 4% to 33 ± 3%.

Algal coverage trends differed between provinces (Figure 3.2.5B), with two provinces with increased algae cover and two provinces stable. It is *extremely likely* (W=130, p=0.02) that algal covered increased in Macuata province, with historic cover of 3 ± 1% growing to 6 ± 1% in 2019. It is also *very likely* (W=15, p=0.08) that algal cover increased in Bua province – from 2 ± 1% to 5 ± 2%. It is *exceptionally unlikely* (p>0.99) that algal cover changed in Nadroga-Navosa or Ba provinces. At the subgroup level, algal cover was most commonly stable, though several subgroups showed increases (Figure 3.2.6B).

At the subgroup level, three subgroups showed increases in algae cover. The greatest increase was for the leeward barrier reef where it was *likely* (W=0, p=0.10) algae increased, with the historic cover 2 ± 1% changing to 7 ± 1%. For the seaward barrier reef it was *very likely* (W=28, p=0.09) that algae cover increased, from 3 ± 1% to 7 ± 2%. Around Yadua Island it was *likely* (W=7.5, p=0.10) that algal cover increased, from 1 ± 1% to 2 ± 1%.

Figure 3.2.2. Benthic habitat cover for (A) hard coral and (B) macroalgae by province across the GSR in 2019.



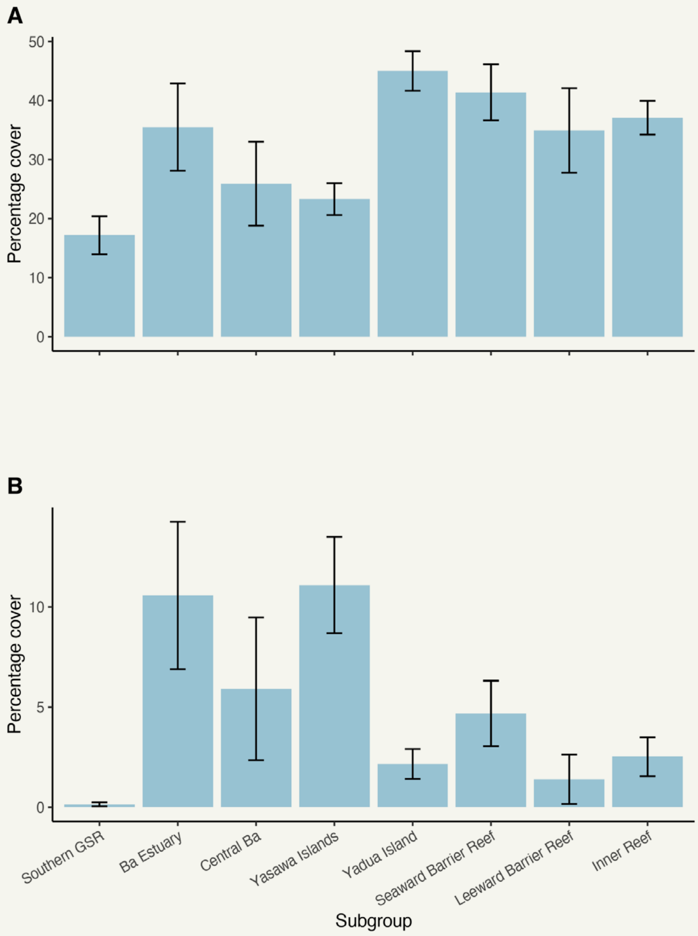


Figure 3.2.3. Subgroup benthic habitat cover for (A) hard coral and (B) macroalgae across the GSR in 2019.

Figure 3.2.4. Change in benthic cover across the GSR.

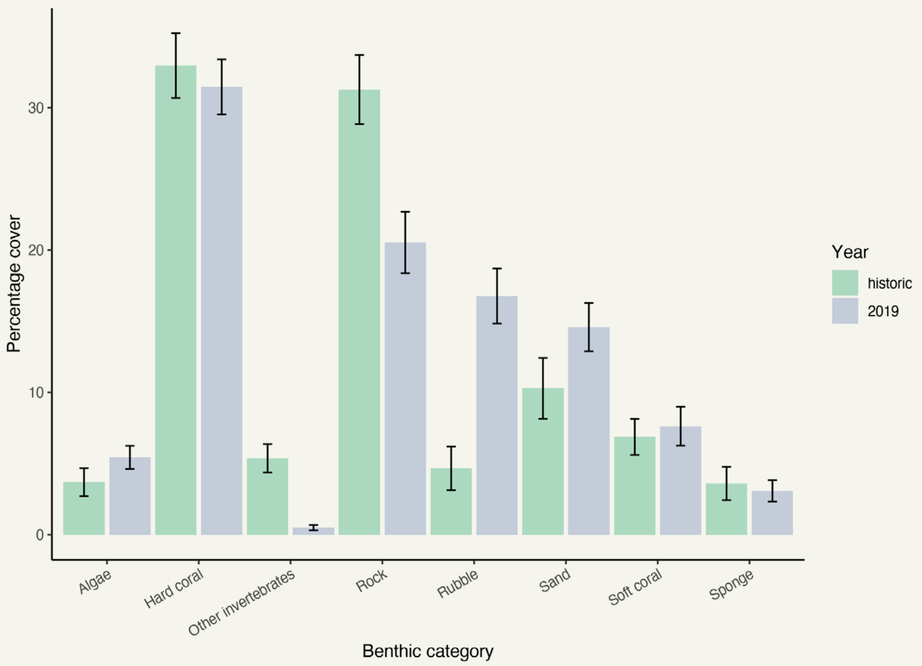


Figure 3.2.5. Change in (A) hard coral cover and (B) macroalgal cover by province across the GSR.

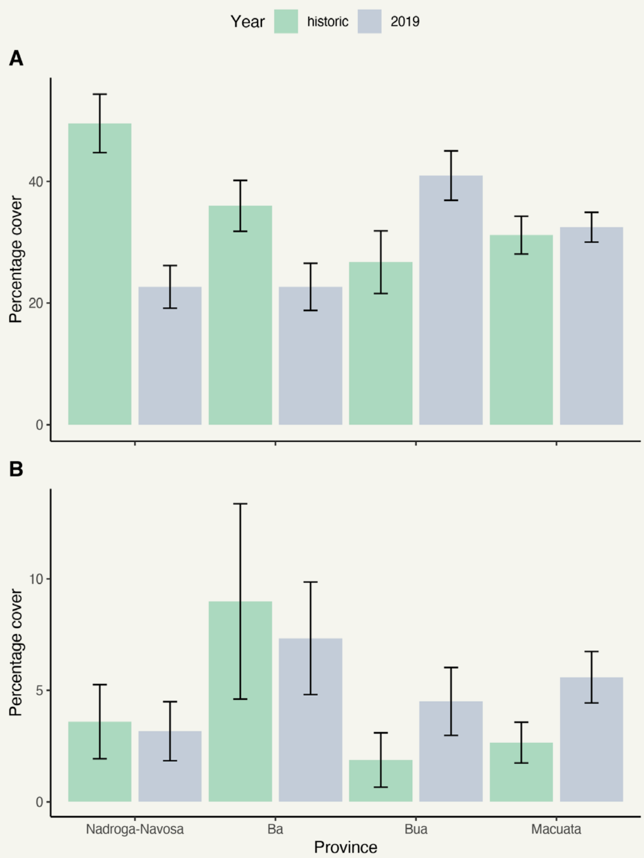
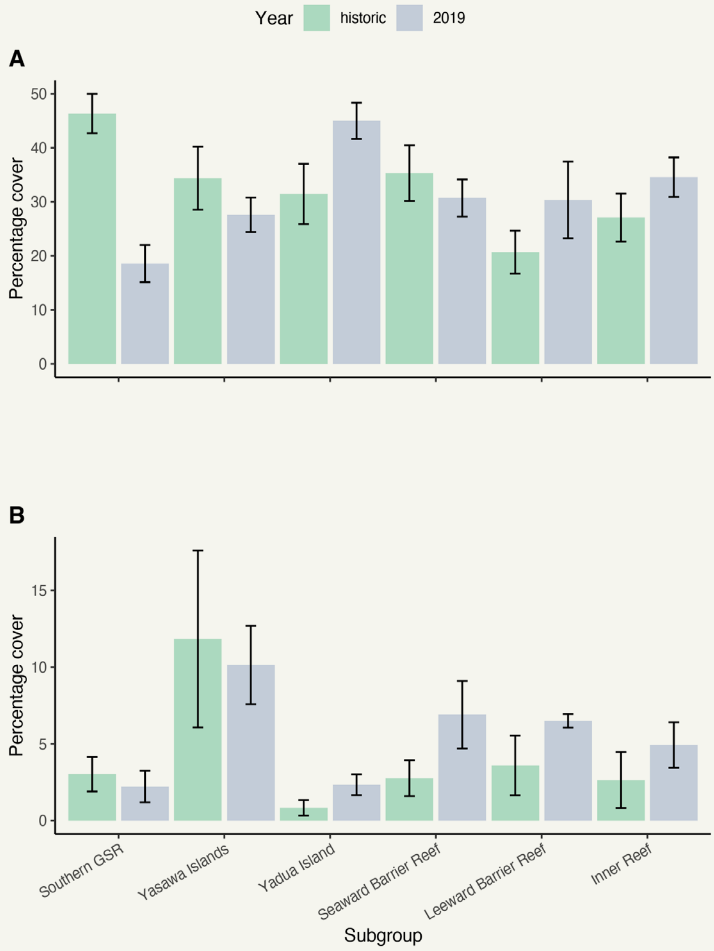


Figure 3.2.6. Change in (A) hard coral cover and (B) macroalgal cover by subgroup across the GSR.

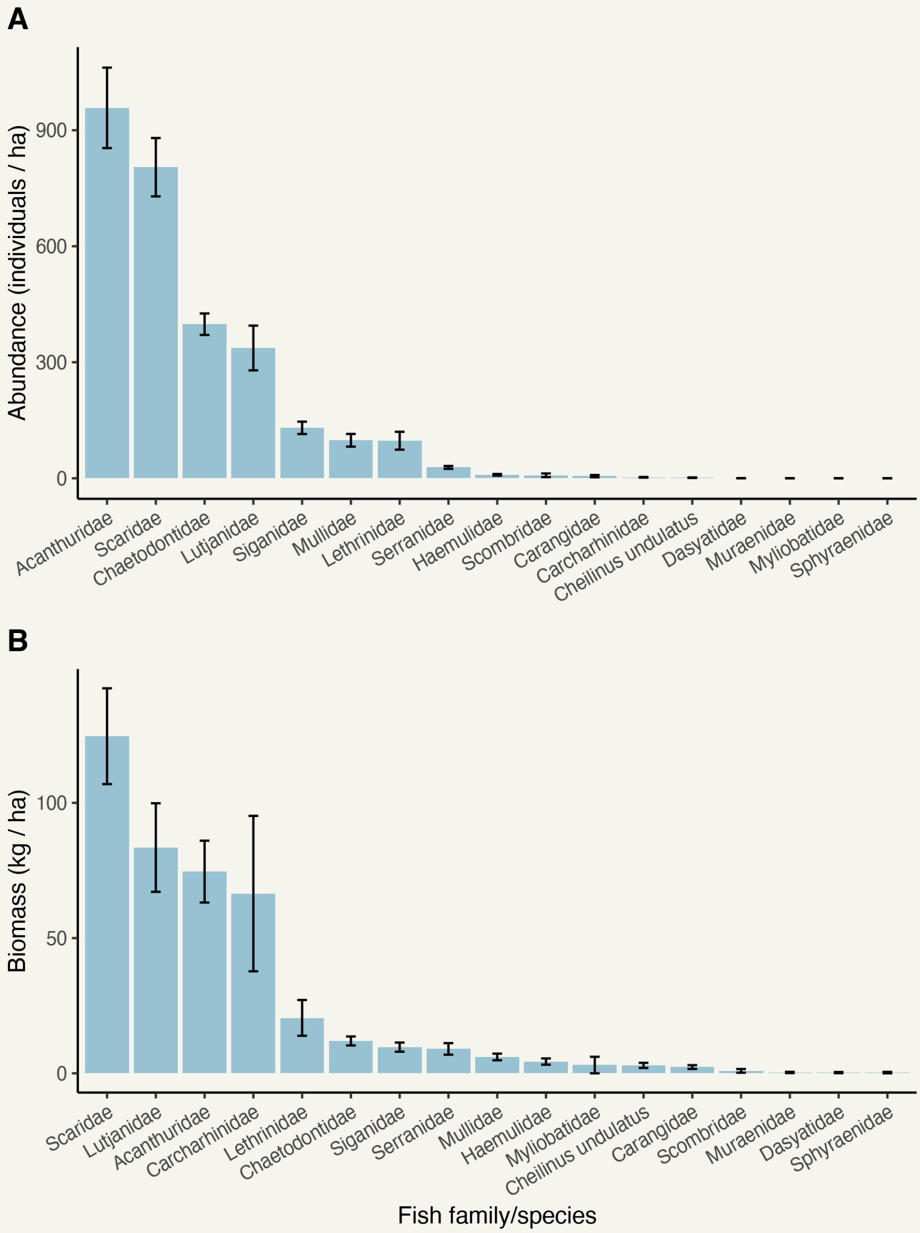


3.3 Fish communities

3.3.1 Reef fish community structure

Fish communities were surveyed at 71 sites across the GSR in 2019. Overall abundance of fish on the target family/species list was 2,878 ± 189 ind/ha, while biomass was at 421 ± 60 kg/ha. The most abundant fish family within the target family/species list observed on the 2019 Great Sea Reef survey was surgeonfish (Acanthuridae) at 957 ± 104 individuals per ha, followed by parrotfish (Scaridae) at 804 ± 76 individuals per ha (Figure 3.3.1A). There was also high abundance of butterflyfish (Chaetodontidae) and snapper (Lutjanidae) recorded. The greatest fish family by biomass was Scaridae, at 125 ± 18 kg/ha, followed by Lutjanidae (83 ± 16 kg/ha) and surgeonfish (75 ± 11 kg/ha; Figure 3.3.1B)). While sharks (Carcharhinidae) were recorded at low abundance in general (3 ± 1 individuals per ha), they comprised a large proportion of the community biomass: at 66 ± 29 kg/ha. Groupers (Serranidae) were recorded at low abundance (28 ± 4 individuals per ha) and biomass (9 ± 2 kg/ha) throughout the survey. Humphead wrasse (*Cheilinus undulatus*) were also recorded at low abundance (2 ± 1 individuals per ha) and biomass (3 ± 1 kg/ha) during the survey.

Figure 3.3.1. Fish community composition by family based on (A) abundance and (B) biomass for the GSR. Results are based on all sites surveyed during 2019.



3.3.2 Trends in key fisheries family abundance

Based on the key fisheries families (Haemulidae, Lutjanidae, Scaridae, and Serranidae) from 44 sites that had historic data available, it was *very likely* (V=640, p=0.09) that fish abundance declined across the GSR (Figure 3.3.2). Key fisheries family abundance was 1,901 ± 290 ind/ha in the historic data, declining to 1,272 ± 140 ind/ha in 2019 – representing a 33% decline across the region. Differing patterns emerged for key fisheries family abundance at the provincial level (Figure 3.3.3). It was *likely* (V=79, p=0.10) that Ba province fish abundance declined from 1,944 ± 439 to 1,003 ± 161 ind/ha – representing a 48% decrease. It was also *likely* (V=118, p=0.16) that Macuata province fish abundance declined from 2,269 ± 545 ind/ha to 1,446 ± 294 ind/ha – representing a 36% decrease. It was *unlikely* that key fisheries family abundance changed for Bua province (V=15, p=0.74), and it was *about as likely as not* (V=3, p=0.63) that Nadroga-Navosa province fish abundance increased.

Two subgroups showed increases in key fisheries family abundance, while three showed declines (Figure 3.3.4). It was *very likely* (V=1, p=0.06) that fish abundance more than doubled around Yadua Island, from 667 ± 190 to 1,403 ± 243 ind/ha — representing a 111% increase. It was *likely* (V=2, p=0.19) that fish abundance also doubled around the Yasawa Islands, from 375 ± 107 to 773 ± 143 ind/ha – representing a 106% increase. In contrast, fish abundance declined in Ba Estuary, the seaward barrier reef, and the inner reefs of Bua and Macuata provinces. For Ba Estuary it was *extremely likely* (V=27 p=0.03) that fish abundance declined, with 2,917 ± 474 ind/ha historically recorded compared to 1,251 ± 280 ind/ha. This represents the greatest decline of any subgroup, at 57%. It was *likely* declines in fish abundance occurred for both the seaward barrier reef (V=36, p=0.13) and the inner reefs (V=34, p=0.19). For the seaward barrier reef, fish abundance declined 43%, from 2,887 ± *936 to* 1,636 ± 474 ind/ha, while fish abundance on the inner reefs of Bua and Macuata provinces declined 50%, from 2,282 ± 691 to 1,147 ± 200 ind/ha. It was *unlikely* (V=9, p=0.84) that there was any change in key fisheries family abundance on the Southern GSR, and *exceptionally unlikely* (V=1, p>0.99) that it changed on the leeward barrier reef.

Figure 3.3.2. Change in key fisheries families abundance across the GSR. Key fisheries families included are Scaridae, Haemulidae, Lutjanidae, and Serranidae. Results based on the 44 sites with historic fish abundance surveys available.

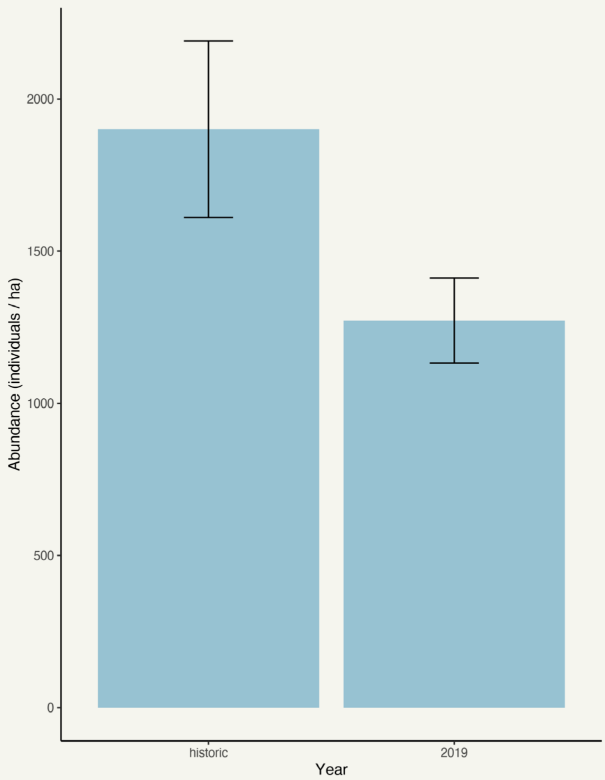


Figure 3.3.2. Change in key fisheries families abundance across the GSR. Key fisheries families included are Scaridae, Haemulidae, Lutjanidae, and Serranidae. Results based on the 44 sites with historic fish abundance surveys available.

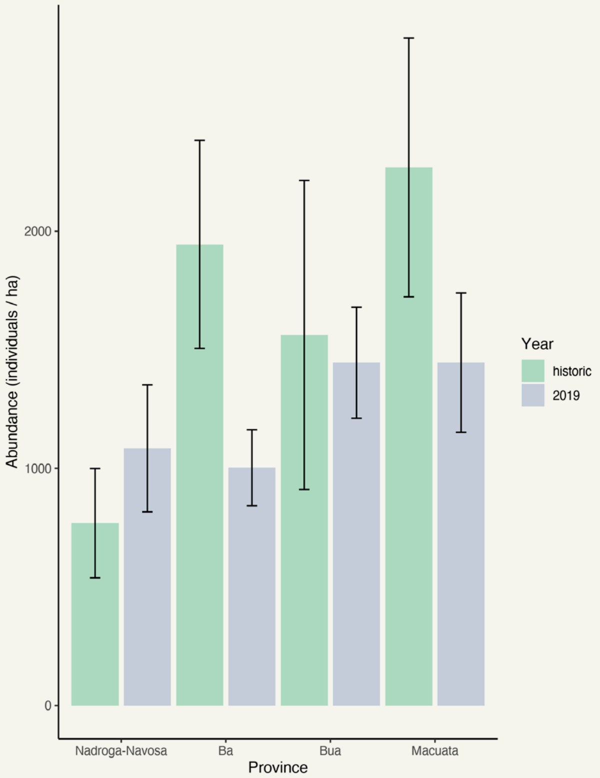
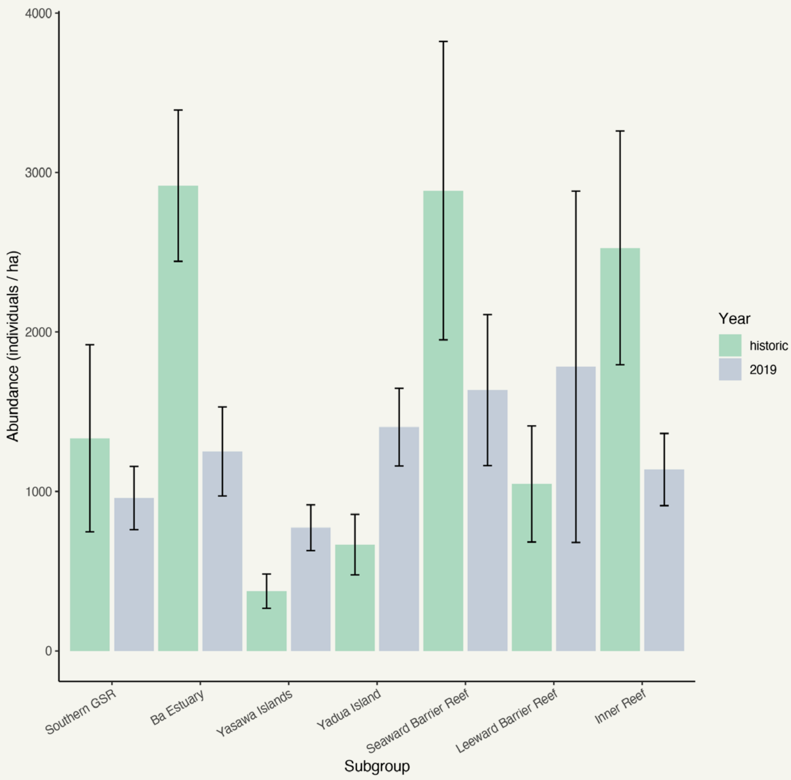


Figure 3.3.4. Change in key fisheries families abundance by subgroup across the GSR. Key fisheries families included are Scaridae, Haemulidae, Lutjanidae, and Serranidae. Results based on the 44 sites with historic fish abundance surveys available.



3.3.3 Trends in key fisheries family biomass

There were 27 sites—restricted to Bua and Macuata provinces and the Ba Estuary—with historic fish length data available allowing us to calculate changes in reef fish biomass. Note, historic fish length data did not record fish lengths for individuals >40 cm TL, therefore for biomass trends presented in this section all fish >40 cm length for both historic and 2019 fish data are treated as 45 cm TL. Across these sites it was *virtually certain* (V=350, p<0.01) that there was an 80% decrease in key fisheries family biomass – from 1,198 ± 365 kg/ha to 283 ± 70 kg/ha (Figure 3.3.5). At the provincial level, it was *virtually certain* (V=151, p<0.01) that fish biomass declined in Macuata province. Macuata had historic biomass of 1,409 ± 539 kg/ha in 2004, which declined by 89% to 301 ± 101 kg/ha in 2019 (Figure 3.3.6). It was also *extremely likely* (V=28, p=0.02) that fish biomass declined in Ba province by 80% – from 643 ± 107 kg/ha in 2010 to 150 ± 48 kg/ha in 2019. Given the limited number of sites (n=2) and high historic variation in Bua province fish biomass, it was *about as likely as not* (V=3, p=0.50) that fish biomass changed in Bua, though there was a clear trend towards decreasing fish biomass.

At the subgroup level, three subgroups showed clear declines in key fisheries family biomass (Figure 3.3.7). It was *extremely likely* (V=40, p=0.04) that biomass declined for the seaward barrier reef sites, from 2,122 ± 1,007 kg/ ha in 2004 to 465 ± 184 kg/ha in 2019 – representing a 78% decline. It was *extremely likely* (V=34, p=0.02) that biomass declined by 77% for inner reef sites of Bua and Macuata provinces, from 997 ± 354 kg/ha to 258 ± 78 kg/ ha. It was also *extremely likely* (V=28, p=0.02) that biomass declined for Ba Estuary sites by 76%, from 644 ± 107 kg/ha in 2010 to 150 ± 48 kg/ha in 2019. For the leeward barrier reef, it was *likely* (V=6, p=0.25) that fish biomass changed, with a declining trend but having only three sites here limited the statistical power to detect change.

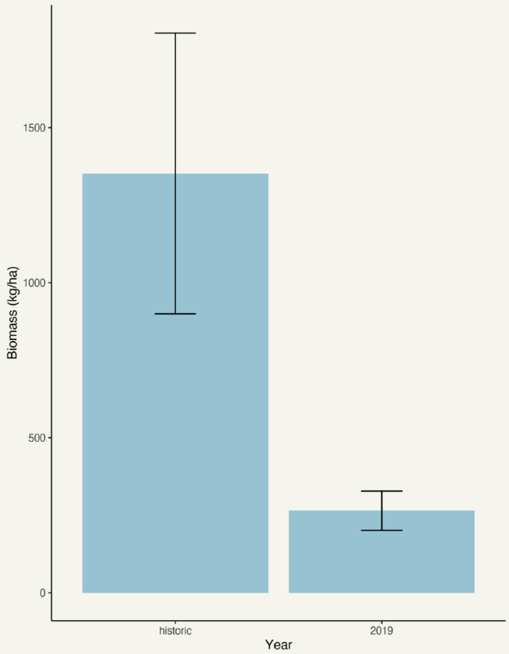


Figure 3.3.5. Change in key fisheries family biomass across the GSR. Key fisheries families included are Haemulidae, Lutjanidae, Scaridae, and Serranidae. Results based on the 27 sites with historic fish biomass available.

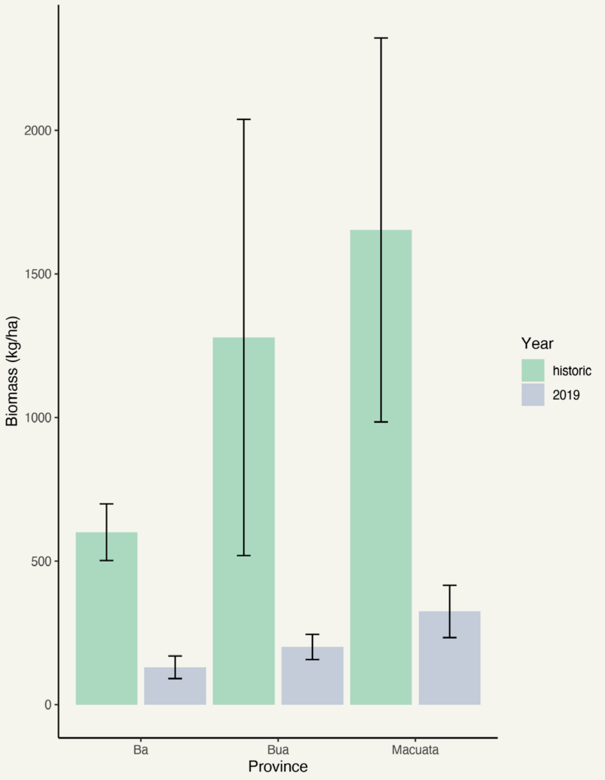


Figure 3.3.6. Change in key fisheries family biomass by province across the GSR. Key fisheries families included are Haemulidae, Lutjanidae, Scaridae, and Serranidae. Results based on the 27 sites with historic fish biomass available.

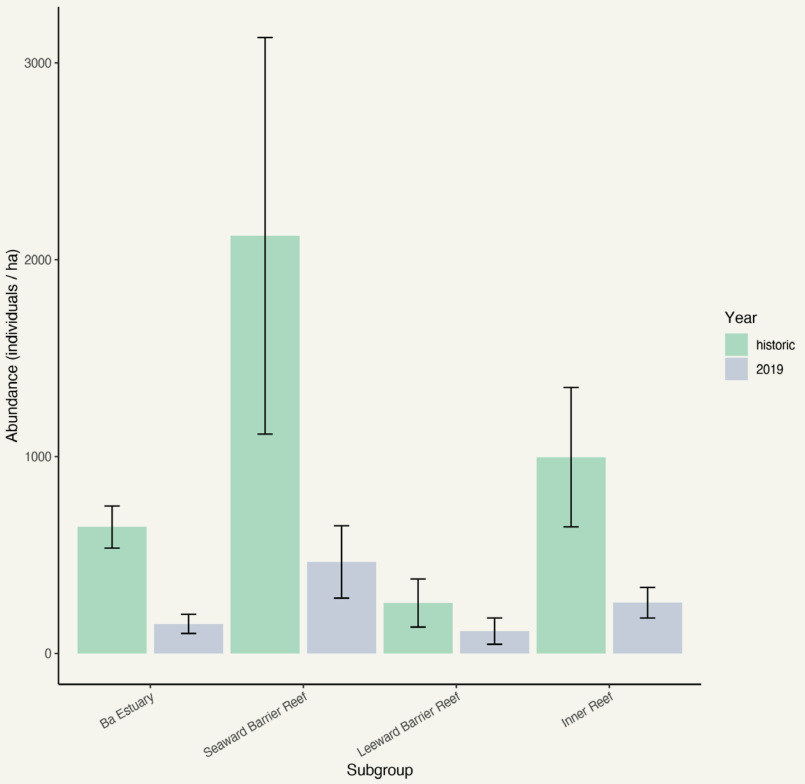


Figure 3.3.7. Change in key fisheries families biomass by subgroup across the GSR. Key fisheries families included are Scaridae, Haemulidae, Lutjanidae, and Serranidae. Results based on the 27 sites with historic fish biomass available.

3.3.4 Changes in key fisheries family lengths

Changes in fish length distribution were analyzed for key fisheries family lengths across the 27 GSR sites with historic fish length data. Based on Kolmogorov-Smirnov tests, it was virtually certain ($D=0.29$, $p<0.01$) that reef fish were smaller in 2019 than in the historic surveys. Median fish size declined from 22.5 cm in historic data to 15.0 cm in the 2019 surveys. Plotting the fish length distributions also indicates that larger fish were at much lower presence in 2019 compared to historic surveys (Figure 3.3.8). Across all provinces it was *virtually certain* the size of individual fish in the key fisheries families decreased between historic surveys and the 2019 survey (Table 3.4.1), with the greatest decline in Macuata province from a median length of 27.5 cm in 2004 to 15.0 cm in 2019. Similar declines were also recorded across all subgroups (Table 3.4.1), with the greatest decline in median length for sites on the seaward barrier reef from 32.5 cm in 2004 to 15.0 cm in 2019.

Figure 3.3.8. Kernel density distribution of key fisheries families length across the GSR. Key fisheries families included are Haemulidae, Lutjanidae, Scaridae, and Serranidae. Results based on the 27 sites with historic fish length data available. To standardize between historic and 2019 survey data, all fish with lengths >40 cm have been allocated the length 45 cm.

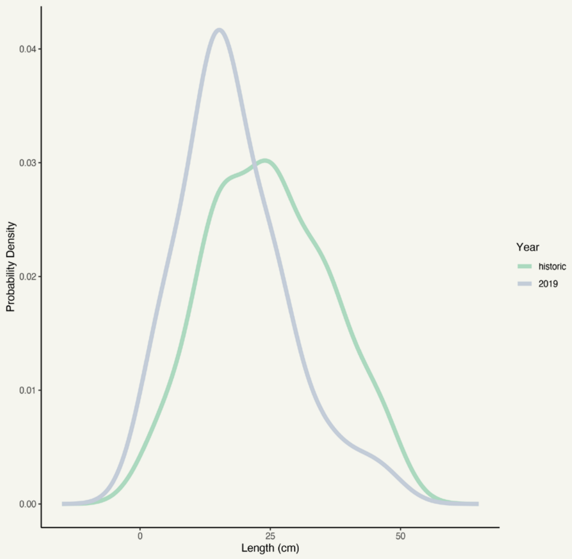


Table 3.4.1. Changes in key fisheries family fish lengths between historic surveys and 2019 by province and subgroup. Key fisheries families included are: Haemulidae (sweetlips), Lutjanidae (snapper), Serranidae (grouper), and Scaridae (parrotfish). Results based on the 27 sites with historic fish length data available. To standardize between survey methods, all fish with lengths >40 cm have been allocated the length 45 cm.

Region	Historic Median Fish Length (cm)	2019 Median Fish Length (cm)	Kolmogorov-Smirnov Test	
			D	p
Province				
Ba	17.5	15.0	0.68	<0.01
Bua	17.5	15.0	0.40	<0.01
Macuata	27.5	15.0	0.45	<0.01
Subgroup				
Ba Estuary	17.5	15.0	0.68	<0.01
Seaward Barrier Reef	32.5	15.0	0.45	<0.01
Leeward Barrier Reef	17.5	15.0	0.53	<0.01
Inner Reef	22.5	15.0	0.40	<0.01

3.4 Rare species

3.4.1 Humphead wrasse (*Cheilinus undulatus*)

During the 2019 GSR survey 15 humphead wrasse were recorded across the 71 reef sites surveyed, with a median length of 55 cm and mean length of 48 ± 7 cm. The 2019 density of humphead wrasse was 1.55 ± 0.71 ind/ha, while biomass was 2.93 ± 0.94 kg/ha (Figure 3.4.9). Across all GSR sites with historic data, it was *unlikely* (V=29, p=0.76) that humphead wrasse abundance changed and *likely* (V=28, p=0.18) that humphead wrasse biomass declined across this time. Declines in humphead wrasse biomass should be treated with caution, as to allow comparisons through time all individuals >40 cm TL are assumed to have a TL of 45 cm.

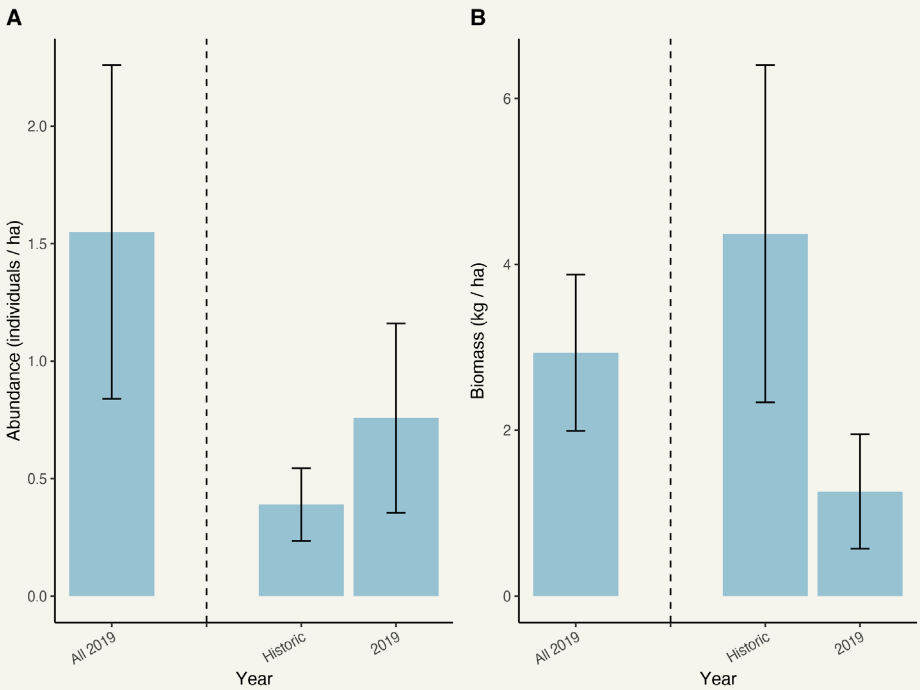
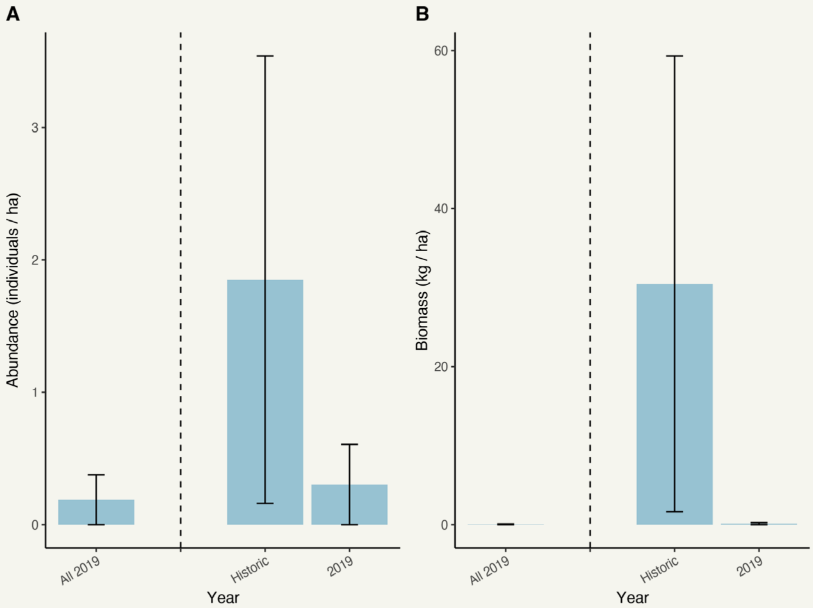


Figure 3.4.1. Humphead wrasse (*Cheilinus undulatus*) (A) abundance and (B) biomass across the GSR. Results are shown for all 2019 sites on the left of each panel, based on the 71 sites surveyed for fish abundance and biomass during the 2019 survey, and using the observed fish lengths in the biomass calculation. Results on the right of each panel compare sites that have both historic and 2019 data available – representing fish (A) abundance for 44 sites and (B) biomass for 27 sites. Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.

3.4.2 Bumphead parrotfish (*Bolbometopon muricatum*)

In the 2019 GSR survey only one bumphead parrotfish was observed across the 71 reef sites surveyed: this was a juvenile with an estimated length of 25 cm at site OB1B on the seaward barrier reef of Macuata province. This meant that 2019 abundance and biomass for bumphead parrotfish across all sites was especially low at 0.19 ± 0.19 ind/ha and 0.05 ± 0.05 kg/ha respectively (Figure 3.4.2). Comparisons between the sites with historic fish abundance and biomass data suggested that it was *about as likely as not* (V=7, p=0.58) that bumphead parrotfish abundance had changed, though it was *likely* (V=9, p=0.20) that bumphead parrotfish biomass has declined. Bumphead parrotfish biomass was 30.47 ± 28.84 kg/ha in historic surveys, declining to 0.12 ± 0.12 kg/ha in 2019.

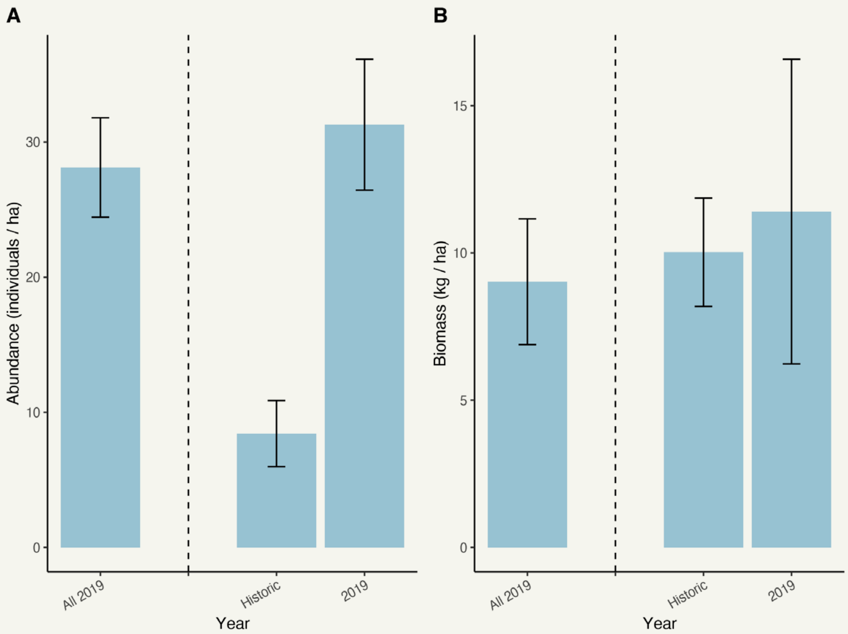
Figure 3.4.2. Bumphead parrotfish (*Bolbometopon muricatum*) (A) abundance and (B) biomass across the GSR. Results are shown for all 2019 sites on the left of each panel, based on the 71 sites surveyed for fish abundance and biomass during the 2019 survey. Results on the right of each panel compare sites that have both historic and 2019 data available – representing f (A) abundance for 44 sites and (B) biomass for 27 sites. Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.



3.4.3 Grouper (Serranidae)

Across the 71 reef sites, 175 Serranidae were recorded during the 2019 survey, with a median length of 25 cm. Serranidae abundance and biomass in 2019 was 28.12 ± 3.68 ind/ha and 9.02 ± 2.14 kg/ha respectively. It was *virtually certain* (V=116, p<0.01) that Serranidae abundance increased at sites with historic data—from 8.43 ± 2.45 to 31.29 ± 4.84 ind/ha—representing a 270% increase (Figure 3.4.3A). It was also *likely* (V=258, p=0.10) that Serranidae biomass increased, from 10.02 ± 1.84 to 11.40 ± 5.17 kg/ha (Figure 3.4.3B). This potential increase in Serranidae biomass, however, was small—only representing a 5% increase. While an increase in grouper was detected at the sites with historical data, grouper populations in 2019 remained very low across all sites, and some sites experienced declines in grouper abundance. The overall trends also hide variation between different grouper species, and that very few large-bodied grouper were observed in the survey. Given the low grouper numbers recorded—grouper populations require further mangement measures to rebuild their populations.

Figure 3.4.3. Serranidae (grouper) (A) abundance and (B) biomass across the GSR. Results are shown for all 2019 sites on the left of each panel, based on the 71 sites surveyed for fish abundance and biomass during the 2019 survey. Results on the right of each panel compare sites that have both historic and 2019 data available – representing (A) abundance for 44 sites and (B) biomass for 27 sites. Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.



3.4.4 Sharks

From the 71 reef sites 53 sharks were recorded during the 2019 survey, comprised of five species. The most frequently recorded species were whitetip reef sharks (*Triaenodon obesus*) -making up 53% of observed sharks (28 individuals). Grey reef sharks (*Carcharhinus amblyrhynchos*) were also frequently observed – comprising 25% (13 individuals) of recorded sharks. Less frequent observations included bull sharks (*Carcharhinus leucas*), observed seven times during the survey. Bull sharks were observed in Macuata province at site OB3 on the seaward side of the barrier reef north of Kia Island, at site CH2A in the Mali Channel, and at site CH4B on the seaward side of the Ravi Ravi passage. Three blacktip reef sharks (*Carcharhinus melanopterus*) and two silvertip sharks (*Carcharhinus albimarginatus*) were also recorded at sites in Macuata province.

Shark abundance across all species was 2.54 ± 0.76 ind/ha and biomass was 66.45 ± 28.74 kg/ha in 2019 across all 71 reef sites with fish surveys (Figure 3.4.2). For the sites with historic data, it was *extremely likely* (V=17, p=0.05) that shark abundance increased. Historic surveys recorded 0.37 ± 0.19 ind/ ha compared to the 2019 surveys at these same sites recording 2.88 ± 1.12 kg/ ha – a 678% increase. It is *about as likely as not* (V=27, p=0.62) that shark biomass also increased, from 2.01 ± 0.96 kg/ ha in historic surveys to 3.01 ± 1.31 kg/ha at these same sites in 2019. Changes in shark biomass should be treated with caution, as to allow comparisons through time; all individuals >40 cm TL are assumed to have a TL of 45 cm.

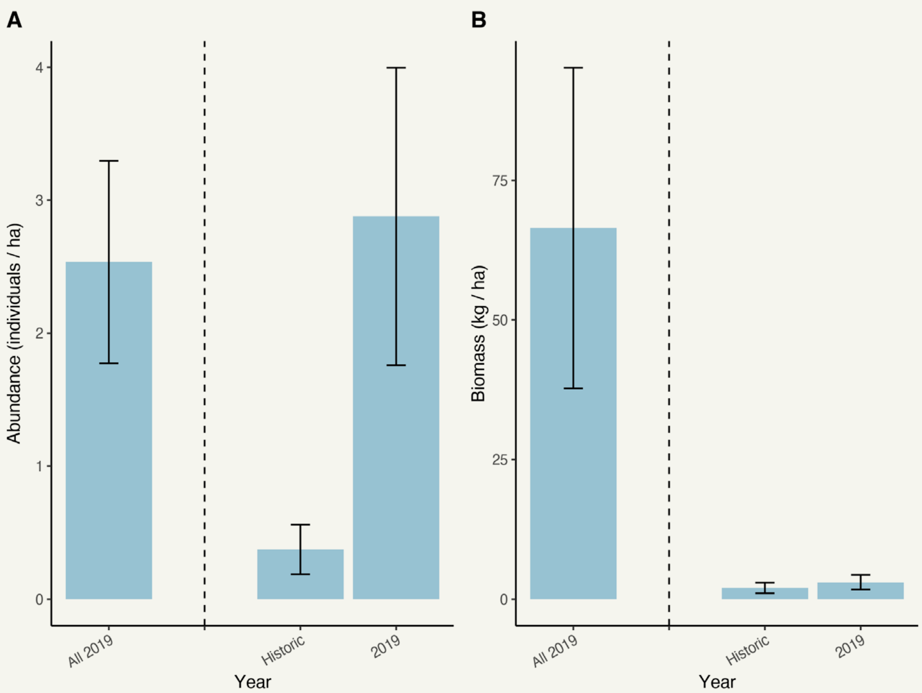


Figure 3.4.4. Shark (Carcharhinidae) (A) abundance and (B) biomass across the GSR. Results are shown for all 2019 sites on the left of each panel, based on the 71 sites surveyed for fish abundance and biomass during the 2019 survey. Results on the right of each panel compare sites that have both historic and 2019 data available – representing (A) abundance for 44 sites and (B) biomass for 27 sites. Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.

HARD CORAL COVER REMAINED STABLE FROM THE EARLY 2000S AT
34%

3.5 Discussion

The 2019 GSR survey highlights the large extent of coral reef, mangrove, and seagrass ecosystems within the GSR region. Across the GSR, it was generally found that benthic components of reef habitats were fairly healthy, but that fish populations have been heavily impacted by fishing and are declining. Some declines in mangrove forest were also recorded for the region, especially in Ba province. Management action led by communities in partnership with NGOs, government, and civil society are needed to ensure long-term reef fisheries sustainability and to protect mangroves.

3.5.1 Benthic habitats

Across the GSR hard coral averaged 34%, which compares favorably with other remote regions in the world. For example, in eastern Indonesia remote protected reefs have coral cover of approximately 30-36% (Ahmadia et al. 2017; Setyawan et al. 2018). Coral cover showed a clear gradient across the GSR region, with lowest coral cover at the most southern sites in the GSR compared to sites in Vanua Levu. These differences are likely because of differences in reef stressors—such as nutrient pollution, sedimentation, and fisheries—across the GSR, and differences between reef types surveyed in the different areas. While the near-continuous barrier reef system spanning much of the GSR represents the third largest barrier reef system in the world—and so receives much attention—the majority of reef area within the GSR is comprised of inner reef flats within the lagoons created by this offshore barrier reef and island system.

SHARKS INCREASED TO
2.54 ind/ha
IN 2019

It was especially encouraging that there was no change in hard coral cover when looking at the regional level between historic surveys and the 2019 survey. Globally, reefs have suffered widespread decline and degradation over recent decades, with much coral cover loss – especially caused by a global bleaching event from 2015-2017 (Eakin et al. 2019). For example, coral cover on the Great Barrier Reef, Australia declined by 30% during a bleaching event in 2016 (Hughes et al. 2017), while other remote reefs in the Indian Ocean experienced >60% declines over the same period, dropping to <10% coral cover (Head et al. 2019). It is therefore encouraging that—despite some localized reports of bleaching (Mangubhai et al. 2019)—the GSR has maintained high coral cover through these global bleaching events. This may be in part because of storm events coinciding with periods when water temperatures normally increase (Mangubhai et al. 2019). Maintaining coral cover across the region also suggests that Cyclone Winston, despite causing some reef damage (Mangubhai 2016) and many social impacts (Andersson-Tunivanua 2020), did not lead to widespread long-term reef damage for most of the GSR. It is important to note that the lack of bleaching or cyclone damage to Fijian reefs does not mean they are immune to future damage, since climate change-induced mass coral bleaching and increasing tropical storm intensity are a major threat for the future. It is important to consider the future impacts of cyclones when planning marine protected area expansion in the region (Box 4).

While Fiji has retained much of its coral cover since historic surveys, future climate change-induced impacts such as cyclones or bleaching remain critical threats

Box 4 - Planning for Cyclone Risk, Biodiversity, and Fisheries Value in the Great Sea Reef

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[2]*Australia Rivers Institute, Australia*

In Fiji, extreme tropical cyclones are expected to increase in frequency as a result of changing global climatic conditions (Ellison, 2010). These extreme events can cause significant damage to the structure and function of coastal coral reef and mangrove ecosystems and their associated fisheries services to communities. Cyclone events of high intensity can result in a loss of structural habitat complexity in these ecosystems, which can lead to associated declines in fish biomass (Fabricius et al. 2008, Adame et al. 2013). Declines in some reef and mangrove-associated fisheries species may also occur as a result of excessive sediment run-off and poor water quality linked to increased rainfall patterns during these cyclonic events (Ellison, 2010, Brown et al. 2017).

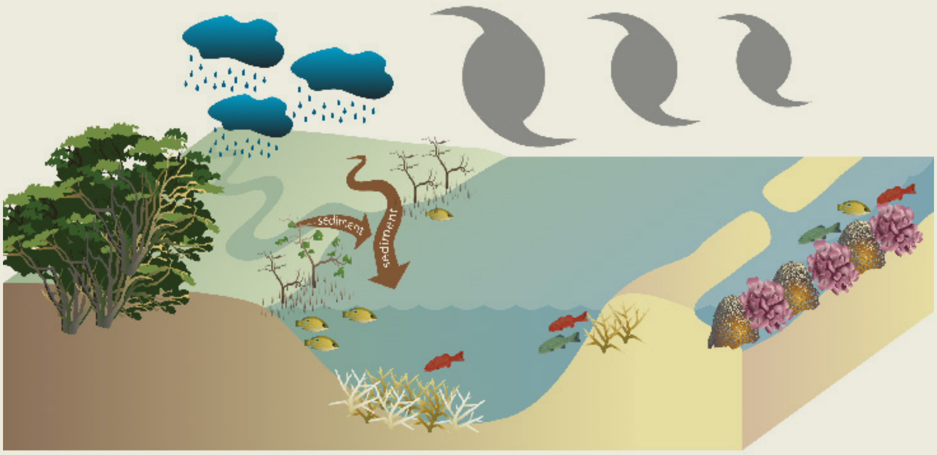


Figure B4.1. Extreme cyclone events can damage coral reef and mangrove ecosystems as a result of increased rainfall generating high volumes of sediment run-off into coastal watersheds. Icon sources: IAN Image Library

Along the GSR in particular, coral reefs and mangroves support a large proportion of subsistence fisheries and livelihoods. Therefore, planning for and implementing management actions, such as marine protected areas (MPAs), are necessary to address extreme event threats to these ecosystems, protect biodiversity, and sustain fisheries in the region. Common approaches to marine spatial planning use generic strategies or design principles to ensure that biodiversity and habitat targets are met in places of low cost to fishers. These approaches assume that areas selected for protection will retain their biodiversity features and ecological processes. They often ignore the potential of outside stressors that can degrade habitats and reduce MPAs' ability to provide their intended fisheries services. To account for the risk of extreme cyclones, the probability of such threats occurring needs to be incorporated into the spatial planning process of MPAs. As not all areas within a system of habitats, such as in the GSR, are equally impacted by extreme cyclonic events, it is possible to prioritize areas for management that have a lower risk of being degraded from a threat event.

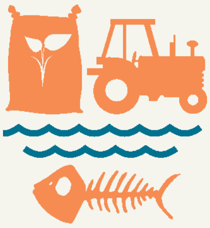
To aid this planning process for management actions along the GSR, a marine spatial plan of the region that takes into account fisheries value, biodiversity targets, and the risk of habitat degradation from extreme cyclonic events is currently in design. It specifically aims to use ecological data gathered from this GSR expedition, and best available data on historical cyclones and rainfall, to determine the spatial risk of increased sediment run-off on mangroves and coral reefs during extreme cyclonic events (Figure 1). This information will then be used to explore different marine spatial planning management prioritization scenarios along the GSR.

Figure B4.2. A healthy coral reef patch with a large number of purple acropora corals photographed at the shallow inner reef sites around the RaviRavi passage (north of Vanua Levu, Fiji). The abundant branching corals in the reef are highly vulnerable to disturbances often inflicted by cyclones.

33%

DECLINE IN REEF FISH ABUNDANCE COMPARED TO HISTORIC DATA

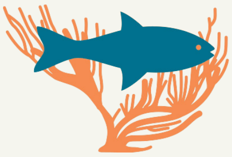
Other benthic groups showed more variable patterns. Macroalgal cover slightly increased across the GSR, from 4% in historic surveys to 5% in 2019. This increase was driven by the northern GSR, though despite increases the actual 2019 algae cover levels remain relatively low here. In the southern GSR, macroalgae levels were greatest and remained stable through time. High or increasing macroalgae cover can be associated with nutrient input onto reefs in other Pacific coral reefs or declining herbivore populations (Koop et al. 2001; Szmant 2002). While water quality monitoring and further analysis is needed to identify drivers of algal growth, it is probable that land-based pollution is partially driving this (Brown et al. 2017). These results highlight the need for sustainable agricultural or farming practices that consider impacts on the adjacent marine environment. Viti Levu and Vanua Levu have 16 major rivers and many other small creeks that outflow into the GSR that contribute to nutrient and sediment input into the reef system. It is important to note, that while macroalgae cover is increasing in the region, it is still relatively low when compared to typically degraded reef systems (Bruno et al. 2009). This suggests that dedicated efforts to prevent further nutrification of the waters and on herbivore population management could readily halt the current increasing algae trend.



Further studies on water nutrification are needed in the GSR to understand drivers of increased algal growth

3.5.2 Reef Fish

Fish abundance and biomass were generally low across the reef system, though results were variable by province and reef type. Mean fish biomass in 2019 across the GSR was 421 ± 60 kg/ha; this is low compared to global reference values for coral reef fish biomass. For example, coral reefs in the absence of fishing pressure would typically be expected to have approximately 1,000 kg/ha (McClanahan et al. 2019). Reef fish play many different functional roles on reefs, including those such as herbivory to maintain algal dynamics and corallivory and bioerosion of reef rock that generates sand. While these different ecosystem functions require different species and different biomass, there is a broad consensus that 500-650 kg/ha across trophic groups are required to maintain these functions (MacNeil et al. 2015; Graham et al. 2017). GSR mean fish biomass is substantially below these ecosystem function thresholds. Herbivores comprised the largest component of reef fish biomass – with Acanthuridae the most abundant family and the third largest family by biomass, and Scaridae the second most abundant family and largest family by biomass. This loss of herbivores is also likely contributing to recorded increases in algal cover. There was also a substantial biomass component from carnivorous families including Lutjanidae and Carcharhinidae (sharks) – suggesting that all trophic groups are still present on the reef and there is good recovery potential for reef fish following increased management.



GSR fish biomass is often below thresholds required to maintain critical ecological functions such as controlling algae

Temporal comparisons indicated declines in reef fish – with fish abundance approximately 33% lower and fish biomass approximately 80% lower compared to historic data for key fish families. Fish surveyed in 2019 were also smaller on average than those historically reported from the GSR. Trends in fish communities must be treated with caution – they are not fully representative of all sites in the GSR because of the limited historic data. While abundance declines were variable by region – with no changes in fish abundance in Nadroga-Navosa and Bua provinces – all areas that had historic fish biomass data showed declines.

Results suggest an urgent need to increase fisheries management and sustainability in the region to reverse declining trends. The FLMMA network working in partnership with communities and NGOs has been successful in establishing LMMAs in many *qoliqoli* across the region. These efforts need to be stepped up to expand to *qoliqoli* within the GSR that do not already have LMMAs, but also evaluate the effectiveness of the existing LMMAs to support increased fish biomass. This could include reviewing minimum size limits for fish, adjusting fisheries closure seasons, or increasing the size or closure duration of tabu areas. Communities implementing LMMAs should agree on targets for fish biomass they wish to achieve to underpin sustainable fisheries. These should be set based on maintaining ecosystem function for reef areas open to sustainable fishing (e.g. 500 kg/ha), and greater fish biomass targets for areas fully closed to fisheries. A monitoring, evaluation, and learning program is needed to help measure whether conservation activities are achieving their desired outcomes in the GSR. This should include regular monitoring surveys using standardized methods such as those in this report, supplemented by new methods that allow for additional insights (e.g. Box 5).

Box 5 - Passive acoustic monitoring

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[1]*Institute of Zoology, Zoological Society of London*

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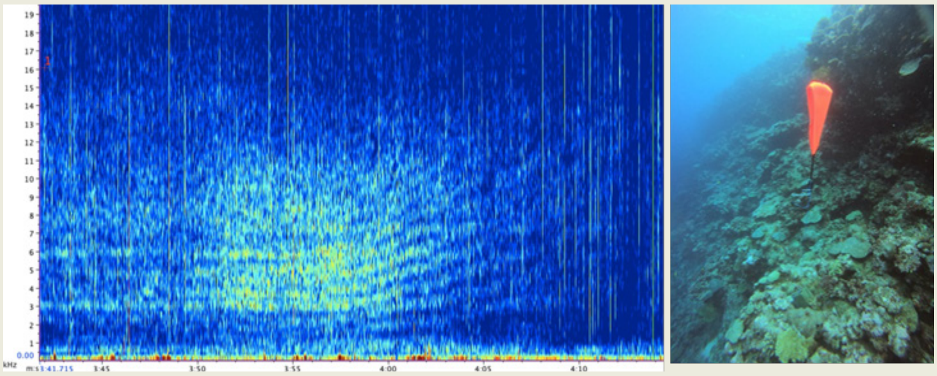


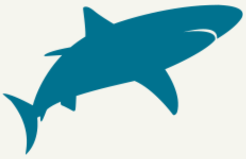
Figure B5.1. A section of the spectrogram output from underwater noise recorded on the Great Sea reef (left), and the hydrophone position on the reef (right).

Marine bioacoustics is a rapidly evolving area of marine research, with sound driving a range of ecological, physiological, and behavioral processes underwater (Montgomery & Radford 2017). Passive Acoustic Monitoring (PAM) has subsequently become increasingly used to monitor biodiversity and provide indicators of reef health, due to the rich data available from relatively low sampling effort (Elise et al. 2019). It is furthermore replicable across multiple spatial and temporal scales, and the raw data can be archived for future re-analyses (Gibb et al. 2019).

Alongside ecological processes, soundscapes can also be used to reveal physical characteristics of an environment, such as rainfall or wave action (Baumgartner et al 2018), or the level of human disturbance, such as boat engine noise, or blast fishing practices (Braulik et al. 2017; Dinh et al. 2019). This technology is therefore allowing researchers to now explore the effects of these types of acoustic disturbances on important ecological processes that depend on such acoustic cues, such as fish larval recruitment, communication, parental care, and predator avoidance (Williams et al., 2015, Ndelec et al., 2017, Gordon et al., 2019).

During the GSR survey, the team trialed the use of short-term underwater acoustic hydrophones (SoundTraps) as a means of capturing reef ecoacoustic indices, recording 50 hours of reef soundscapes across three sites. These recordings will enable Biome Health1 researchers to see if this method can quantify the acoustic soundscape effectively and be scaled up for deployment across more sites in future expeditions.

3.5.3 Rare species



In places where tourism and shark fisheries coexist, tourism-based conservation agreements may be a viable protection scheme for sharks

Sharks showed large increases in abundance, though this was mainly driven by sharks observed along the coast of Vanua Levu. Sharks are threatened by fisheries across Fiji, and often caught as bycatch before release or potentially kept for consumption (Glaus et al. 2015). Targeted shark fisheries, however, do occur in the inshore area—especially on coral reefs—and are most extensive around Viti Levu and the Yasawa Islands (Glaus et al. 2015). These fisheries most commonly catch blacktip reef sharks, whitetip reefs sharks, and bull sharks (Glaus et al. 2019). Results therefore parallel these fishing patterns – with increases in shark numbers in areas with limited targeted shark fisheries. When informally discussing sharks with local fishers around Yadua Island and Kia Island, fishers from both *qoliqoli* reported that bull shark numbers had increased in the area in recent years, causing concern for them when spearfishing. In Yadua, a fisher told the survey team about a community member who unfortunately died from a shark bite while spearfishing at night on the small barrier reef to the south of Yadua. Fishers in both Yadua and Kia reported that tiger sharks (Galeocerdo cuvier) did still occur on reefs in the area but were rarely encountered compared to bull sharks. No tiger sharks were observed during the survey. Previous research has shown that no-take areas within Fijian LMMAs in Bua province can have positive effects for shark abundance and biomass (Goetze and Fullwood 2012). These LMMA approaches are recommended to be expanded to other sites on the GSR – particularly in the southern GSR where shark numbers are lower. Sharks are highly valued by the dive tourism industry, both globally (Gallagher and Hammerschlag 2011) and in Fiji (Brunnschweiler 2010). Therefore, in areas with high tourism where targeted shark fisheries continue—such as the Yasawas Islands—tourism-based conservation agreements that bring value to the local community while protecting sharks seem a potential mechanism to increase shark protection (Mangubhai et al. 2020).

Serranidae (grouper) abundance increased across the GSR, though biomass remained stable. Serranidae are amongst the most commercially valuable and threatened reef fish species globally (Sadovy de Mitcheson et al. 2020), and make up a large proportion of Fijian inshore reef fisheries (Teh et al. 2009). The increased abundance of Serranidae is encouraging, and while biomass does not show any change, this is likely an artifact of historic data not recording the size of individual grouper >40 cm, and so forcing the analysis to truncate fish lengths for biomass calculations of all individuals >40 cm. Results suggest that existing management measures for Serranidae may be beginning to show an effect across the GSR. For example, since 2015 an annual national campaign (called the 4Fiji Campaign) promoted the protection of Serranidae during the spawning season from June to September. In 2018 the Fijian Government passed regulations prohibiting the harvesting of all Serranidae during spawning season. There have also been several regional efforts. For example, in Macuata province WWF has worked with several *qoliqoli* owners to ban the harvesting of camouflage grouper (*Epinephelus polyphekadion*) since 2016. There are also ongoing discussions on increasing the minimum size limits allowed for Serranidae capture as part of an anticipated revision to the Fiji Fisheries Act.

Recent measures to protect grouper populations include the protection of spawning groupers in 2015 and 2018

Humphead wrasse population density and size across the GSR were low compared to unfished populations (Sadovy de Mitcheson et al. 2019). However, it is encouraging that humphead wrasse populations are stable through time compared to the historic data despite widespread fishing in Fiji

Only a single juvenile bumphead parrotfish was observed in 2019.

(Yeeting et al. 2001) – for example, 194 individuals were reported landed from reefs within 20 km of Kia Island in the northern GSR in 2012 (Rokomate 2013). The recorded population density of 1.55 ind/ha appears in line with other global locations where humphead wrasse fishing occurs (Sadovy de Mitcheson et al. 2019). While densities do currently vary across the GSR region (see later sections), this likely reflects past fishing pressure and natural variation in reef habitat types. For example, historic surveys around Kia Island in 2012 recorded humphead wrasse densities of 11.7 ind/ha at sites local communities identified as locations where the species was commonly seen or caught (Rokomate 2013). Across the GSR a mean humphead wrasse length of 48 cm was recorded. While historic length data from the broader GSR is not available, the 2012 Kia Islands surveys recorded mean length of landed humphead wrasse at 75 cm, though these landed individuals were larger than the mean size observed on the reef during surveys (Rokomate 2013). This survey's results echo a previous survey in Bua province, which recorded few humphead wrasse individuals and suggested "the very low numbers should be noted and a total ban on fishing for this species should be considered" (Yeeting et al. 2001).

Bumphead parrotfish, previously presumed locally extirpated, but recorded in the 2004 WWF surveys (Jenkins et al. 2005) have remained rare. While bumphead parrotfish were recorded at lower densities in 2019 than in historic surveys, this decline is likely an artifact of the 2004 WWF survey, which in addition to encountering two juvenile bumphead parrotfish at Vatuka Island, encountered a school of over 50 adult bumphead parrotfish in the Raviravi passage (Jenkins et al. 2005). Despite visiting more survey sites and surveying a larger geographic range of the GSR, only a single juvenile bumphead parrotfish was encountered in 2019. Given the stochastic nature of encounters with bumphead parrotfish schools, there is no conclusive evidence of further population declines in this species, but these results suggest this is probable. Bumphead parrotfish, a slow-growing and long-lived species, are particularly vulnerable to fisheries. Therefore, a complete ban on fisheries of this species in the future is recommended.

3.88 km^2
OF MANGROVE COVER WAS LOST BETWEEN 1996 AND 2016

3.5.4 Southern GSR – Viti Levu

Reef condition was generally lower in the southern areas of the GSR region, at sites in Nadroga-Navosa and Ba provinces. This southern region contains several major cities and is the most developed area within the GSR region. Threats to coastal ecosystems here include coastal development, poor landuse practices, shipping, and mining. In general, GSR reef sites nearest to human impacts show the most degradation (e.g. low coral cover and high algae cover) and loss (e.g. declines in mangrove cover).

The southern end of the GSR along the Viti Levu coastline in Nadroga-Navosa and Ba provinces is particularly vulnerable to impacts from land-based activities associated with the main cites. Here, the GSR includes coastal areas adjacent to the cities of Lautoka and Nadi. The surveyed reef site adjacent to Lautoka city had very high turbidity and heavily impacted reefs – with over 51% of the seabed covered by sand and silt and only 4% live coral cover. This site had the lowest hard coral cover of any surveyed during the 2019 GSR survey. Lautoka is the major city in Fiji's sugarcane producing region and contains the main sugarcane mills and a large port, as well as growing tourism. Nadi is the main tourist entry hub into Fiji, and as such there has been extensive coastal development around this coastline and on inshore islands (e.g. Denarau). Both cities have increasing populations, and development has caused mangrove loss and increased coastal vulnerability. Both also have issues with waste management, and there is likely leakage of toxic waste from city dumps into surrounding mangrove areas and coastal waters (e.g. Andradi-Brown 2020). Lautoka coastal areas also face additional pollution from discharge from the sugar mills, while river dredging occurs in Nadi, which likely increases silt loads into coastal reefs. Conservation work along the coastline around Nadi and Lautoka should focus on protecting the remaining mangrove forests and reducing pollution impacts into the coastal areas.

In Ba province on the northwestern coast of Viti Levu the Ba River flows out into the Ba Estuary system – which includes expansive mangrove forests and coral reef ecosystems. Here, survey results identified a severe decline in marine ecosystems. For example, 3.25 km^2 of mangroves were lost in Ba province between 1996-2016, representing 64% of mangrove loss in the GSR region over this period. Reef fish biomass also declined on Ba Estuary reefs by 76% from 2010 to 2019 and is now at 150 kg/ha. These results suggest that the Ba Estuary is in urgent need of conservation action. Previous research has highlighted the importance of Fijian river estuaries for supporting shark populations (Rasalato et al. 2010), with the Ba Estuary having been identified as an important parturition and nursery area for hammerhead sharks (Vierus et al. 2018). Fisheries management should be implemented here as a priority to begin to rebuild reef fish populations and to protect shark populations. The Ba Estuary represents the largest contiguous mangrove forest stand in Fiji (Ellison 2010). The drivers of mangrove loss here need urgent further research, but it has been suggested that altered hydrological connectivity could be responsible (Ellison 2010). More broadly, the Ba Estuary faces many other threats. Sand and gravel mining is taking place in coastal waters on the estuary (GREENPAC 2011), while gold mining occurs in Vatukoula and along the Nasivi river east of the estuary. These activities disturb sediment and increase turbidity in coastal waters. Unfortunately, no historic benthic data was available from reefs in the estuary to allow us to track how these activities have impacted benthic communities, but it is likely to have had an

Southern areas of GSR have poorer reef conditions in general, likely correlated to extensive urban developments in the region.

impact. Ba Estuary reef sites had the greatest sponge cover of any area within the GSR, and shifts from high coral cover towards increase sponge dominance are a sign of reef degradation elsewhere in the Pacific (e.g. Knapp et al. 2016). Improvements to water quality through minimizing sediment disturbance and pollution input are therefore important to stop further reef degradation.

The offshore island archipelagos associated with Nadroga-Navosa and Ba provinces—the Mamanuca Islands and the Yasawa Islands—both showed declines in hard coral cover, though the Yasawa Islands showed increases in fish abundance. These islands are major tourism attractions, with island resorts hosting coastal tourism (e.g. beaches, watersports, snorkeling, diving). In the past, these islands are known to have suffered from coral bleaching (Skyes and Morris 2009), though Cyclone Winston also passed directly over these reefs in 2016 (Mangubhai 2016). Therefore, it is hard to disentangle the causes of coral decline without more detailed monitoring but is likely to be caused by multiple stressors. The Yasawa Islands had the highest macroalgae cover in the GSR, suggesting that benthic communities here are likely affected by human impacts. Encouragingly though, fish abundance remains stable in the Mamanuca Islands and is increasing in the Yasawa Islands, albeit from a low initial level. This suggests that efforts to increase fisheries sustainability and protect some areas of the reef for tourism as an income source for communities through conservation agreements (e.g. Mangubhai et al. 2020) may be resulting in positive biodiversity gains. Given these gains for reef fish abundance, and the conservation efforts in this area, it is surprising how few sharks, grouper, and humphead wrasse were observed in these areas. Development in these islands remains particularly sensitive to increasing storm intensity and sea levels from climate change. Conservation efforts in these islands should focus on increasing sustainability of the tourism sector on the island, climate adaptation using nature-based solutions (e.g. mangroves for coastal protection), and targeted efforts to increase populations of rare species.

Highest macroalgae cover in GSR was found in Yasawa, which may indicate human impacts.

45% coral
COVER - THE HIGHEST IN THE ENTIRE GSR REGION - WAS FOUND IN BUA PROVINCE

3.5.5 Northern GSR

This 2019 GSR survey includes scientific assessments of the remote offshore barrier reef in northern Bua province and reef sites on Udu Point in the eastern extreme of Macuata province. Both of these areas have been very poorly studied in the past, and there is little published data on marine ecosystems in these locations. In general, hard coral cover in the northern GSR region was higher than in the south, though most reefs have low and declining fish abundance and biomass. Several rare species were also observed while conducting surveys in the northern GSR, such as turtles (Box 6).

In Bua province the surveyed reef systems can broadly be divided into three groups with different ecosystem health and trends: (i) the outer GSR barrier reef, (ii) inner island reefs, and (iii) Yadua island off the western coast of Vanua Levu. Bua province had the highest coral cover of any province in the GSR—at 45%—which had increased since historic surveys. This suggests recovery from any historical impacts of coral bleaching (Skyes and Morris 2009), and at a province level there have been no major benthic disturbance events. Both the outer GSR barrier reef and the inner island reefs, however, showed evidence of high fishing pressure, with declining fish biomass. It has previously been suggested that grouper catches in this region have declined by more than 70% between the 1980s and 2000s and the fishing fleet in the region expanded by more than ten times over the same period (Sadovy 2006). In addition to this high fisheries pressure, on the inner reefs around Galoa Bay there is very high turbidity and sedimentation on the reefs – likely caused by the adjacent bauxite mines on the north coast of Vanua Levu. Therefore, more attention to building sustainable fisheries and minimizing land-based pollution is needed for these Bua province reefs. In contrast, fish abundance more than doubled around Yadua Island since historic surveys – though current fish abundance and biomass is still low. Several sharks and humphead wrasse were also observed around Yadua. Efforts should be made to ensure that the local governance conditions that have enabled this recovery are maintained and secured longer term.

Macuata province hard coral was high at 36% and also stable through time, though increases in algae cover on the reefs and a 36% decline in fish abundance were recorded. Macuata province suffers from high rates of sediment input from rivers such as the Dreketi and Labasa along the northern Vanua Levu coastline because of unsustainable land practices. These include logging of upland forests and farming without leaving riparian vegetation in place to prevent soil erosion into watercourses. Labasa, as the largest city in Vanua Levu, hosts agricultural industry – including a sugar mill which produces waste and drains into the northern GSR through the Labasa River. These rivers—especially the Dreketi, which is the deepest river in Fiji—have been identified as important shark areas (Rasalato et al. 2010). Macuata province also had unique mangrove and reef-fringed islands along the Vanua Levu coastline from the western part of the province to Mali Island. Many of these islands contained small central lagoons that are accessible at high tide and fished by local communities. Around these islands generally the turbidity was high, and a unique ecosystem exists with many black corals (Box 7). While these ecosystems are well known by local communities and were identified in the 2004 WWF GSR survey (Jenkins et al. 2005), they are worthy of more detailed study and should be protected, as they are unique in the GSR region.

Unique reefs with abundant black corals are found within some lagoons of Macuata province

Box 6 - A Tower Guard for Turtles

WWF - Pacific

WWF - Pacific Affiliation

Figure B6.1. Henry Koliniwai, a turtle monitor, overlooks the bay from the WWF-built guard house on northern Mali Island.

Fiji is home to five of the seven sea turtle species, of which two have been seen on the GSR during the recent survey (green, hawksbill). Pacific Islanders have strong cultural and spiritual ties to these turtles: here in the Fijian islands, turtle meat is a traditional staple. Once reserved for chieftains and special events like weddings or funerals, over time it became a common food item, its consumption contributing to declining turtle populations (Golden et al. 2014; Mangubhai 2019). Today, turtle species here are registered on the IUCN Red List, with the loggerhead listed as vulnerable and the hawksbill as critically endangered.

In 1995, the Fiji government imposed a temporary ban on turtle harvesting; in 2008, WWF successfully pushed for a 10-year moratorium, during which harvesting was allowed only by permit for special occasions (Laveti and MacKay 2009; Mangubhai 2019). Now, communities are the ones leading protection efforts. For example, on Mali Island a guardhouse was erected in 2016 for communities members to monitor their *qoliqoli* and turtle nesting beach from. Community members watch for outside fishers coming into the area to fish or hunt turtles and are able to prevent them fishing. The community members leading this work are Dau ni Vonu—guardians of turtles—many of which were former turtle hunters who now lead marine protection efforts.

Midway through the GSR survey, researchers visited the *qoliqoli* area on Mali Island overlooked by this guardhouse, speaking with Henry Koliniwai, one of the turtle monitors. Koliniwai says he protects the turtles so his children and grandchildren can have them too, and he's happy to see the impact he and others are having. "Before, when my father and I went fishing, we saw very few turtles," he says. "Now, we see a bit more."

Box 7 - Black corals of western Macuata

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[2]*ARC Centre of Excellence for Coral Reef Studies, James Cook University, Australia*

[3]*WWF-Pacific, Suva, Fiji*

Figure B7.1. A black coral photographed in about 10m of depth north of Vanua Levu in a mangrove rich region. Great Sea Reef Survey, Fiji.©Tom Vierus / WWF-US.

During the 2019 GSR survey we conducted surveys on the fringing reefs surrounding the coastal mangrove islands of western Macuata province. These reefs represented a unique system within the GSR, with highly abundant black corals (Hexacorallia: Antipatharia) on the shallow reefs starting from 5 m depth and continuing down the reef slope. Black corals are colonial animals that inhabit all oceans from 2 m down to 8,500 m depth, though are normally most commonly found on deeper tropical reefs (Wagner et al. 2012). Their common name is attributed to their dark coloured proteinaceous skeleton. Black coral provide important structure habitat on the reef and support many associated species. For example, studies elsewhere in the Pacific have found over 2,250 invertebrates living within a single dead black coral colony (Love et al. 2007) and many reef fish live or shelter within black coral branches (Boland and Parrish 2005). In western Vanua Levu, black corals have been identified as the primary substrate that penguin's wing oyster (*Pteria penguin*) spat settle on (Passfield, 1995). This species can be important in pearl production, through requires seeding.

Black corals have historically been harvested in many locations around the world, as their black skeletons can be polished to make jewellery (Bruckner 2016). Black coral harvesting is often characterized by rapid overexploitation, leading to near-eradication because of their slow growth rates (Bruckner 2016), and populations have often failed to recover following harvesting even after management implementation (e.g. Gress and Andradi-Brown 2018). In Fiji, black coral was collected from Beqa Lagoon and used to make jewellery in the mid-1980s to 1990, but this harvesting ceased (Lovell 2001). In October 2020, while visiting tourist shops and market stalls in Nadi, we observed several shops and stalls selling small carved pieces of black coral as curios. When asked about the source of the black corals, multiple separate shop owners/stall holders answered that it was harvested and carved in the Yasawa Islands. Therefore, black coral harvesting is still continuing within Fiji for sale to tourists. All black corals are listed on CITES Appendix II, making international trade or export of them illegal without export permits.

The presence of black corals on inner Vanua Levu reefs has long been known, with local community leaders telling the survey team that these high densities can be observed on reefs from western Vanua Levu in Bua province through to Mali Island in central Macuata province. The 2004 WWF survey also noted the unusual presence of black corals on these reefs (Jenkins et al. 2005). The community leaders also said that no one harvests the black corals in the area, but if there was interest, harvesting within the *qoliqoli* would be controlled by community leaders in the same way as other fishing access rights.

We recommend that as part of improved fisheries management within these *qoliqoli*, that the unique black coral ecosystems of norther Vanua Levu should be protected from any future harvest efforts.

Figure B7.2. Underwater portrait of Dr. Dominic Andradi-Brown (WWF-US) in front of a black coral. North of Vanua Levu, Fiji.©Tom Vierus / WWF-US.

A parrotfish photographed at the reef surrounding Yadua island, west of Vanua Levu, Fiji. Parrotfish fulfill an important ecological role on coral reefs. At the same time parrotfish are generally sought after food fish and often among the first species to be overfished on reefs.

4 MANAGEMENT RECOMMENDATIONS

at least 30% OF THE GSR SEASCAPE SHOULD BE INCLUDED IN PROTECTED AREA NETWORKS, PRIORITIZING SENSITIVE OR UNIQUE HABITATS.

The following management actions are recommended to improve the ecosystem health of the GSR:

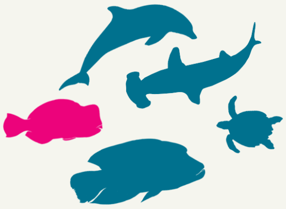
1. Expand existing and establish new protected areas and other effective conservation measures (OECMs) across the GSR to form a representative network.

Existing work by NGOs and the FLMMA network in partnership with local communities has provided a model for increased marine protection in *qoliqoli*. These approaches have been demonstrated effectively in several *qoliqoli*, for example Qoliqoli Cokovata in Macuata and in Kubulau *qoliqoli* in Bua province. New protected areas and OECMs should be equitably established within *qoliqoli*. OECMs in particular offer much promise for formal national and international recognition of many customary management practices that provide biodiversity benefits (e.g. period harvest closures) but do not have biodiversity conservation as a primary objective. These areas should be implemented to ensure they are representative of ecosystems and also provide protection to particularly sensitive and biologically unique habitats identified in the region (e.g. black coral dominated reefs in Macuata). Ideally a minimum of 30% of the seascape should be included in these areas with significant biodiversity protection.

THERE IS AN URGENT NEED TO IMPROVE REEF FISHERIES SUSTAINABILITY IN THE GSR..

2. Develop specific conservation programs for rare and endangered wildlife.

Many rare (including IUCN listed endangered species) species were identified on the GSR. Rare species include humphead wrasse (*Cheilinus undulatus*), bumphead parrotfish (*Bolbometopon muricatum*), camouflage grouper



Many rare species in the region warrant conservation programs tailored to their needs

(*Epinephelus polyphekadion*), sea turtles, and many shark species. A specific program focused on awareness, monitoring, and management should be established focusing on these globally important species.

3. Improve suitable fisheries management within the GSR.

Fish abundance, biomass, and size is generally declining across the GSR. There is an urgent need to improve fisheries sustainability in most *qoliqoli*. This should be supported by updated/revised legislation to address exiting fisheries management gaps and increase recognition of communities' rights to sustainably manage their fisheries resources. Approaches should follow guidance developed for ecosystem-based fisheries management. There are already positive enabling conditions for effective sustainable fisheries management, with governance practices that recognize the rights of communities to control access to their *qoliqoli*. A key first step is to ensure existing fish minimum size restrictions, fisheries closure seasons, and species harvest bans are being followed. Additional approaches could include further fisheries closure seasons for target groups, gear restrictions to reduce the most damaging fishing gears, increased minimum capture size limits for species (e.g. grouper), and in some cases extending or implementing complete harvesting bans on particularly rare species (e.g. humphead wrasse, bumphead parrotfish, camouflage grouper, turtles).

4. Promote economic incentives and community livelihood approaches that support sustainability and conservation.

There is a need for alternative livelihoods to reduce dependence on fisheries within the GSR region. Local leaders have illustrated potential approaches as part of sustainability efforts in Qoliqoli Cokovata (e.g beehives, small-scale agriculture) and the Yasawa Islands (e.g. community owned and managed tourist accommodation, coconut oil and cassava chips production for sale to tourists). These approaches should be shared through regional learning opportunities, as well as support provided to communities wishing to replicate similar initiatives. In the northern GSR, where less tourism currently occurs, any future tourism development should be focused on sustainability and ecotourism. For the area around Kia Island, the high biodiversity and relatively intact reefs also have some of the best surfing waves in the world. Promoting a sustainable surfing tourism industry, through local surf-lodges, is worth investigating as a sustainable income earner for northern portions of the GSR.

Increasing livelihood diversity with less dependence on reef fisheries will be beneficial to marine conservation.

5. Strengthen customary governance systems and state governance systems for both formal and informal management approaches.

Human and financial resources for conservation and sustainable development are limited within the GSR region. Strengthening the capacity of villages, government departments, and NGOs to actively manage and confront the growing pressures on the environment is an important priority, especially in the face of declining fish biomass and increasing risk from climate change. It is key to increase enforcement of existing legal protections and legislation, as well as customary protection, to address poaching and MPA enforcement. This work should also include a thorough revision of current legislation to support customary governance and sustainable financing opportunities for the GSR region.

6. Increase cross-institutions coordination.

Our ability to understand how systems interact and respond to change and hence our ability to support effective ecosystem management is hindered by the partitioning of knowledge and responsibilities. For example, multiple government departments, customary institutions, and other agencies all have responsibilities for different aspects of land and marine management that affect GSR marine ecosystems. More coordination and synergies across sectors and stakeholders is needed to improve conservation outcomes for the GSR.

7. Develop sustainable financing plans and mechanisms to support conservation activities in the GSR region.

Establishing, monitoring, and adaptively managing conservation and sustainable development interventions requires funding. Many recommended activities for the conservation of marine ecosystems in the GSR will require sustained long-term efforts. It is essential to secure stable and sufficient longterm financial resources to support effective conservation activities in the region. Sustainable financing must also invest in community livelihoods and in community-based fisheries management plans and rules.

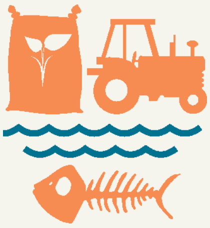
Restoration efforts will not only address the current loss of mangrove forests, but also increase the region's resilience against climate change.

8. Initiate legal protection for existing mangrove forests and seagrass beds and restore mangroves and seagrass in places that have been lost.

Mangrove forests and seagrass beds support important biodiversity and provide nursery habitat for many important fisheries species in the GSR. Mangroves also play an important role both in the global context for climate mitigation though carbon storage, but also in the local context for climate adaptation. Mangrove and seagrass protect coastlines from erosion and storm damage. With the GSR region particularly vulnerable to rising sea level, existing mangroves and seagrass should be protected, and mangroves and seagrass should be restored in places they have been lost following best-practice scientific guidelines. Protection should have legal recognition and be implemented in partnership with local communities and other stakeholders. Mangrove forests will also naturally migrate inland as sea levels rise, therefore coastal development and planning should ensure that there is sufficient space in-land behind mangrove forests to allow this migration. Allowing development right up to the edge of mangrove forests will prevent this inward migration, leading to "coastal squeeze" and reducing the width of the mangrove forest, and thereby reduce protection benefits provided.

9. Assess and mitigate environmental impacts of land-based activities.

Many of the major threats to the coastal habitats of the region originate from land-based activities such as coastal development, logging, agriculture, and



Increased control and mitigation measures for land-based and extractive activities is needed.

mining. Potential impacts of these activities are likely driving changes on reefs. For example, agricultural practices are likely responsible for increasing algae cover in some parts of the GSR, and low turbidity on inner reefs in Bua province are likely associated with bauxite mining in the region. These sectors need to work towards elimination or mitigation of these impacts. Watershed management needs to be a primary objective in provincial land-use plans, and coastal pollution and impacts considered when approving development anywhere in the watershed if coastal systems are to be conserved.

10. Assess and mitigate environmental impacts from coastal resource extraction and prohibit the most damaging extractive activities.

Significant local threats to the coastal habitats in the GSR region originate from coastal resource extraction such as sand and gravel mining. These activities directly damage sensitive coastal habitats which support important biodiversity. For example, most river deltas in the GSR region act as shark nurseries or feeding areas. Extractive coastal activities also have much wider impacts beyond the extraction locations, with disturbed silt and sediment settling over larger areas. Sectors involved in these activities need to work towards elimination or mitigation of these impacts. The threshold for acceptable negative impacts identified by environmental impact assessments prior to project implementation should be raised to require extensive mitigation measures before similar activities are approved in the future.

11. Promote sustainable coastal development practices.

There is an urgent need to promote best-practice approaches for coastal development. This is particularly important in the north coast of Vanua Levu where most coastal ecosystems remain intact and there has been much less past coastal development compared to Viti Levu. Sustainable coastal development needs to consider issues such as waste management and the potential future impacts of climate change.

Regular monitoring and evaluation is critical to support adaptive managment. This may be supported by commerical sectors such as the diving tourism industry.

12. Establish more regular monitoring and evaluation that can feed into adaptive management.

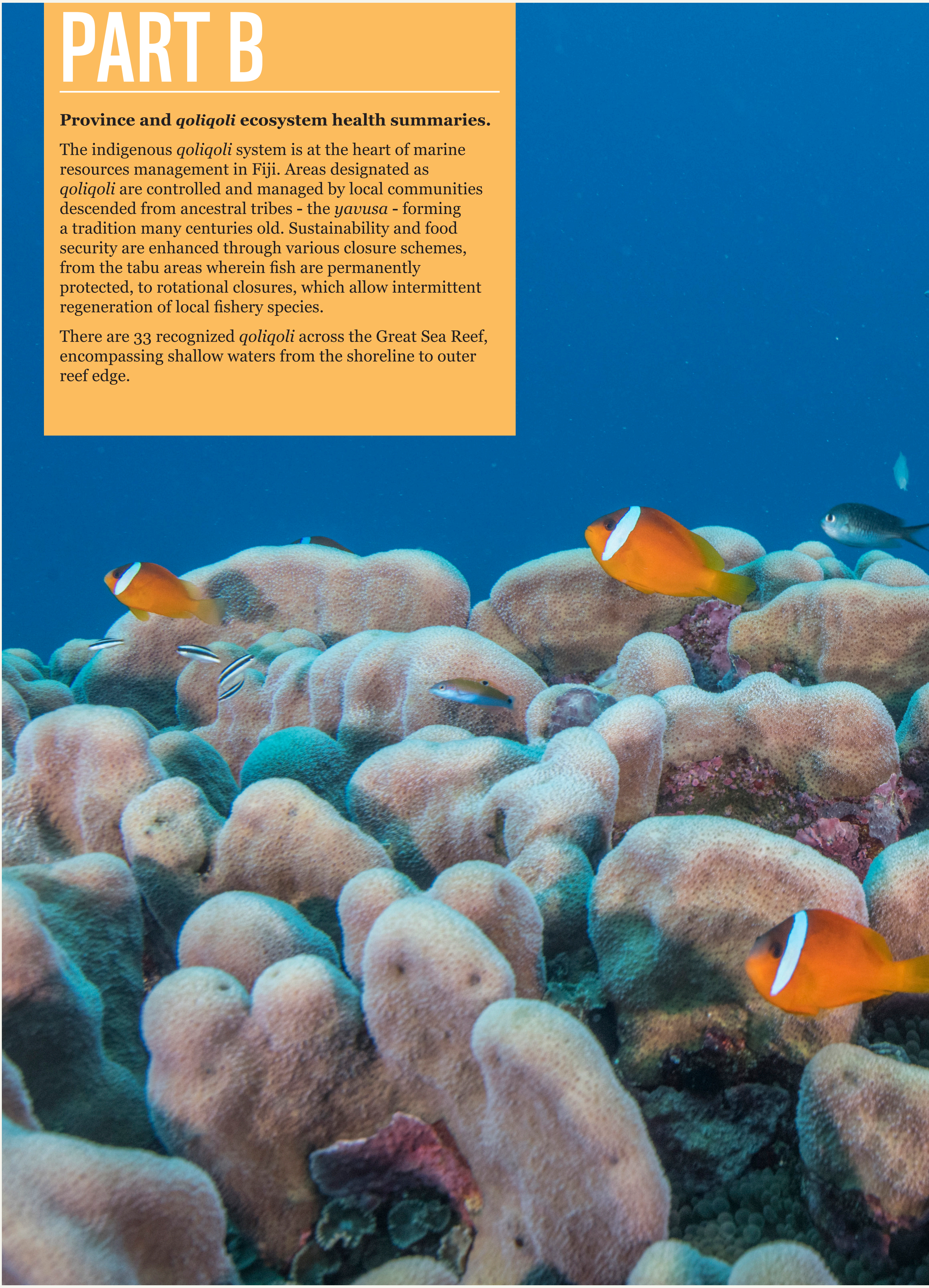
There is little regular ecological and socio-economic monitoring occurring on the GSR. This prevents understanding of the impact of existing conservation interventions being undertaken, and also makes adaptive management to improve outcomes hard. There is an urgent need to establish a regular monitoring program to track changes in water quality, ecosystem health, and social conditions to better understand the impacts of conservation interventions. Funding such a program will be challenging, but there is strong interest from the diving tourism industry in Fiji to support ecological monitoring that should be explored further.

PART B

Province and *qoliqoli* ecosystem health summaries.

The indigenous *qoliqoli* system is at the heart of marine resources management in Fiji. Areas designated as *qoliqoli* are controlled and managed by local communities descended from ancestral tribes - the *yavusa* - forming a tradition many centuries old. Sustainability and food security are enhanced through various closure schemes, from the tabu areas wherein fish are permanently protected, to rotational closures, which allow intermittent regeneration of local fishery species.

There are 33 recognized *qoliqoli* across the Great Sea Reef, encompassing shallow waters from the shoreline to outer reef edge.



5 NADROGA-NAVOSA

5.1 Nadroga-Navosa province

5.1.1 Introduction and critical habitat coverage

Nadroga-Navosa province lies in southwestern Viti Levu, encompassing part of Viti Levu and offshore islands – including the Mamanuca Islands. Nadroga-Navosa province has a land area of approximately 2,385 km² and a population of approximately 59,000 people. The northern waters of Nadroga-Navosa province, in Malolo *qoliqoli*, represent the southernmost extent of the GSR – where the offshore reefs and islands comprising the GSR system merge with the fringing reefs of Viti Levu. Therefore, the surveys focused on Malolo *qoliqoli*, which contain the Mamanuca Islands and associated reefs. Malolo *qoliqoli* span 1,095 km² (Figure 5.1.1).

Reefs take multiple forms within Malolo *qoliqoli*, with shallow fringing reefs and small barrier reefs along the coastline of the Mamanuca Islands, and an extensive barrier reef along the western edge of the *qoliqoli* (Figure 5.1.2). In total, coral covers approximately 19 km² within Malolo, though summing all Allen Coral Atlas benthic categories that likely contribute to broader coral reef ecosystem composition (i.e. coral/algae, microalgal mats, rock, and rubble) suggests a coverage of 54 km² of shallow reef-related ecosystems. The majority of these reefs are comprised of inner reef flats (23 km²), closely followed by outer reef flats (21 km²) and reef slopes (8 km²), with many other reef types also present (Figure 5.1.3).

Mangrove extent is low in Malolo *qoliqoli*, with none detected by satellite remote sensing. Mangroves within the *qoliqoli* are restricted to narrow coastal fringes around the islands, limiting extent (Figures 5.1.4; 5.1.5). Seagrass covers approximately 83 ha within Malolo *qoliqoli*, with much of this in the south (Figure 5.1.6).

Figure 5.1.1. Bathymetry of Malolo *qoliqoli*.

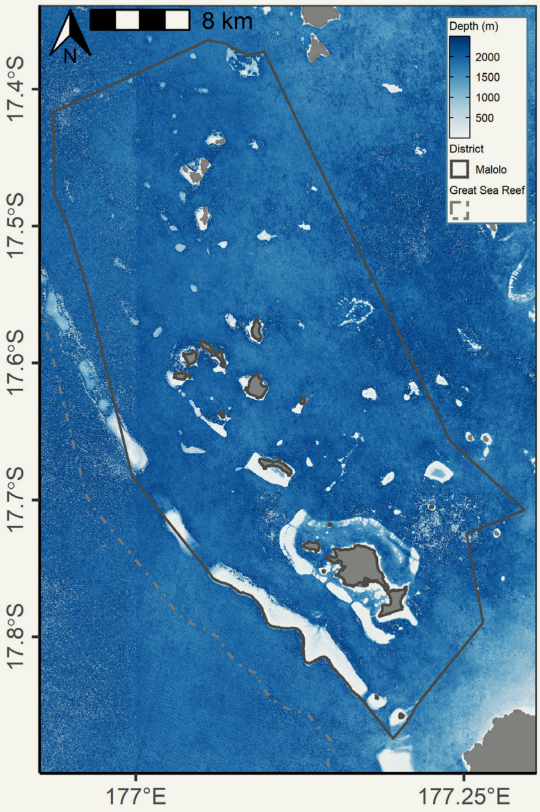


Figure 5.1.2 Coral reef extent Malolo *qoliqoli*.

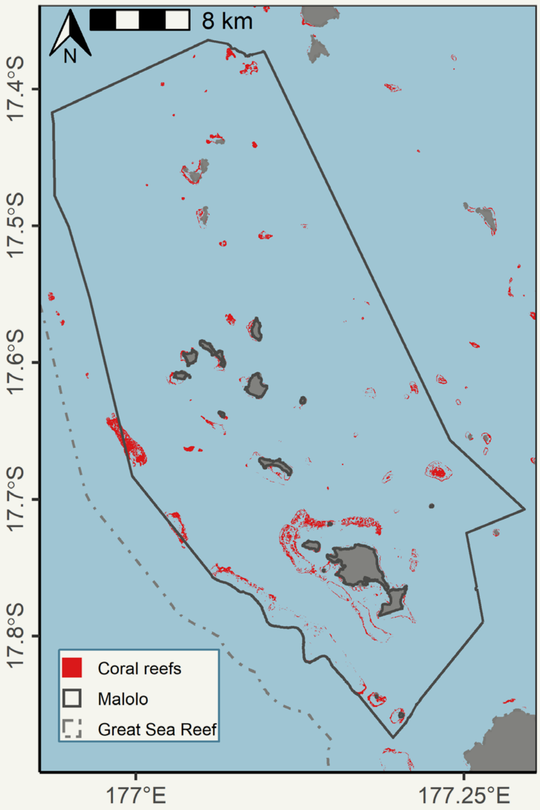


Figure 5.1.3. Reef geomorphic types in Malolo *qoliqoli*.

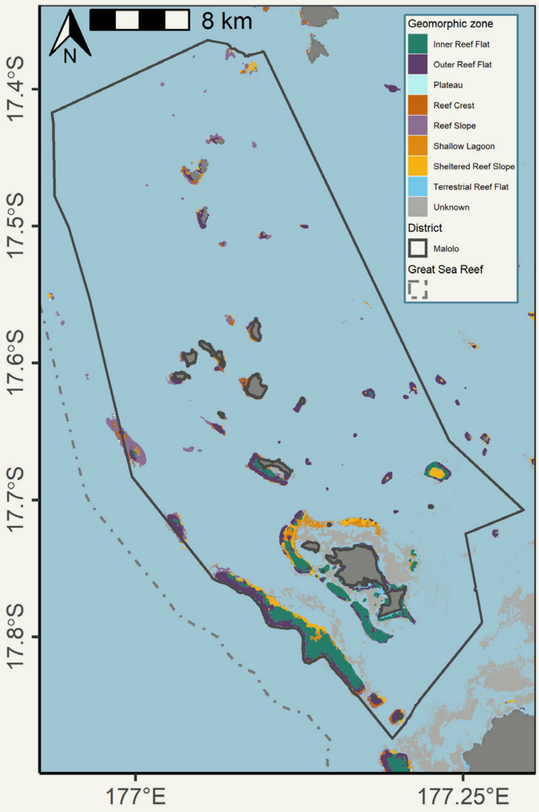
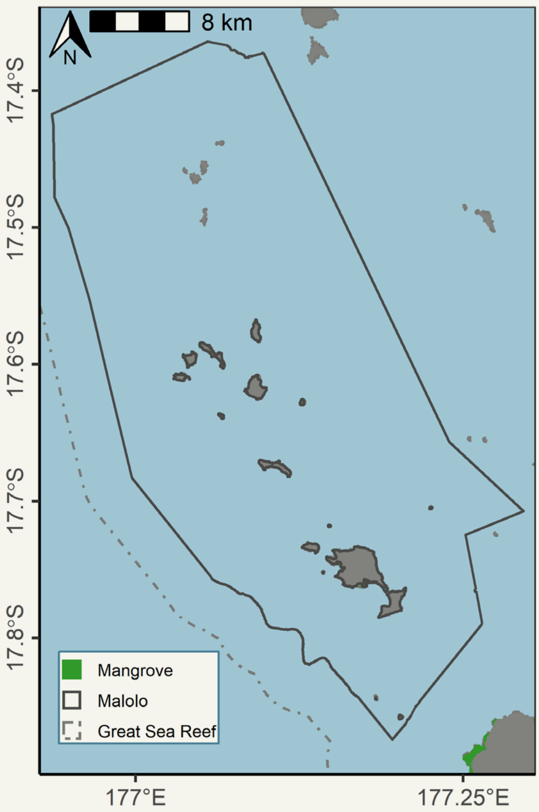


Figure 5.1.4. Mangrove extent in Malolo *qoliqoli*.



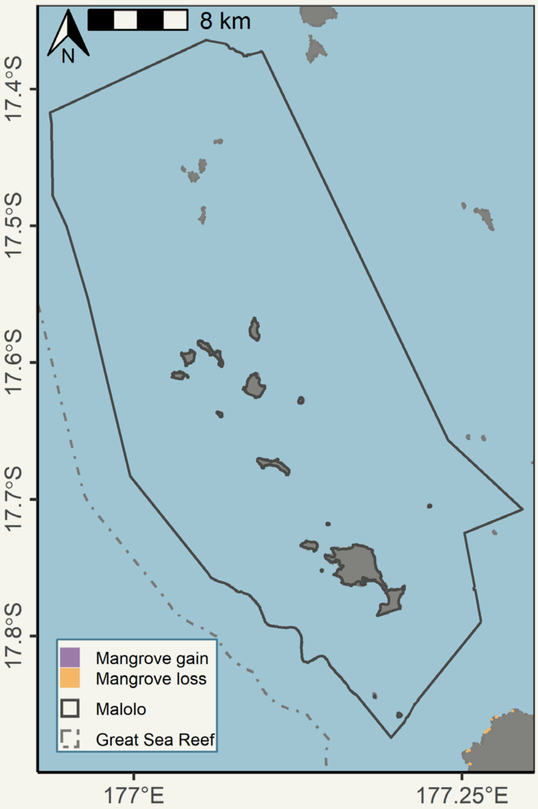


Figure 5.1.5. Mangrove change between 1996-2016 in Malolo *qoliqoli*.

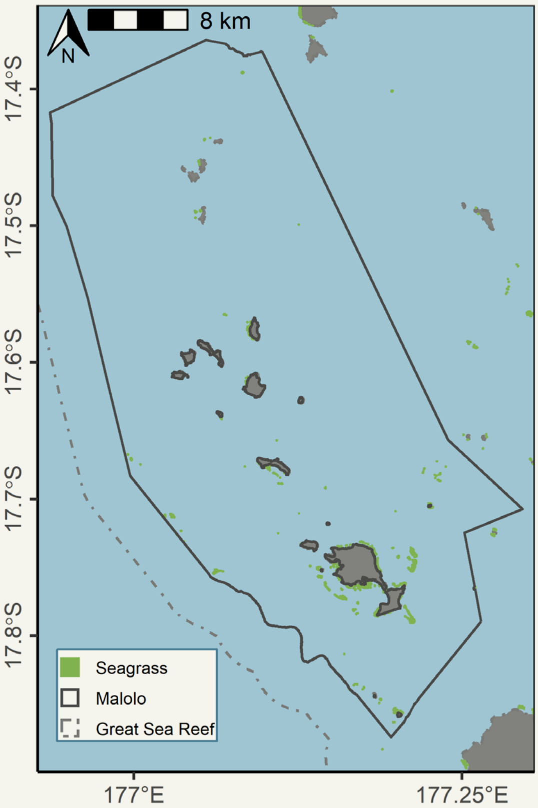


Figure 5.1.6. Seagrass cover in Malolo *qoliqoli*

5.1.2 Survey sites

Surveys were completed at four sites within Malolo *qoliqoli* (Figure 5.1.7). Sites were located around Tokoriki Island, with three sites on the Tokoriki fringing reef and one site on a small patch reef a short distance offshore. All four of these sites had historic data available from Reef Check (Reef Check Foundation 2019). Historic surveys were conducted in 2004 for all sites, providing benthic cover and fish abundance. No historic fish biomass data was available.

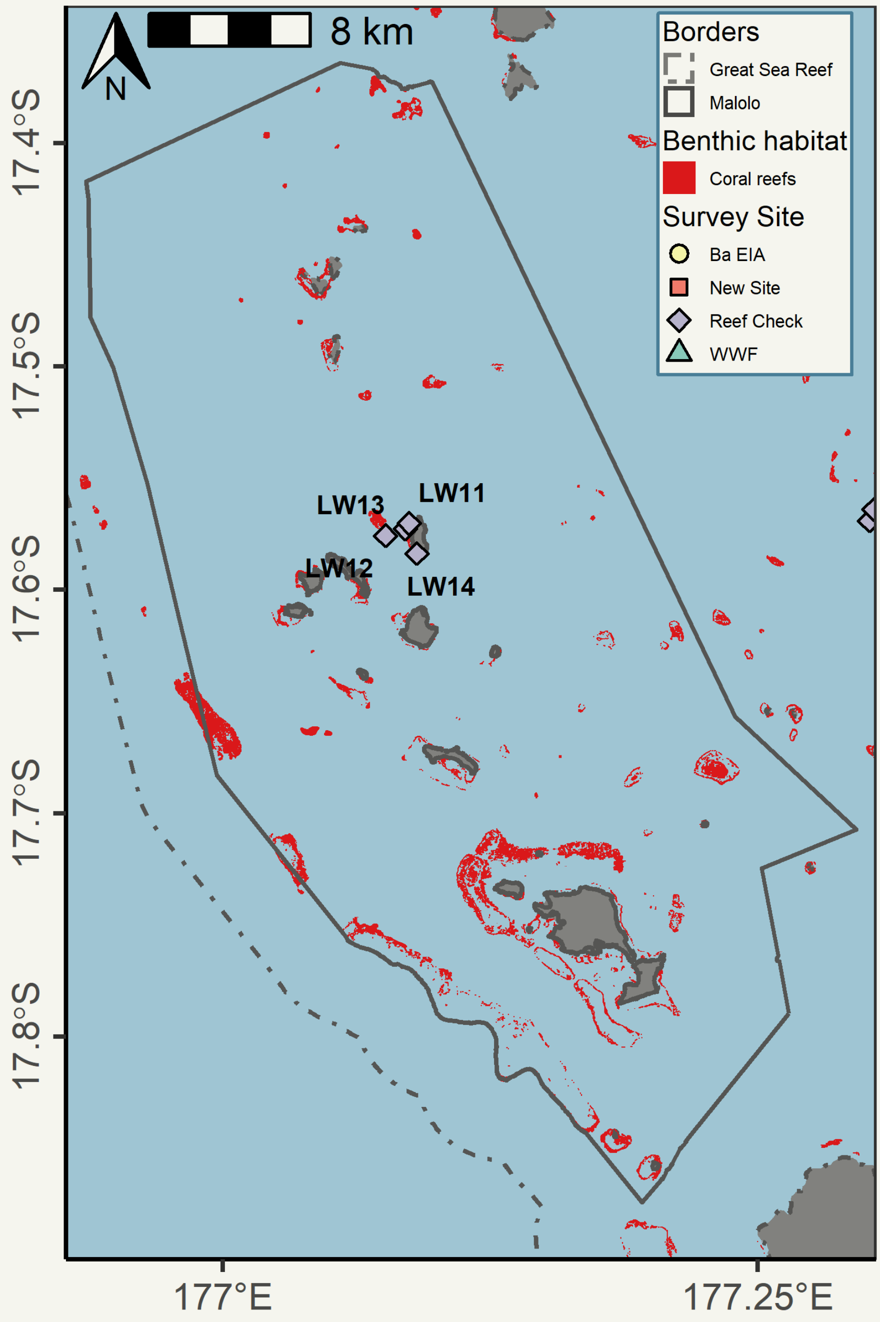


Figure 5.1.7. Survey sites in Malolo *qoliqoli*.

5.1.3 Benthic cover

Hard coral cover was 23 ± 4% across reefs in Malolo *qoliqoli* in 2019 (Figure 5.1.8). This coral cover was lower than in the northern GSR. The second highest live benthic cover on reefs was crustose coralline algae, at 12 ± 6%. Macroalgae cover was very low (<1%). Non-living benthic cover was high in the province, with rubble at 21 ± 4%, sand at 7 ± 4%, and bare substrate at 28 ± 11% cover.

Based on all four sites, it was *extremely likely* (W=16, p=0.03) that hard coral cover declined, from 50 ± 5% in 2004 to 23 ± 4% in 2019 (Figure 5.1.9). It was also *extremely likely* (W=0, p=0.03) that the amount of rubble on the reefs increased, from 3 ± 1% to 21 ± 4%. There have been limited changes in most other benthic groups (Figure 5.1.9).

Figure 5.1.8. Benthic cover in 2019 for Malolo *qoliqoli*.

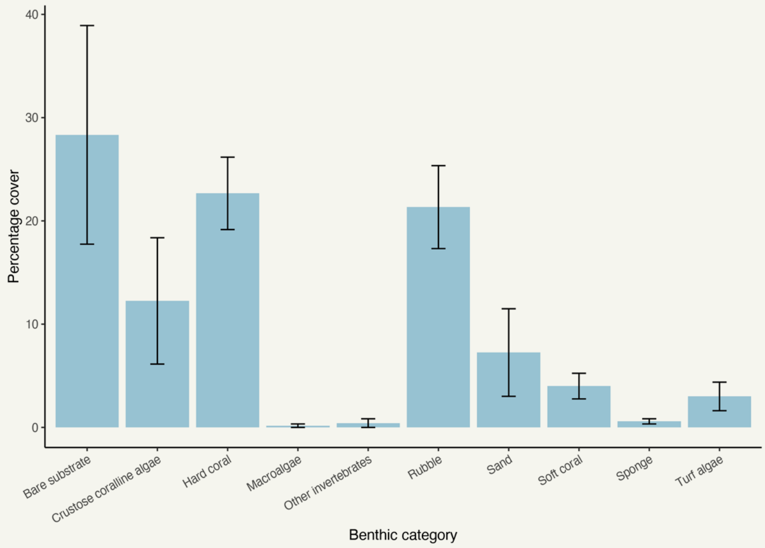
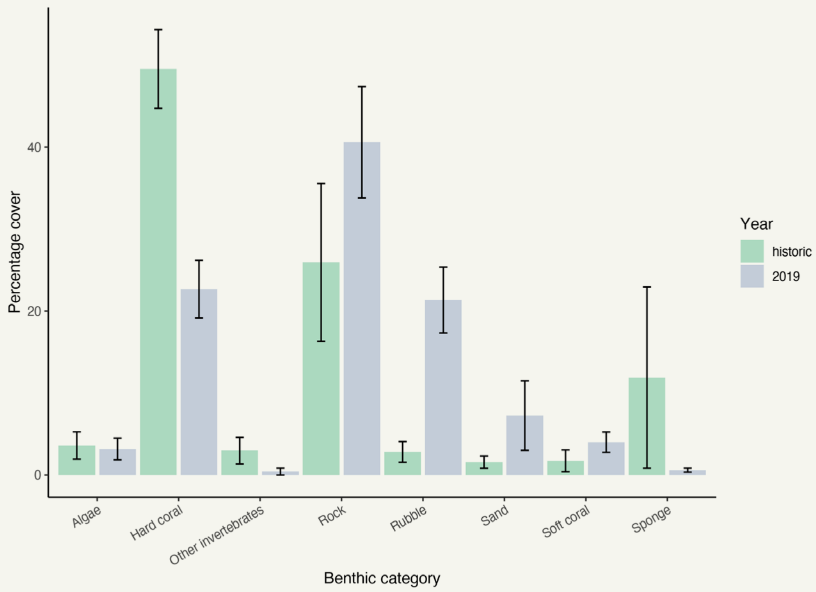


Figure 5.1.9. Change in benthic communities for Malolo *qoliqoli*.



5.1.4 Fish communities

A mean fish abundance for the target family/species list of 3,863 ± 697 ind/ha was recorded across all Malolo sites, while mean fish biomass was 587 ± 171 kg/ha. Fish communities were dominated by herbivores in both abundance and biomass (Figure 5.1.10). The most abundant fish family was Acanthuridae (1,854 ± 452 ind/ha) followed by Scaridae (874 ± 168 ind/ha). Acanthuridae was also the largest fish family by biomass (194 ± 69 kg/ha), with Scaridae the second largest (194 ± 69 kg/ha). Carnivores made up a low proportion of the fish community by abundance and biomass, with Lutjanidae the largest carnivorous family at 150 ± 104 ind/ha and 35 ± 32 kg/ha. It was *about as likely as not* (V=3, p=0.63) that key fisheries family abundance changed between the 2004 and 2019 surveys in Malolo, from 769 ± 230 ind/ha to 1,084 ± 268 ind/ha (Figure 5.1.11).

Figure 5.1.10. Fish community structure by (A) abundance and (B) biomass for Malolo *qoliqoli*.

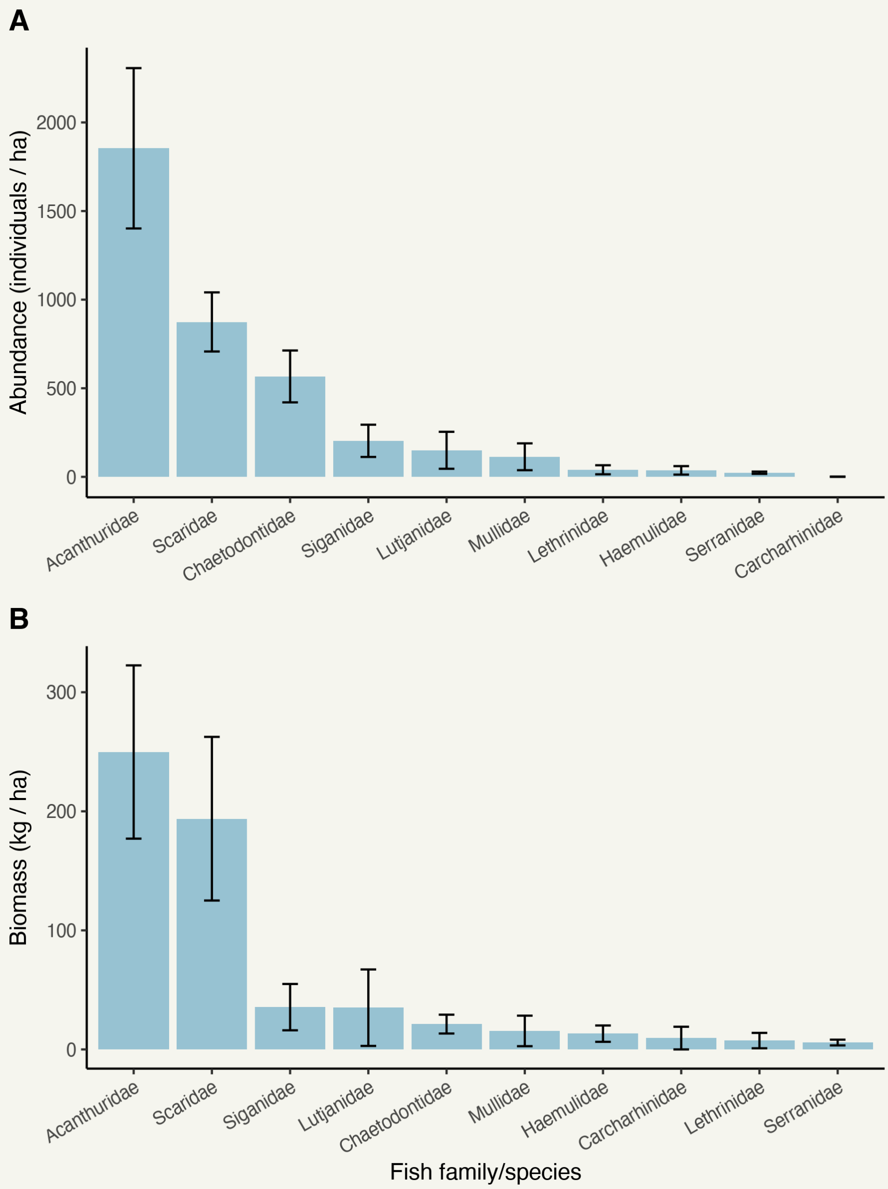
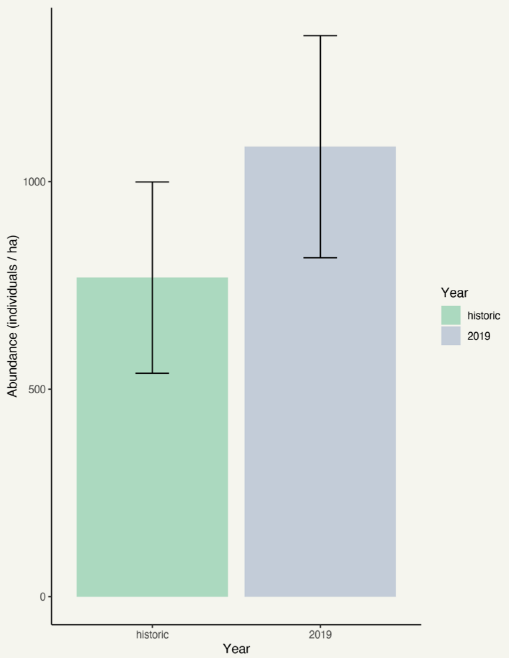


Figure 5.1.11. Change in key fisheries family abundance (Haemulidae, Lutjanidae, Scaridae, and Serranidae) for Malolo *qoliqoli*.

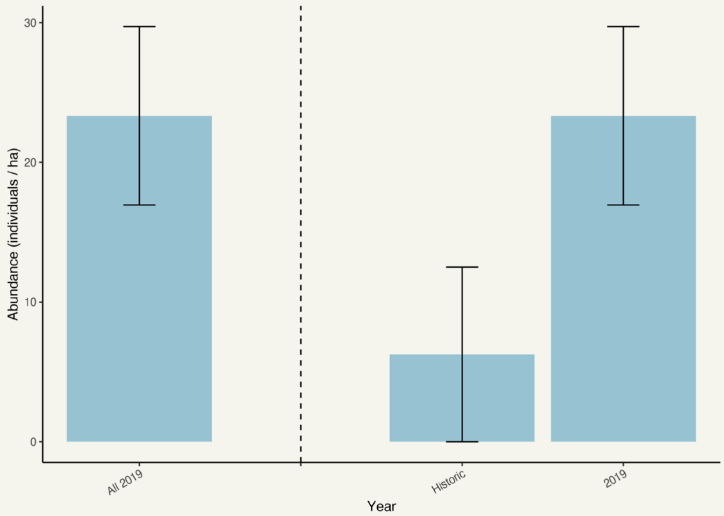


5.1.5 Rare Species

No humphead wrasse or bumphead parrotfish were recorded across the four sites in Malolo during historic surveys in 2004, nor in the surveys in 2019. Sharks in the family Carcharhinidae were recorded at an abundance of 0.83 ± 0.83 ind/ha and biomass of 9.52 ± 9.52 kg/ha across all Malolo sites in 2019. No sharks were recorded in the 2004 surveys at these sites.

Serranidae abundance and biomass was 23 ± 6 ind/ha and 5.79 ± 2.40 kg/ha, respectively, across the four surveyed Malolo sites in 2019 (Figure 5.1.12). It was *likely* (V=1, p=0.25) that Serranidae abundance increased, with surveys in 2004 recording 6 ± 2 ind/ha.

Figure 5.1.12. Serranidae (grouper) abundance for Malolo *qoliqoli*. Figure shows data for all sites on both the left and right of the dashed line, as all sites had historic data.



6 BA

6.1 Ba province

6.1.1 Introduction and critical habitat coverage

Ba province lies in northeastern Viti Levu, encompassing part of Viti Levu and offshore islands – including the Yasawa Group . Ba province has a land area of approximately 2,634 km² and a population of approximately 250,000 people – making it the largest province by population in the GSR region and in Fiji. The waters of Ba are divided into 14 *qoliqoli*, and span 8,989 km² (Figure 6.1.1). Provincial waters are bounded to the south by the Viti Levu fringing reefs, and in the north by several narrow ribbon reefs offshore of the Yasawa Islands. Within Ba provincial waters there are extensive fringing reefs and smaller barrier reefs surrounding the Yasawa Islands, many small isolated reef systems in central Ba waters, and extensive reef systems associated with the Ba river estuary. The Viti Levu coastline and Yasawa Islands also contain significant mangrove areas. The Yasawa Islands are a major tourism attraction, and regularly boats link tourism hubs on Viti Levu to resorts in these islands.

Reefs take multiple forms within Ba province, with shallow fringing reefs along the coastlines of Viti Levu and the Yasawa Islands, and several small offshore barrier reefs and patch reefs (Figure 6.1.2). In total, coral covers approximately 176 km² within Ba province, though summing all Allen Coral Atlas benthic categories that likely contribute to broader coral reef ecosystem composition (i.e. coral/algae, microalgal mats, rock, and rubble) suggests a coverage of 347 km² of shallow reef-related ecosystems. The majority of these reefs are comprised of inner reef flats (109 km²), closely followed by outer reef flats (99 km²) and shallow lagoons (73 km²), with many other reef types also present (Figure 6.1.3).

Mangrove extent is high in Ba province at 107 km², though there was a net 3 km² mangrove loss between 1996 and 2016 (Figures 6.1.4; 6.1.5). This high mangrove cover reflects the extensive coastline with rivers providing sediment input for mangroves. The largest Ba province mangrove stands are associated with coastal areas on Viti Levu. Seagrass covers approximately 58 km² within Ba province, with much of this associated with coastal areas of Viti Levu (Figure 6.1.6).

Figure 6.1.1. Bathymetry of Ba province.

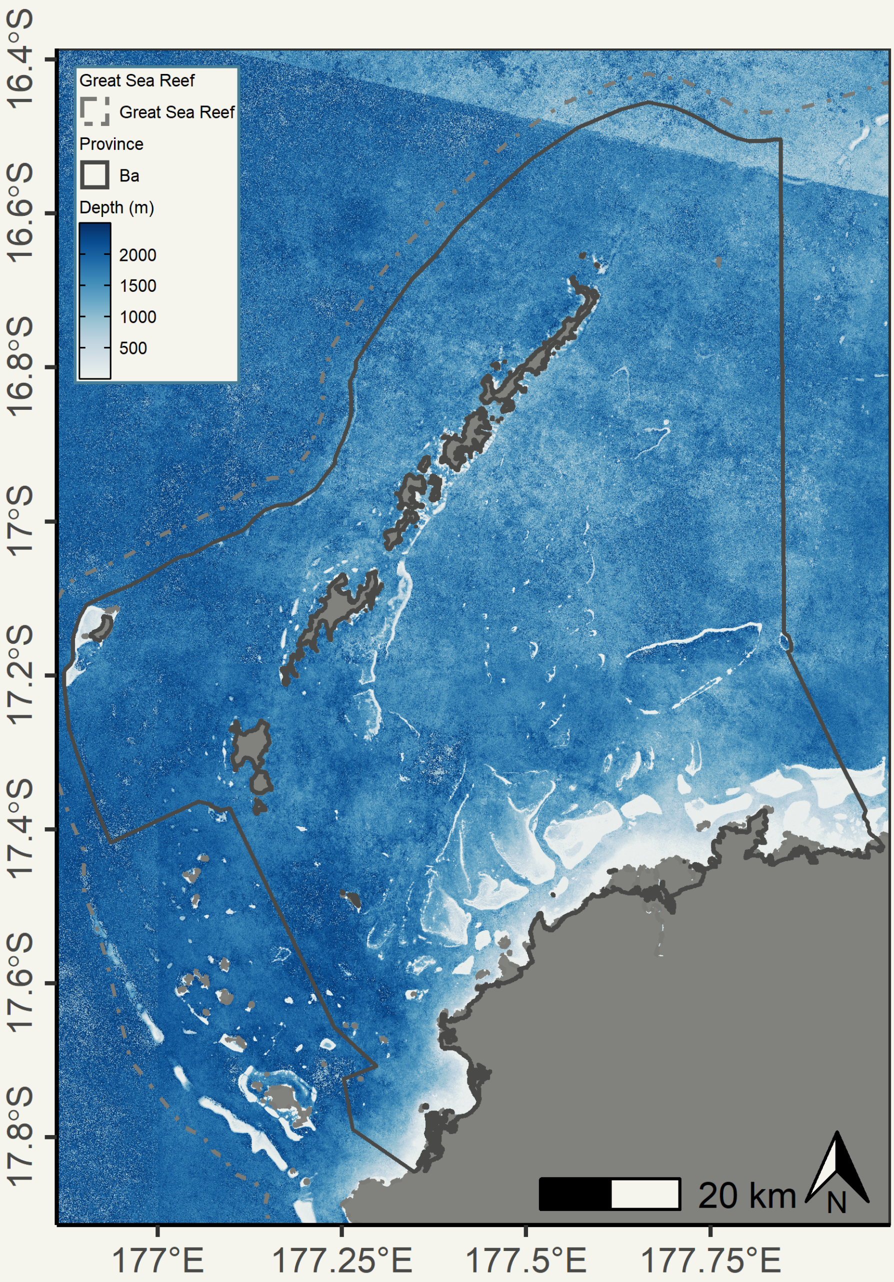


Figure 6.1.2. Coral reef extent Ba province.

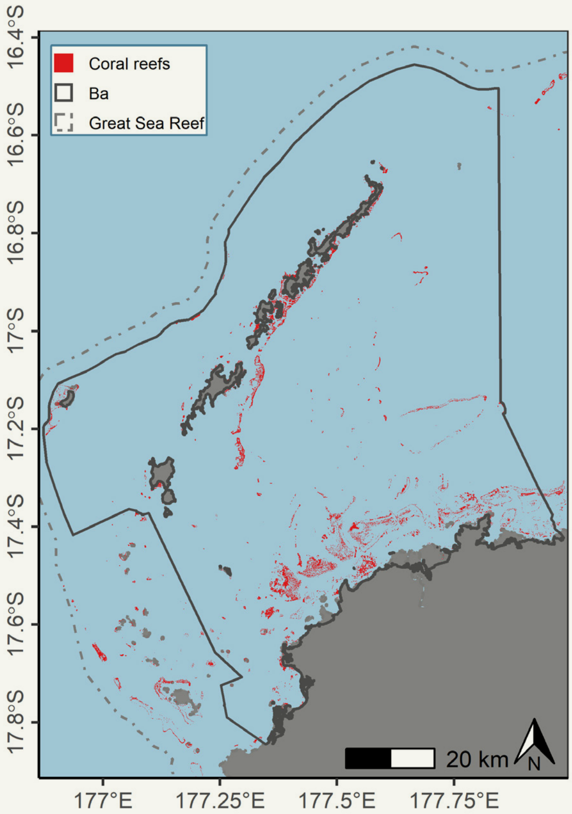


Figure 6.1.3. Reef geomorphic types in Ba province.

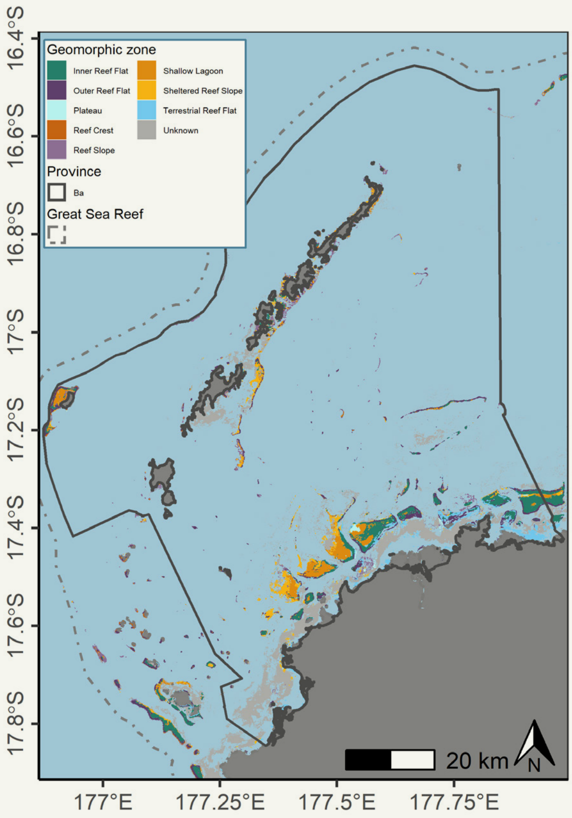


Figure 6.1.4. Mangrove extent in Ba province.

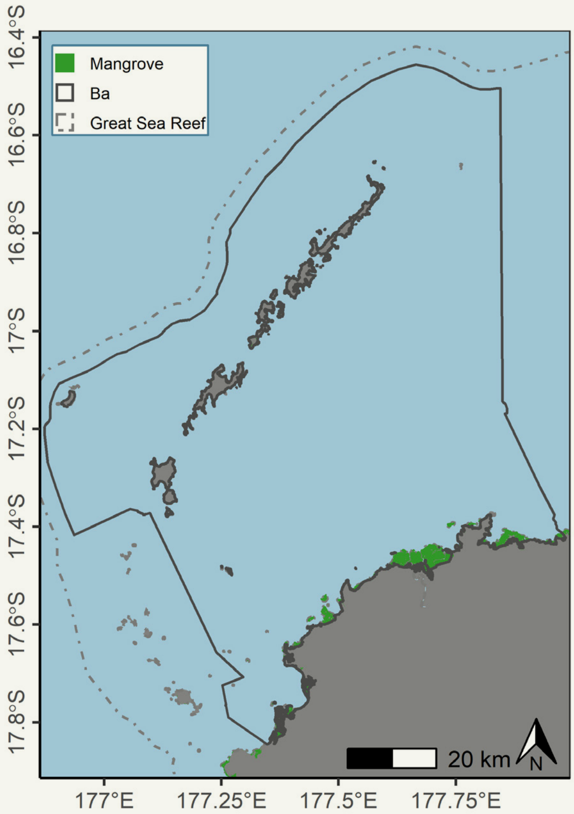


Figure 6.1.5. Mangrove change between 1996-2016 in Ba province.

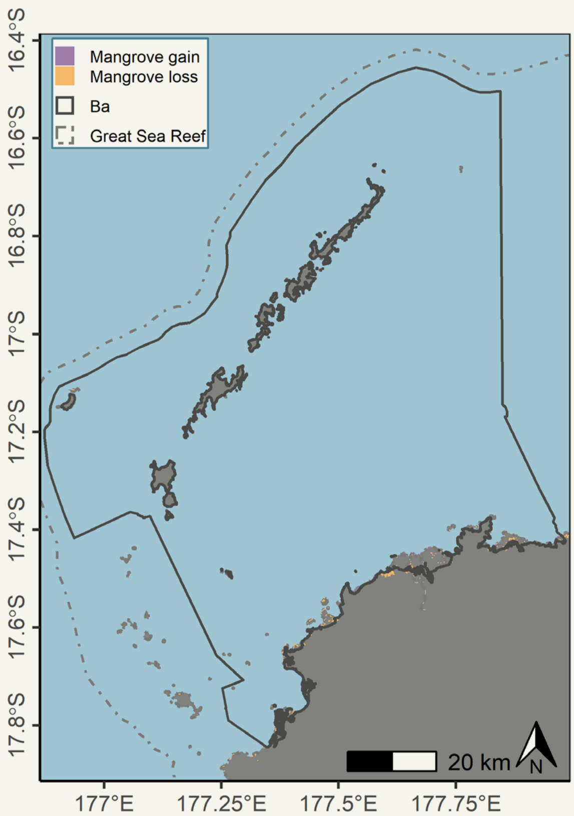
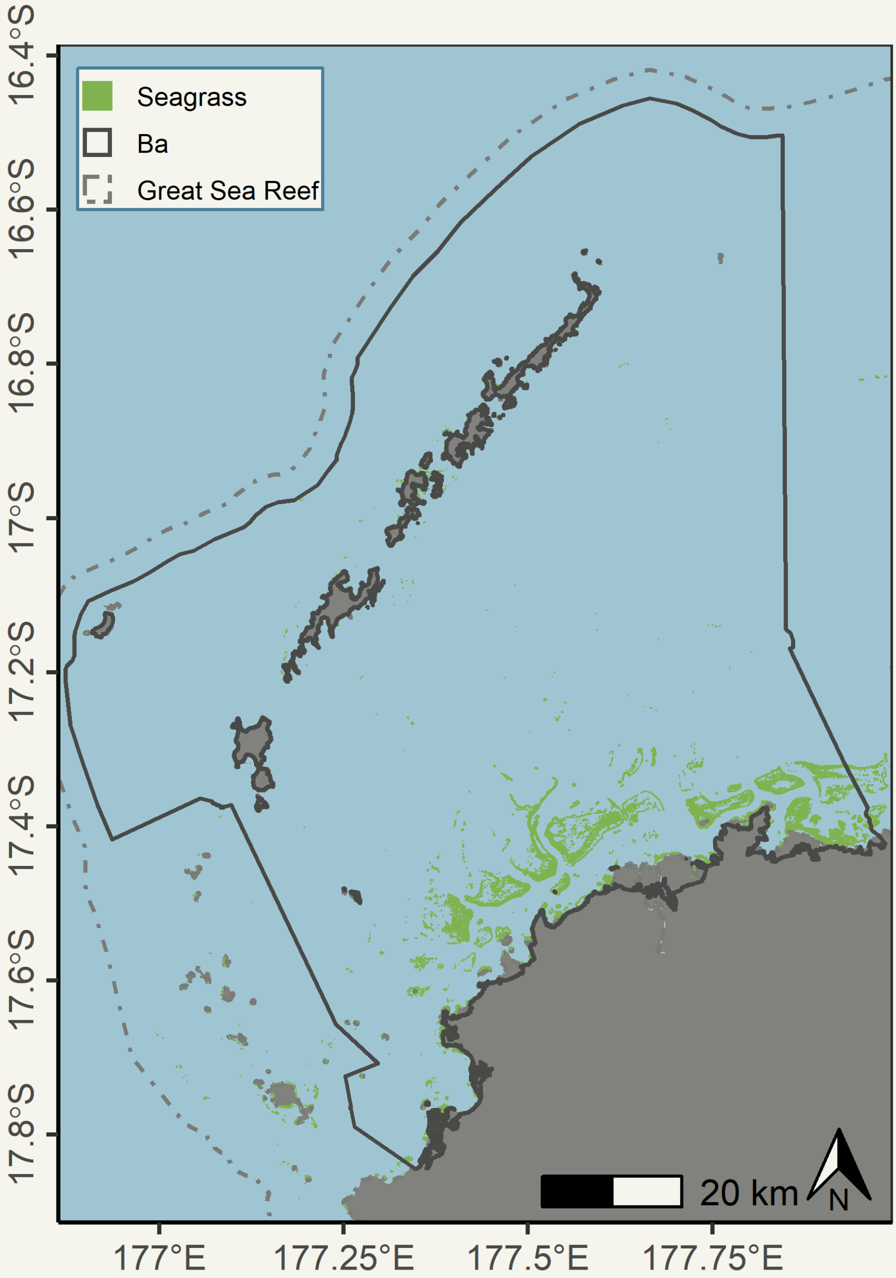


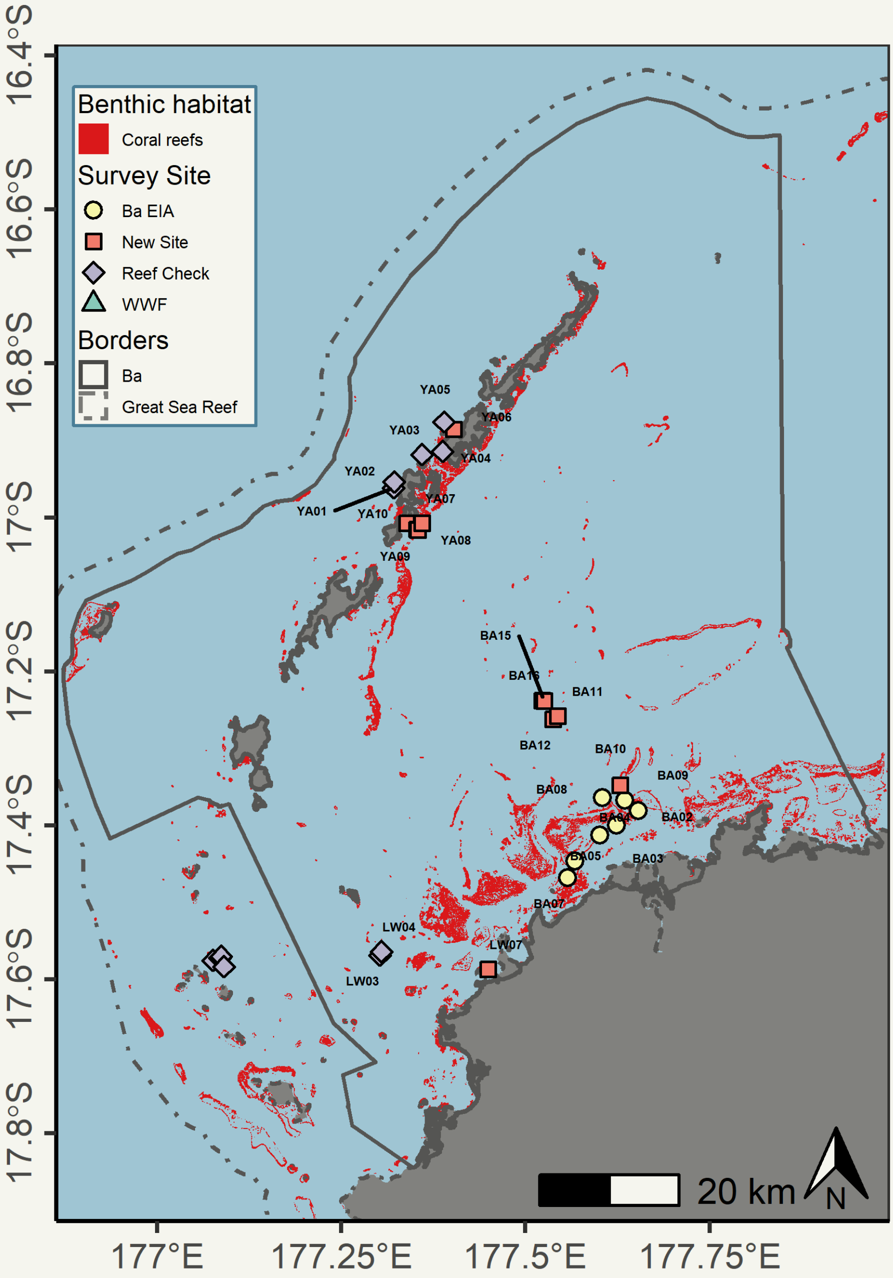
Figure 6.1.6. Seagrass cover in Ba province.



6.1.2 Survey sites

Surveys were completed at 25 sites within Ba province (Figure 6.1.7). Sites covered south Ba (three sites), Ba Estuary (12 sites), and the Yasawa Islands (10 sites). Of these 25 sites, 14 had historic data. This historic data came from three sources: (i) Reef Check surveys for benthic and fish communities around the Yasawa Islands (five sites) in 2003 and 2006, (ii) Reef Check surveys conducted around Samu's Reef in the south (two sites) in 2007 and 2011, and (iii) the Ba River sand mining environmental impact assessment that conducted fish surveys (no benthic) in Ba Estuary in 2010 (GREENPAC 2011).

Figure 6.1.7. Survey sites in Ba province.



6.1.3 Benthic cover

Hard coral cover was 26 ± 3% across reefs in Ba province in 2019 (Figure 6.1.8). This coral cover was lower than in the northern GSR. The second highest live benthic cover on reefs was macroalgae, at 9 ± 2%. Non-living benthic cover was high in the province, with rubble at 20 ± 3%, sand at 17 ± 2%, and bare substrate at 14 ± 2% cover.

Sites surveyed in Ba province split into three subgroups based on reef type and geographic location. The greatest hard coral cover was found in Ba Estuary sites at 32 ± 5%, with the lowest in south Ba at 10 ± 1% (Figure 6.1.9A). Macroalgae cover was similar between Ba Estuary and Yasawa Islands sites, while the southern GSR sites in Ba province had very low macroalgae (Figure 6.1.9B).

Historic benthic data for Ba province was based on seven sites, two sites in the south and five around the Yasawa Islands. Based on these sites, it was *very likely* (W=40, p=0.06) that hard coral cover declined, from 36 ± 4% in historic surveys to 23 ± 4% in 2019 (Figure 6.1.10). It was also *extremely likely* (W=5, p=0.02) that the amount of sand on the reefs increased, from 4 ± 1% to 14 ± 3%. There have been limited changes in other benthic groups (Figure 6.1.10). Breaking apart the data between the two subgroups, it was *likely* (W=4, p=0.33) that coral cover declined in the southern Ba province sites (Figure 6.1.11).

Figure 6.1.8. Benthic cover in 2019 for Ba province.

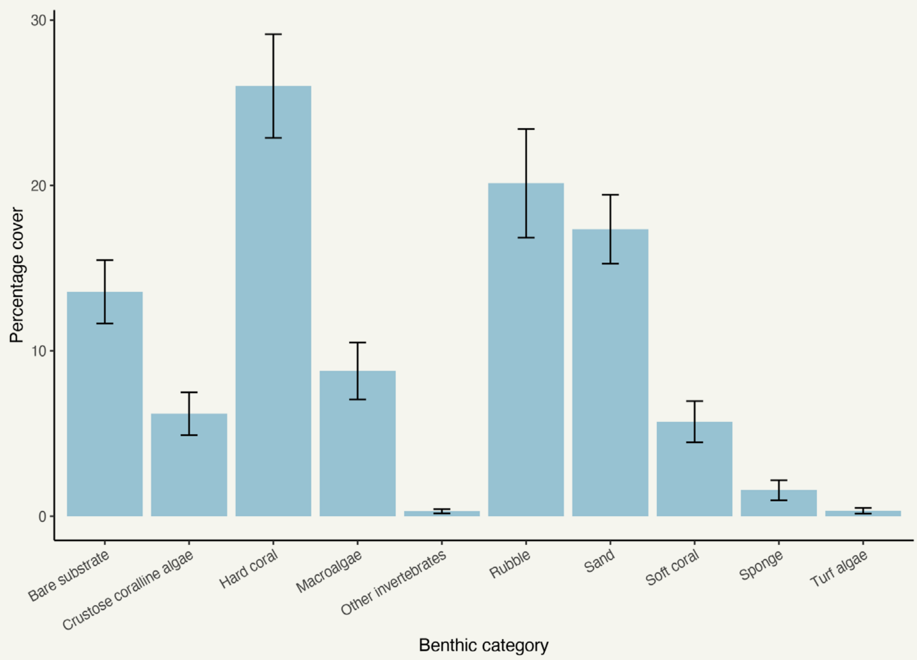


Figure 6.1.9. (A) Hard coral cover and (B) macroalage cover by subgroup for sites within Ba province.

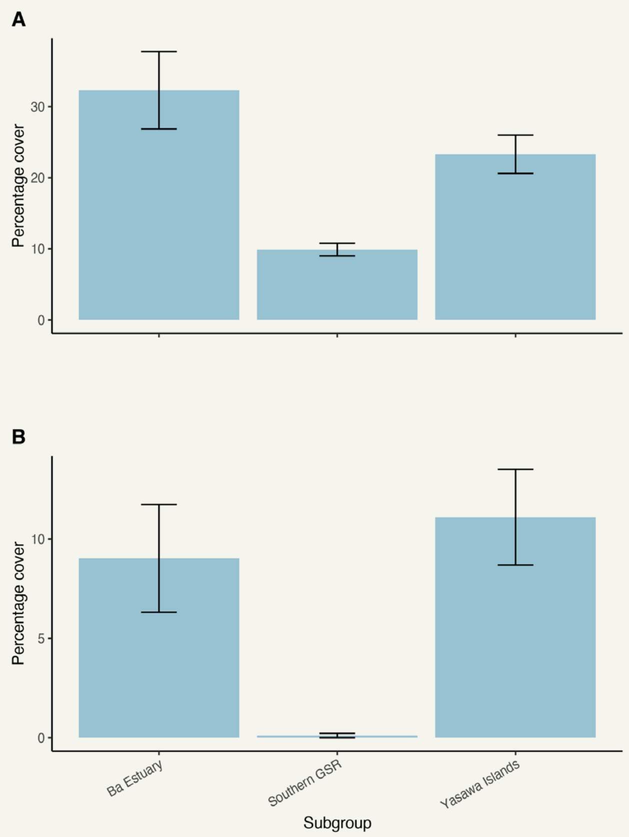
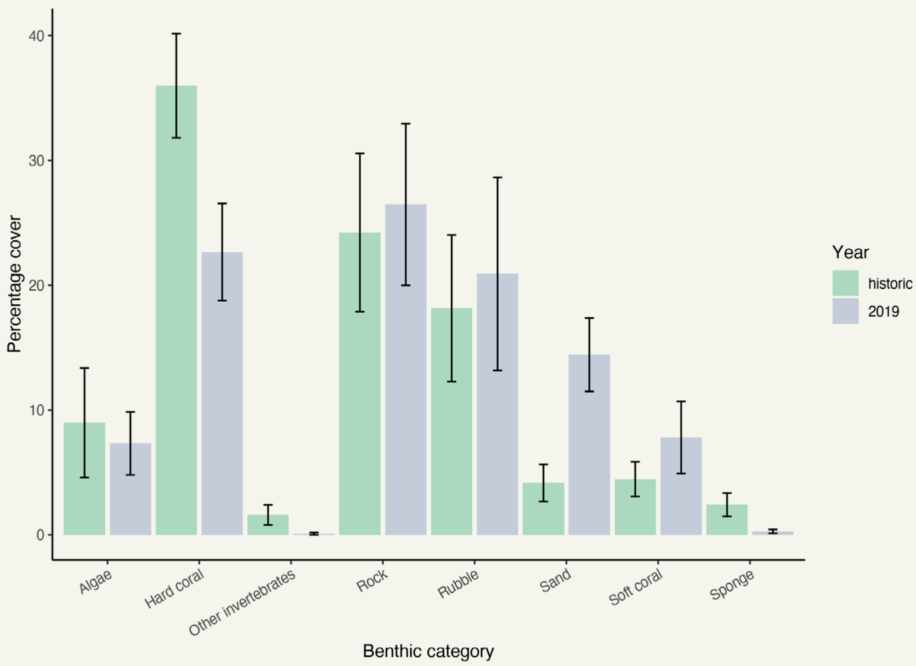


Figure 6.1.10. Change in benthic communities for Ba province



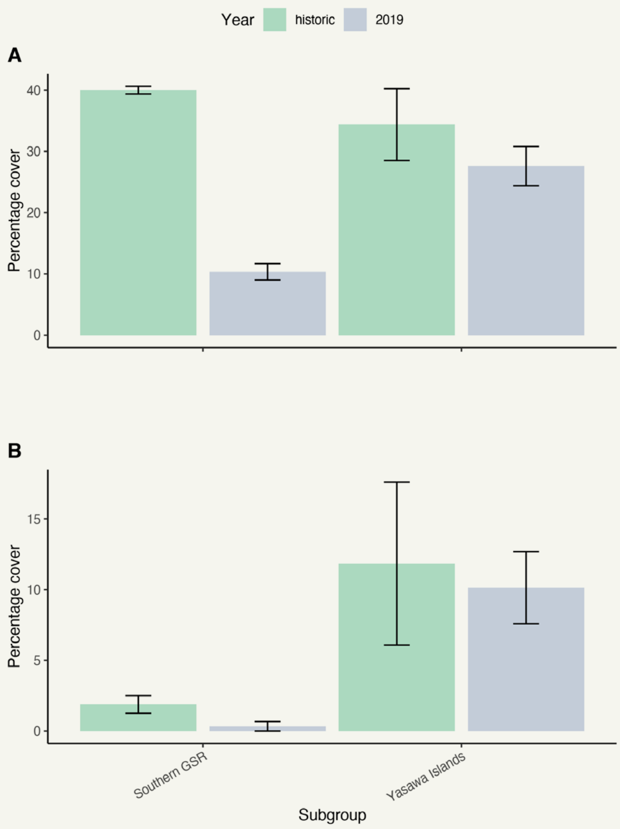


Figure 6.1.11. Change in (A) hard coral and (B) algae cover for sites with historic data in Ba province. Note data for the seaward barrier reef and inner reef each are represented by one site, and no algae was recorded on the inner reef site in historic surveys.

6.1.4 Fish communities

A mean fish abundance for the species list of 2,311 ± 263 ind/ha was recorded across all Ba province sites, while mean fish biomass was 225 ± 38 kg/ha. Fish communities were dominated by herbivores by both abundance and biomass (Figure 6.1.12). The most abundant fish family was Scaridae (816 ± 118 ind/ha) followed by Acanthurdae (685 ± 188 ind/ha). Scaridae was also the largest fish family by biomass (94 ± 17 kg/ha), with Acanthuridae the second largest (58 ± 24 kg/ha). Carnivores made up a low proportion of the fish community by biomass, with Lutjanidae the largest carnivorous family at only 19 ± 7 kg/ha. The Yasawa Islands generally had the greatest mean fish abundance and biomass, though there were low levels of variation between subgroups across Ba province (Figure 6.1.13).

It was *likely* (V=79, p=0.10) that key fisheries family abundance declined between the historic surveys and 2019 in Ba province, from 1,944 ± 439 ind/ha in historic surveys to 1,003 ± 161 ind/ha in 2019 (Figure 6.1.14A). However, this overall trend masked differing trends within the province (Figure 6.1.14B). It was *extremely likely* (V=27, p=0.03) that fish abundance declined in Ba estuary, from 2,917 ± 474 ind/ha in 2010 to 1,251 ± 280 ind/ha in 2019. In contrast, it was *likely* (V=2, p=0.19) that fish abundance increased in the Yasawa Islands, from 375 ± 107 ind/ha in 2003 and 2006 to 773 ± 143 ind/ha in 2019. Historic fish biomass data was only available from seven sites in Ba estuary. It was *extremely likely* (V=28, p=0.02) that key fisheries family fish biomass declined in Ba estuary, with historic biomass at 643 ± 107 kg/ha compared to 150 ± 48 kg/ha in 2019 (Figure 6.1.15).

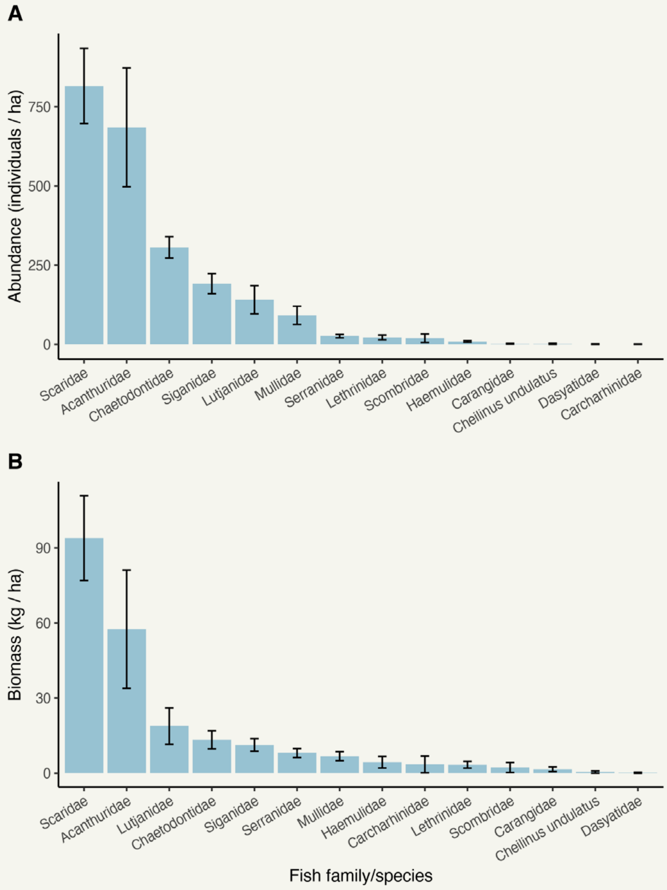


Figure 6.1.12. Fish community structure by (A) abundance and (B) biomass for Ba province

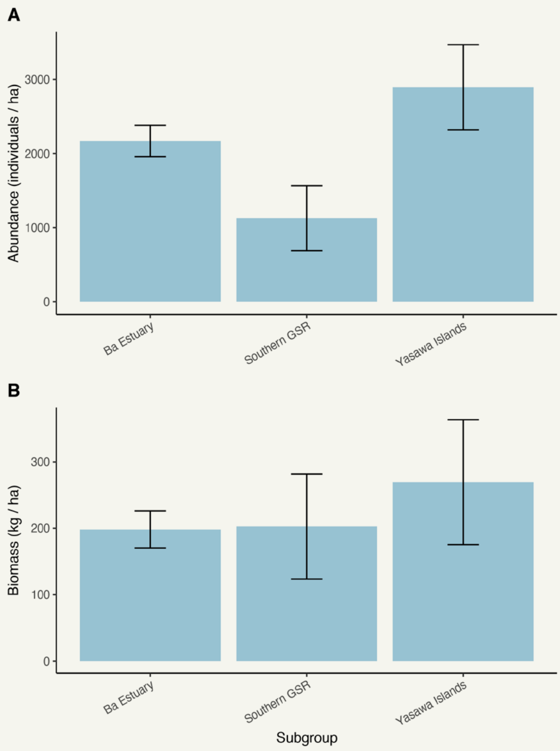


Figure 6.1.13. Overall fish (A) abundance and (B) biomass for sites surveyed in 2019 in Ba province. Results divided by subgroups representing broad reef types.

Figure 6.1.14. Change in key fisheries family abundance (Haemulidae, Lutjanidae, Scaridae, and Serranidae) for Ba province for (A) all sites with historic data and (B) sites with historic data by subgroup.

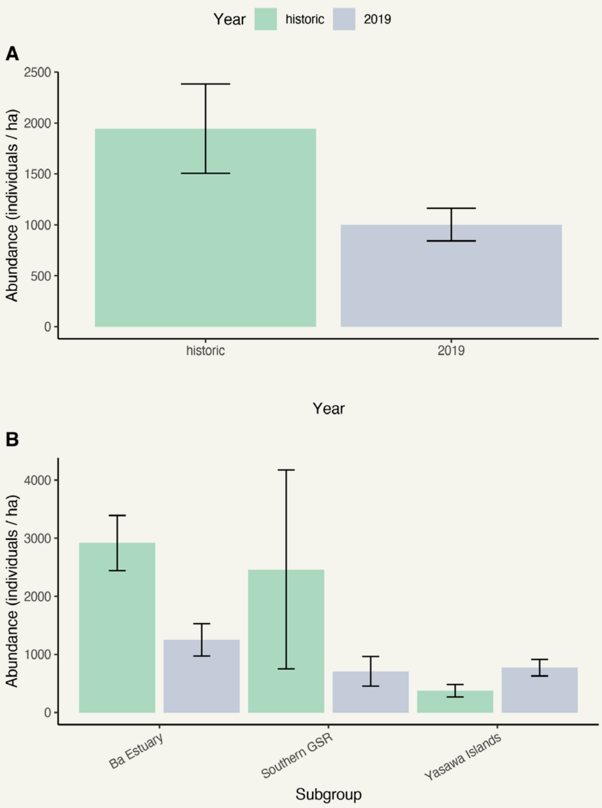
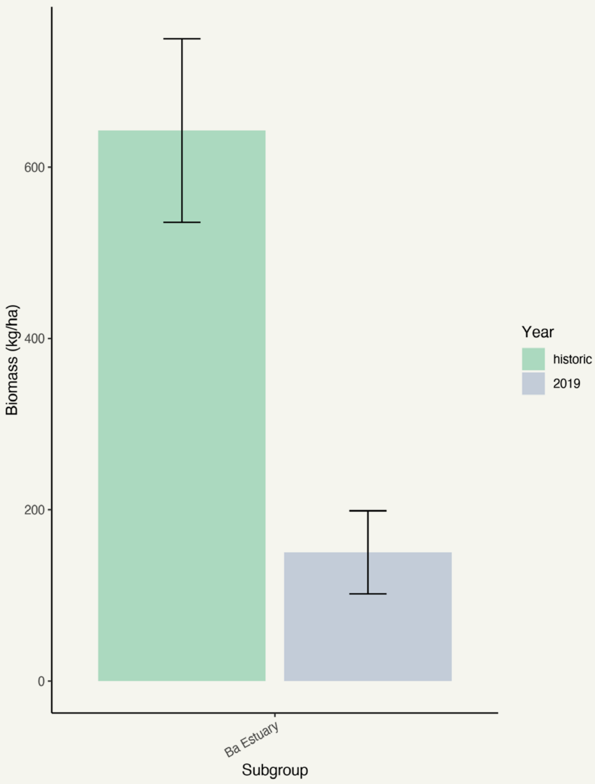


Figure 6.1.15. Change in key fisheries family biomass (Haemulidae, Lutjanidae, Scaridae, and Serranidae) for Ba estuary sites with historic data.



6.1.5 Rare Species

Humphead wrasse were recorded at a density of 1.81± 1.67 ind/ha with a biomass of 0.48 ± 0.44 kg/ha across the 25 sites surveyed in 2019 in Ba province (Figure 6.1.16). It was *likely* (V=8, p=0.36) that humphead wrasse abundance declined within Ba province – as past surveys at the 14 sites with historic fish abundance data available recorded densities of 0.71 ± 0.44 ind/ha compared to 0.24 ± 0.24 ind/ha at these same sites in 2019 (Figure 6.1.16). At the seven sites in Ba Estuary with historic biomass data available, we did not record any humphead wrasse in 2019.

No bumphead parrotfish were recorded in Ba province during the 2019 GSR survey. However, there are historic records of bumphead parrotfish for Ba. Across the 14 sites with historic fish abundance data, bumphead parrotfish were recorded at 0.57 ± 0.57 ind/ha in Ba. For Ba Estuary where historic fish biomass data is available from 2010, bumphead parrotfish were recorded at 20 ± 20 kg/ha.

Serranidae abundance and biomass were 30 ± 5 ind/ha and 8 ± 2 kg/ha, respectively, across all surveyed Ba province sites in 2019 (Figure 6.1.17). For the 14 sites with historic data, it was *extremely likely* (V=10, p=0.02) that Serranidae abundance increased, with historic surveys recording 4 ± 1 ind/ha and 2019 surveys recording 24 ± 7 ind/ha (Figure 6.1.17). For the seven Ba Estuary sites with historic fish biomass data, it was *very likely* (V=25, p=0.08) that Serranidae biomass declined, from 43 ± 15 kg/ha in 2010 to 5 ± 2 kg/ha in 2019.

Sharks in the family Carcharhinidae were recorded at an abundance of 0.42 ± 0.31 ind/ha and biomass of 3.50 ± 3.34 kg/ha across all Ba province sites in 2019 (Figure 6.1.18). It was *exceptionally unlikely* (V=1, p>0.99) that shark abundance changed at the 14 sites with historic data, and also *exceptionally unlikely* (V=1, p>0.99) that shark biomass changed at the seven sites in Ba Estuary with historic data (Figure 6.1.18).

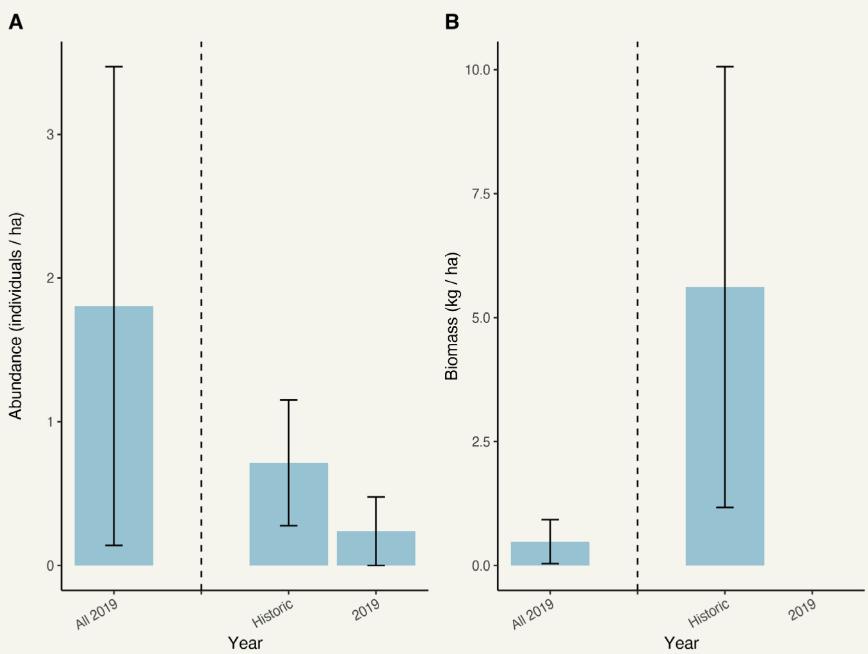


Figure 6.1.16. Humphead wrasse (Cheilinus undulatus) (A) abundance and (B) biomass for Ba province. Both panels show data for all 2019 sites to the left of dashed vertical line, and only the sites with historic data available to the right of dashed vertical line. Historic abundance data was available from 14 sites, while historic biomass data was limited to seven Ba Estuary sites. Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.

Figure 6.1.17. Serranidae (grouper) (A) abundance and (B) biomass for Ba province. Each panel shows data for all sites (left of dashed vertical line) and only the two sites with historic data available (right of dashed vertical line). Historic abundance data was available from 14 sites, while historic biomass data was limited to seven Ba Estuary sites. Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.

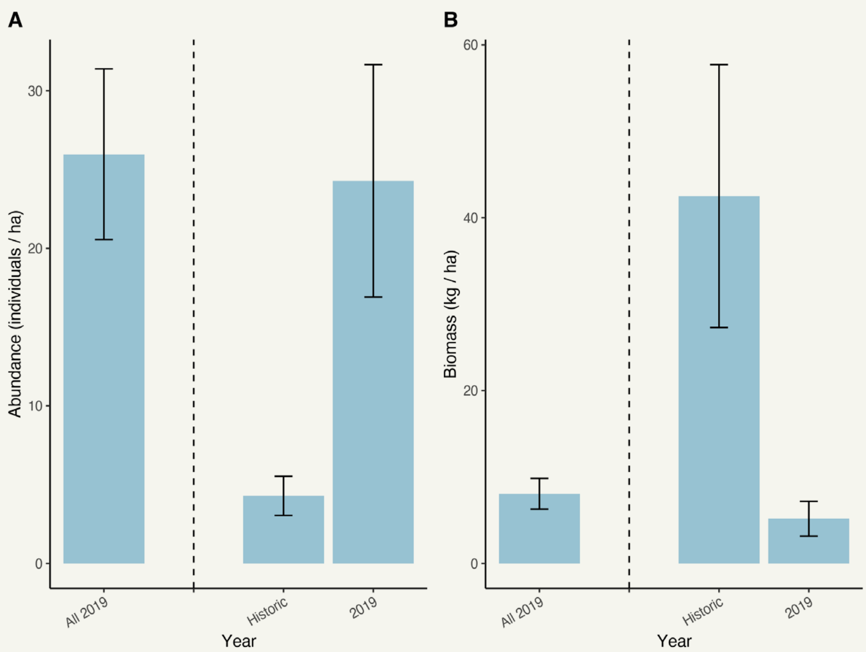
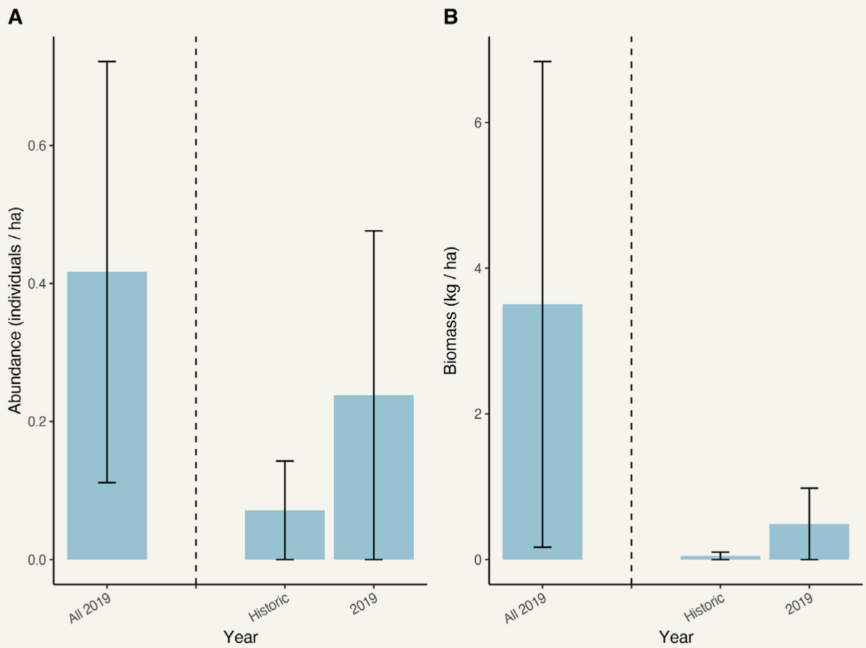


Figure 6.1.18. Carcharhinidae (shark) (A) abundance and (B) biomass for Ba province. Each panel shows data for all sites (left of dashed vertical line) and only the two sites with historic data available (right of dashed vertical line). Historic abundance data was available from 14 sites, while historic biomass data was limited to seven Ba Estuary sites. Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.



6.2 Vuda and Waya

6.2.1 Introduction and critical habitat coverage

Vuda and Waya is the most southerly *qoliqoli* in Ba province and stretches from the western coast of Viti Levu to the southern Yasawa Islands and includes several islands and many offshore reefs. Vuda and Waya marine areas span 735 km^2 (Figure 6.2.1).

Reefs take multiple forms within Vuda and Waya *qoliqoli*, with shallow fringing reefs along the coastline of Viti Levu and the Yasawa Islands, and several small offshore reefs (Figure 6.2.2). In total, coral covers approximately 11 km^2 within Vuda and Waya, though summing all Allen Coral Atlas benthic categories that likely contribute to broader coral reef ecosystem composition (i.e. coral/algae, microalgal mats, rock, and rubble) suggests a coverage of 14 km^2 of shallow reef-related ecosystems. The majority of these reefs are comprised of sheltered reef slopes (7 km^2), followed by outer reef flats (4 km^2) and terrestrial reef flats (4 km^2), with many other reef types also present (Figure 6.2.3).

Mangrove extent is high in Vuda and Waya *qoliqoli* at 4 km^2, with 14 ha lost between 1996 and 2016 (Figures 6.2.4; 6.2.5). The largest Vuda and Waya mangrove stands are associated with coastal areas on Viti Levu. Seagrass covers approximately 3 km^2 within Vuda and Waya, with much of this associated with coastal areas of Viti Levu (Figure 6.2.6).

Figure 6.2.1. Bathymetry of Vuda and Waya *qoliqoli*.

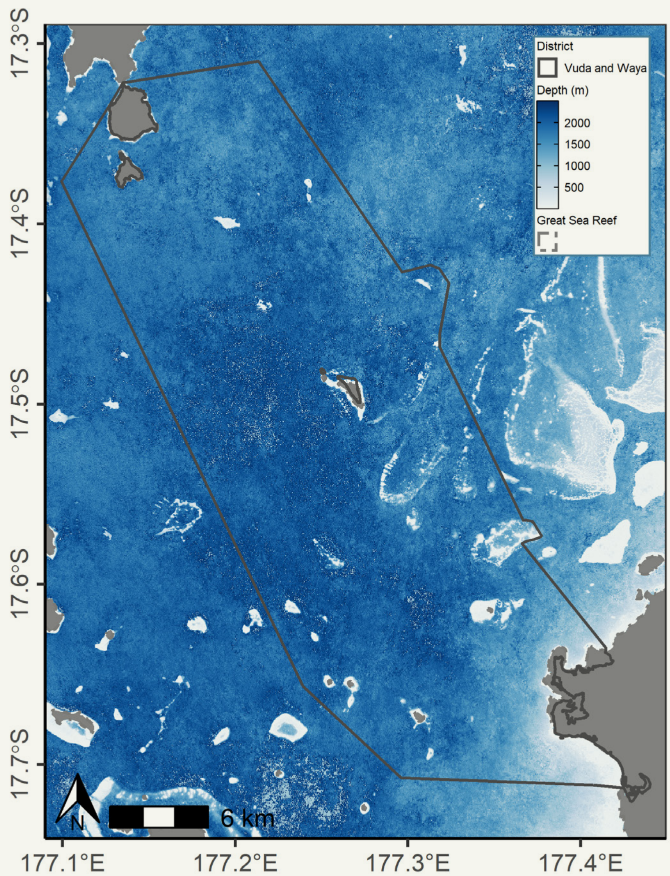


Figure 6.2.2. Coral reef extent in Vuda and Waya *qoliqoli*.

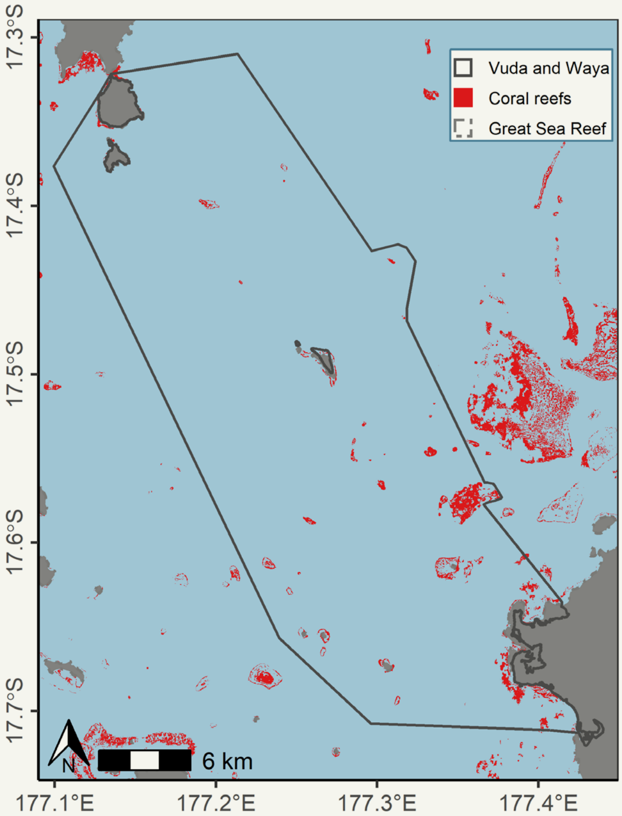
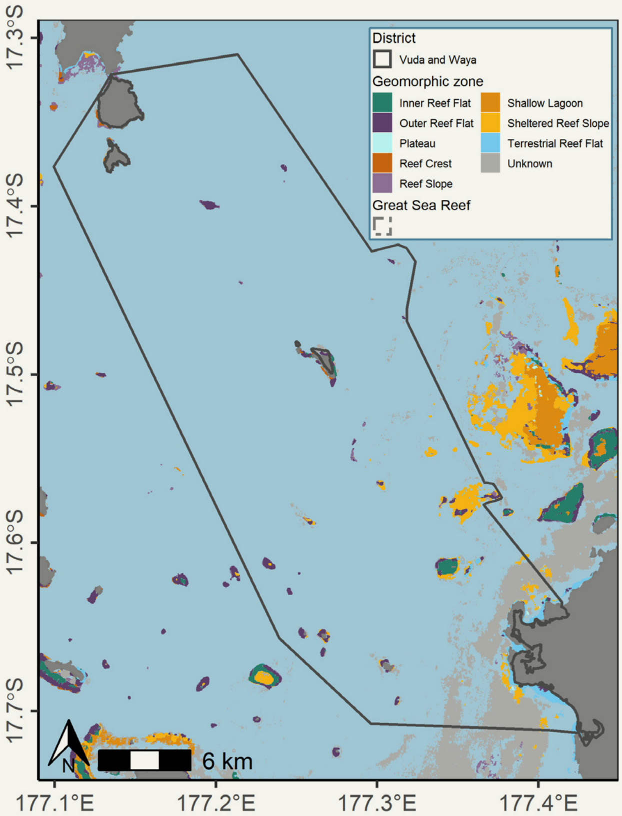


Figure 6.2.3. Reef geomorphic types in Vuda and Waya *qoliqoli*.



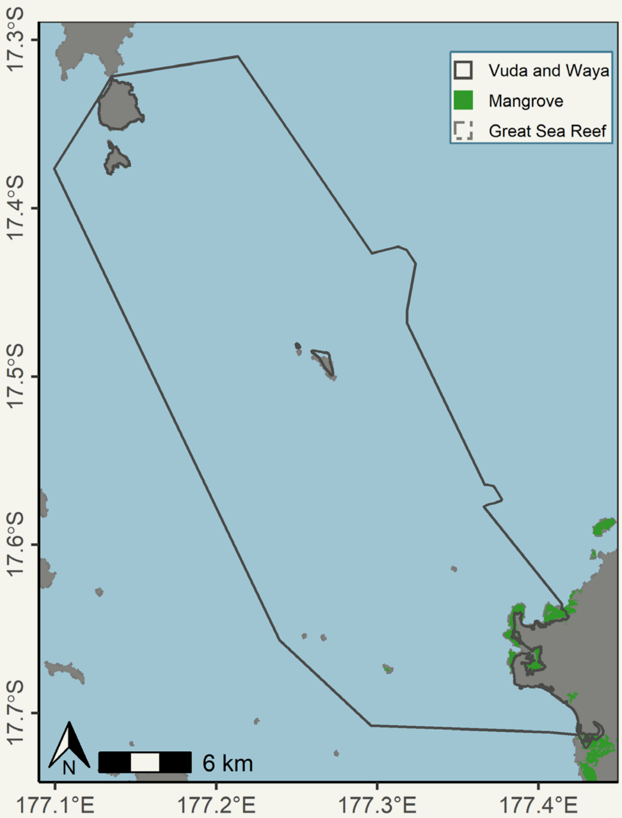


Figure 6.2.4. Mangrove extent in Vuda and Waya *qoliqoli*.

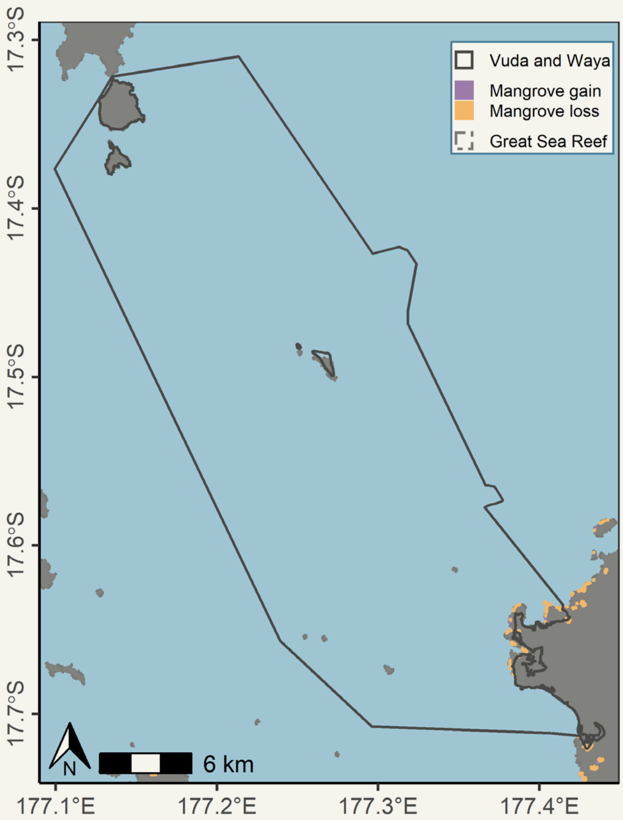


Figure 6.2.5. Mangrove change between 1996-2016 in Vuda and Waya *qoliqoli*.

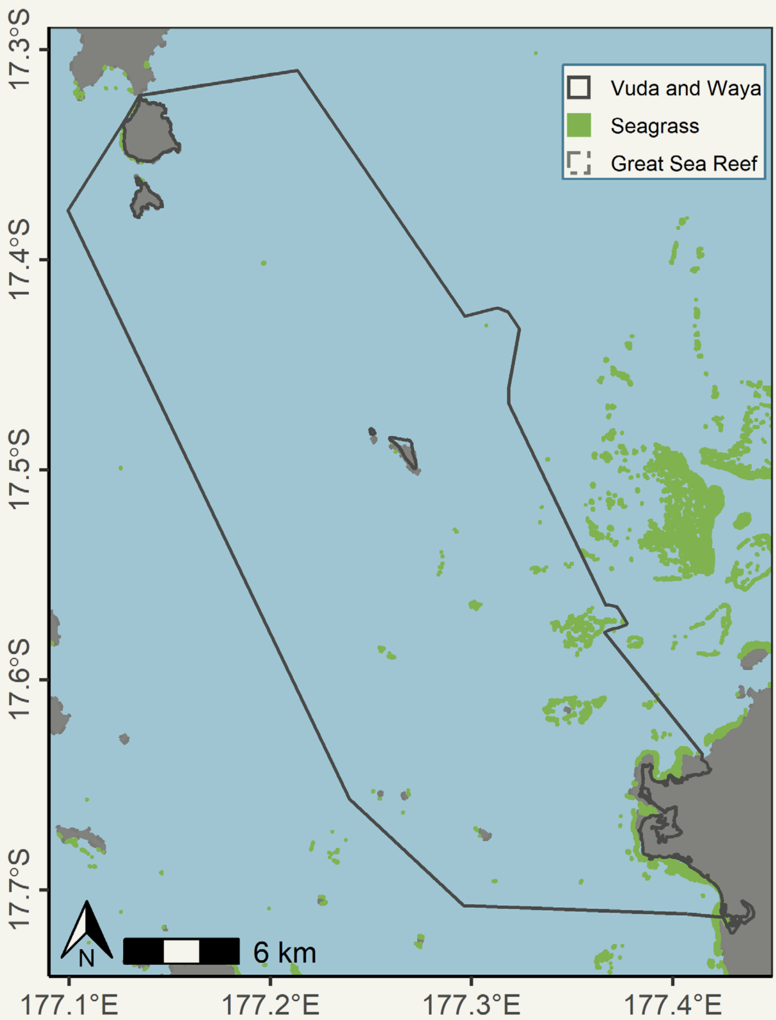


Figure 6.2.6. Seagrass cover in Vuda and Waya *qoliqoli*.

6.2.2 Survey sites

Surveys were completed at two sites within Vuda and Waya *qoliqoli* (Figure 6.2.7). Both sites were on Samu's Reef, a small offshore reef in the center of the *qoliqoli*. One site was on the southwest of the reef (LW03), while the other was on the northeast (LW04). Both sites had historically been surveyed by Reef Check (Reef Check Foundation 2019) for benthic cover and fish abundance, with LW03 surveyed in 2011 and LW04 surveyed in 2007.

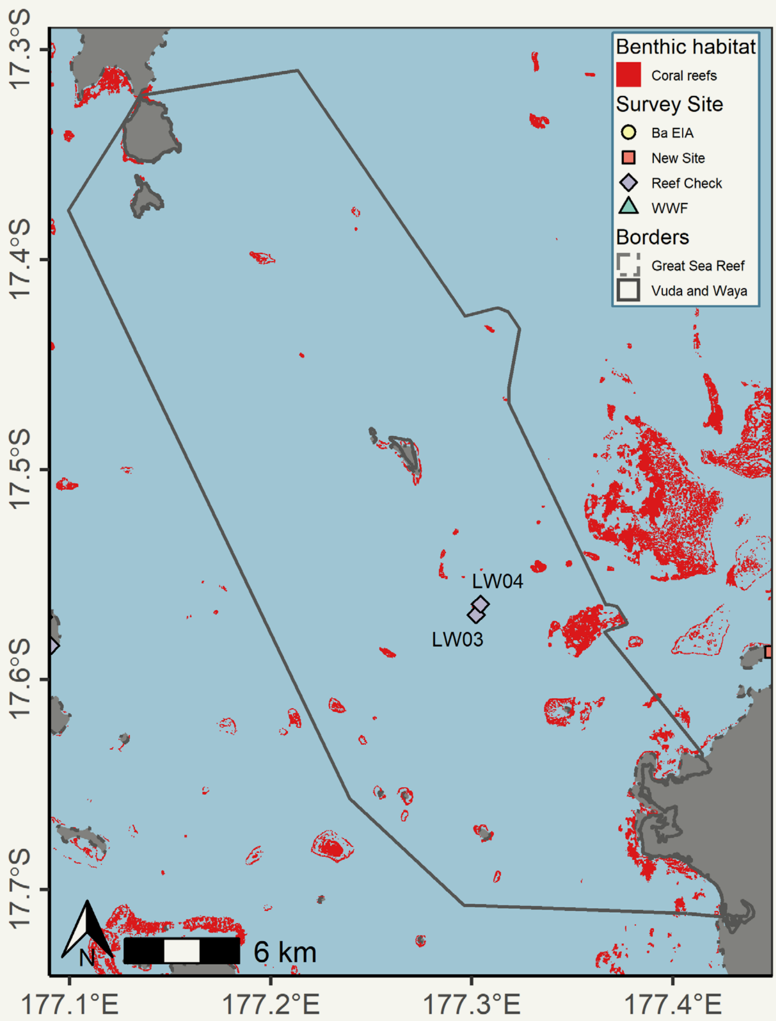


Figure 6.2.7. Survey sites in Vuda and Waya *qoliqoli*.

6.2.3 Benthic cover

Hard coral cover was 10 ± 1% across reefs in Vuda and Waya in 2019 (Figure 6.2.8). This coral cover was amongst the lowest cover recorded on the GSR. The second highest live benthic cover on reefs was crustose coralline algae, at 9 ± 6%. Non-living benthic cover was high, with rubble at 48 ± 12%, bare substrate at 19 ± 14%, and sand at 12 ± 3%. This suggests that these reefs have experienced significant physical damage in recent years, also potentially from Cyclone Winston.

Historic benthic data for Vuda and Waya suggests it was *about as likely as not* (W=4, p=0.33) that hard coral cover declined, from 40 ± 1% in historic surveys to 10 ± 1% in 2019 (Figure 6.2.9). It was also *about as likely as not* (W=0, p=0.33) that algae cover declined and rubble cover increased. Note, statistical comparisons have limited power because data is only available from two sites.

Figure 6.2.8. Benthic cover in 2019 for Vuda and Waya *qoliqoli*.

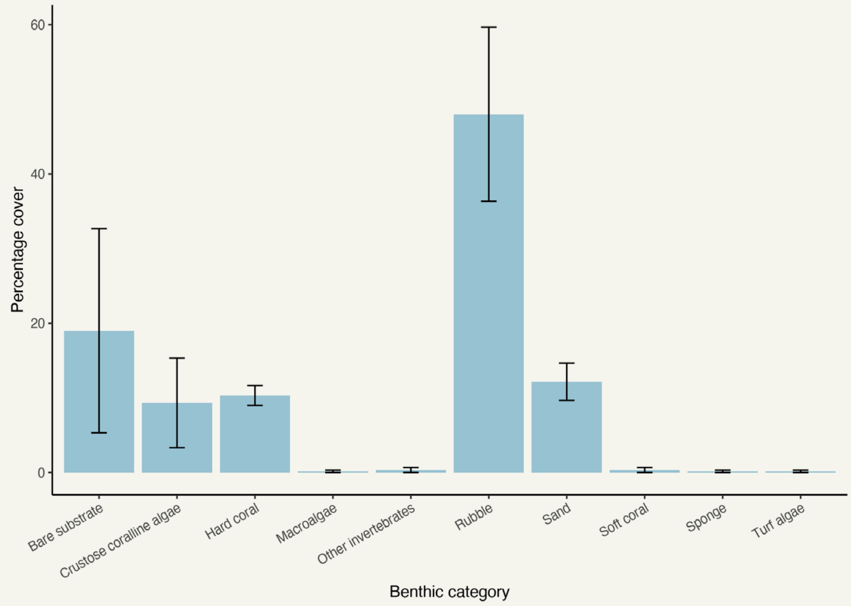
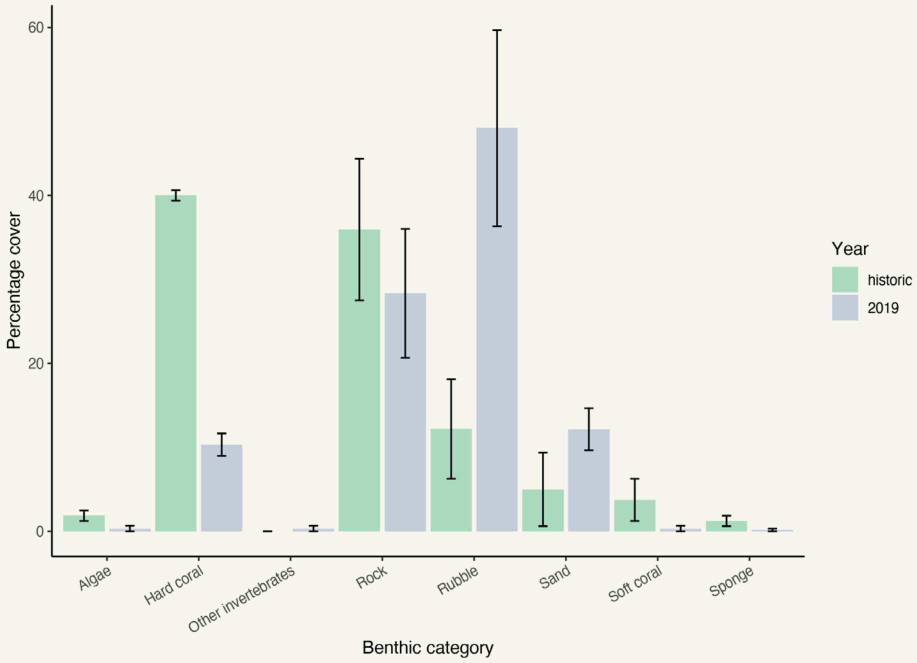


Figure 6.2.9. Change in benthic communities for Vuda and Waya *qoliqoli*.



6.2.4 Fish communities

A mean fish abundance for the target family/species list of 1,510 ± 373 ind/ha was recorded across all Vuda and Waya sites, while mean fish biomass was 282 ± 4 kg/ha. Fish communities were dominated by herbivores in both abundance and biomass (Figure 6.2.10). The most abundant fish family was Scaridae (573 ± 373 ind/ha) followed by Chaetodontidae (367 ± 46 ind/ha). Acanthuridae were surprisingly rare in Vuda and Waya compared to other GSR sites, recorded at only 60 ± 60 ind/ha. Scaridae was also the largest fish family by biomass (137 ± 77 kg/ha), with Chaetodontidae the second largest (50 ± 39 kg/ha). Carnivores made up a low proportion of the fish community by both abundance and biomass, with Lutjanidae the largest carnivorous family at only 100 ± 100 ind/ha and 26 ± 26 kg/ha. These results suggest that both sites at Samu's reef within Vuda and Waya are subject to high fisheries pressure.

It was *exceptionally unlikely* (V=2, p>0.99) that key fisheries family abundance changed between the historic and 2019 surveys in Vuda and Waya (Figure 6.2.11). Key fisheries family abundance was 2,463 ± 1,712 ind/ha in the historic surveys, compared to 708 ± 255 ind/ha in 2019. No historic fish biomass data is available from Vuda and Waya.

Figure 6.2.10. Fish community structure by (A) abundance and (B) biomass for Vuda and Waya *qoliqoli*.

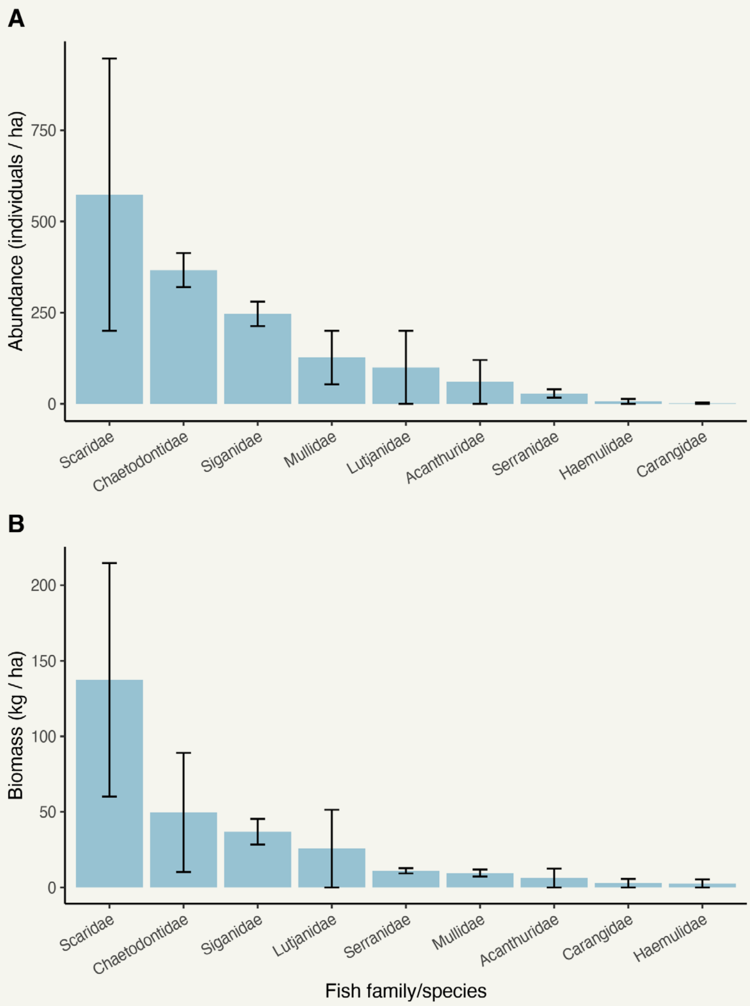
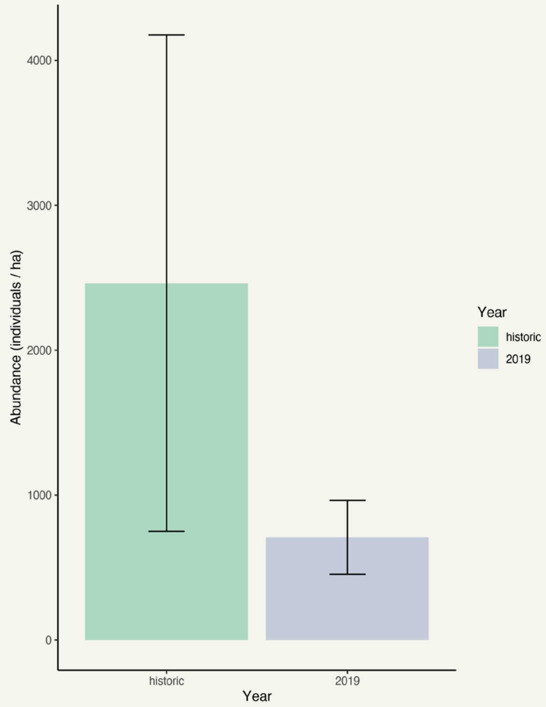


Figure 6.2.11. Change in key fisheries family abundance (Haemulidae, Lutjanidae, Scaridae, and Serranidae) for Vuda and Waya *qoliqoli*.

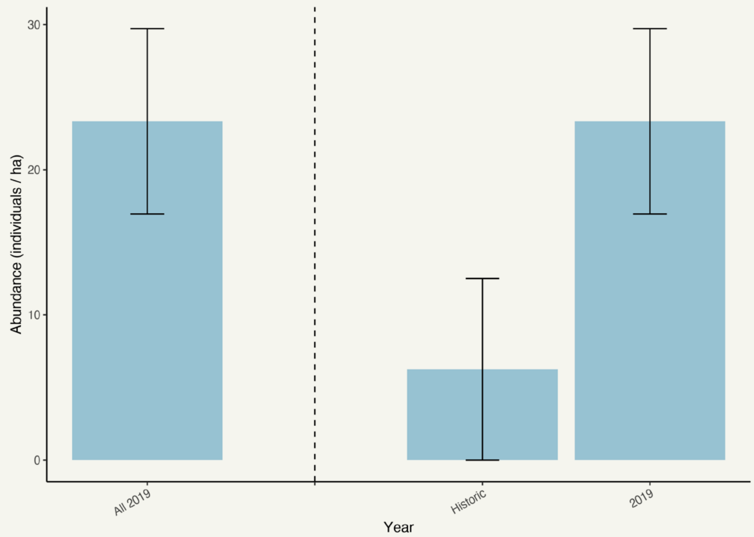


6.2.5 Rare Species

No humphead wrasse, bumphead parrotfish, or sharks were recorded in Vuda and Waya during the 2019 surveys or the historic surveys at these sites.

Serranidae abundance and biomass were 28 ± 11 ind/ha and 11 ± 2 kg/ha, respectively, across both sites surveyed in Vuda and Waya in 2019 (Figure 6.2.12). For abundance, it was *about as likely as not* (V=0, p=0.50) that Serranidae abundance changed, with historic surveys recording 13 ± 0 ind/ha.

Figure 6.2.12. Serranidae (grouper) abundance for Vuda and Waya *qoliqoli*. Data for both sites surveyed in 2019 (left of dashed vertical line) and compared with the historic data (right of dashed vertical line). Data in both the left and right of the figure represent the same two sites.



6.3 Vitogo (Lautoka)

6.3.1 Introduction and critical habitat coverage

Vitogo is a *qoliqoli* in Ba province located on the western coast of Viti Levu and includes several islands and offshore reefs. Vitogo *qoliqoli* is also adjacent to Lautoka, the second largest city in Fiji, with a population of approximately 72,000 people. The western coast of Viti Levu around Lautoka is the major production area for sugarcane in Fiji. Vitogo marine areas span 231 km² (Figure 6.3.1).

Reefs take multiple forms within Vitogo *qoliqoli*, with shallow fringing reefs along the coastline of Viti Levu and the islands, and several small offshore reefs (Figure 6.3.2). In total, coral covers approximately 19 km² within Vitogo *qoliqoli*, though summing all Allen Coral Atlas benthic categories that likely contribute to broader coral reef ecosystem composition (i.e. coral/algae, microalgal mats, rock, and rubble) suggests a coverage of 32 km² of shallow reef-related ecosystems. The majority of these reefs is comprised of sheltered reef slopes (17 km²), followed by shallow lagoons (9 km²), and inner reef flats (8 km²), with many other reef types also present (Figure 6.3.3).

Mangroves cover 10 km² in Vitogo *qoliqoli*, with 35 ha lost between 1996 and 2016 (Figures 6.3.4; 6.3.5). The largest Vitogo mangrove stands are associated with coastal areas on Viti Levu and the coastal islands. Seagrass covers approximately 6 km² within Vitogo, with much of this growing on the shallow seabed in the center of the *qoliqoli* (Figure 6.3.6).

Figure 6.3.1. Bathymetry of Vitogo *qoliqoli*.

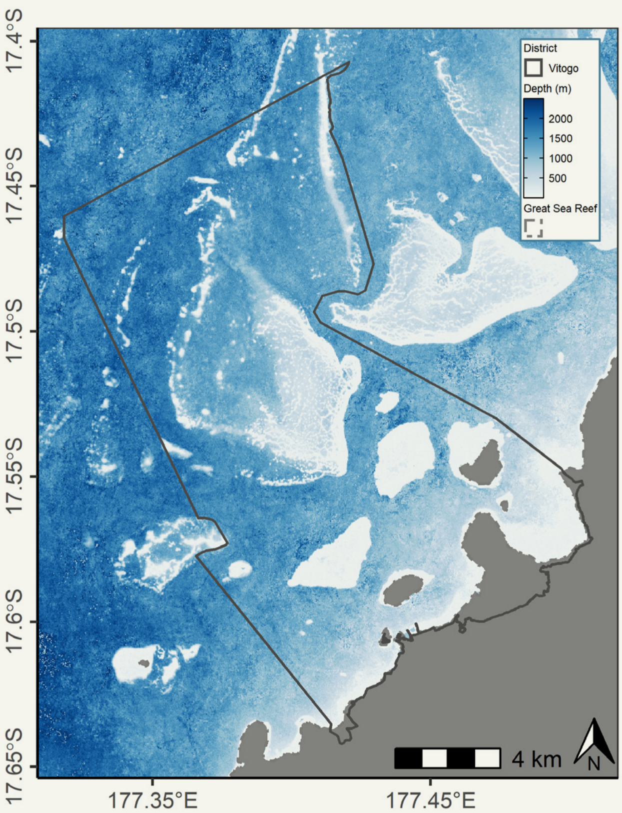


Figure 6.3.2. Coral reef extent in Vitogo *qoliqoli*.

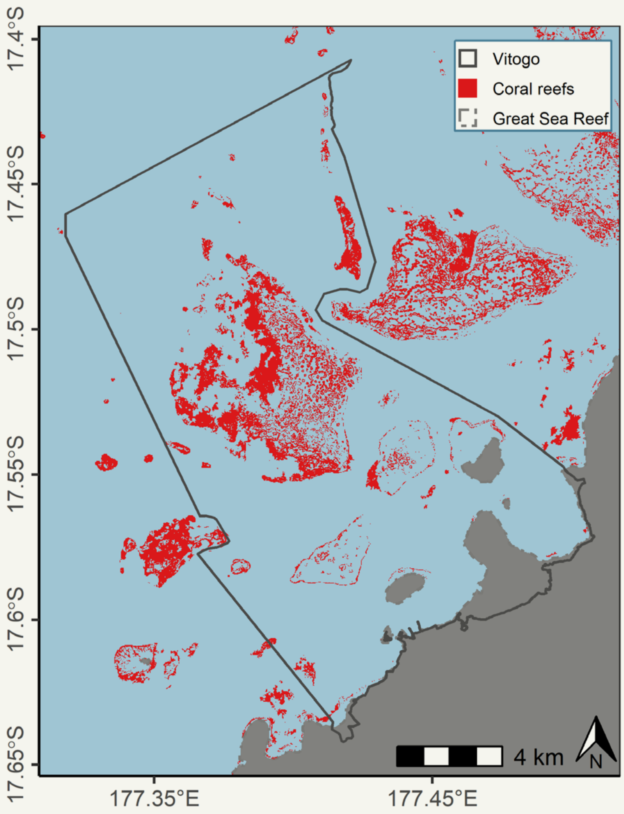


Figure 6.3.3. Reef geomorphic types in Vitogo *qoliqoli*.

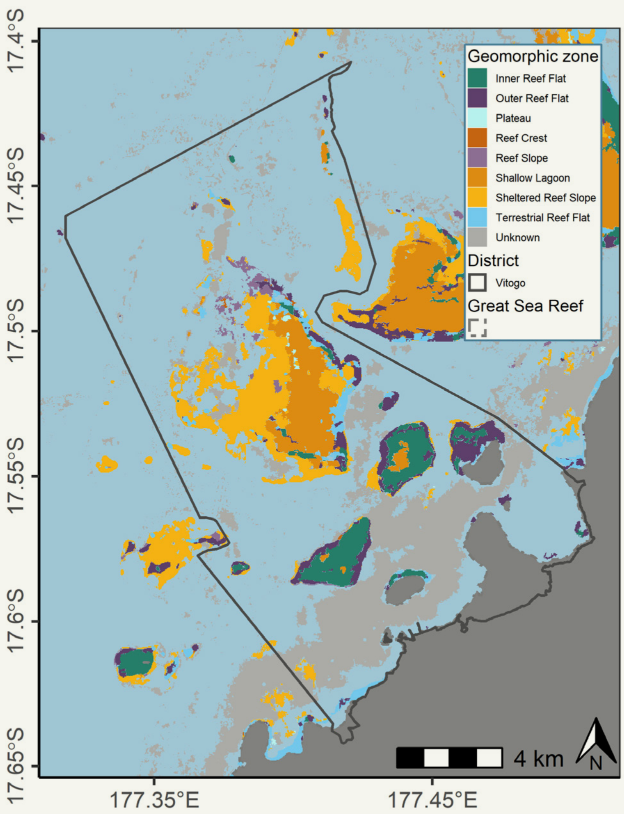


Figure 6.3.4. Mangrove extent in Vitogo *qoliqoli*.

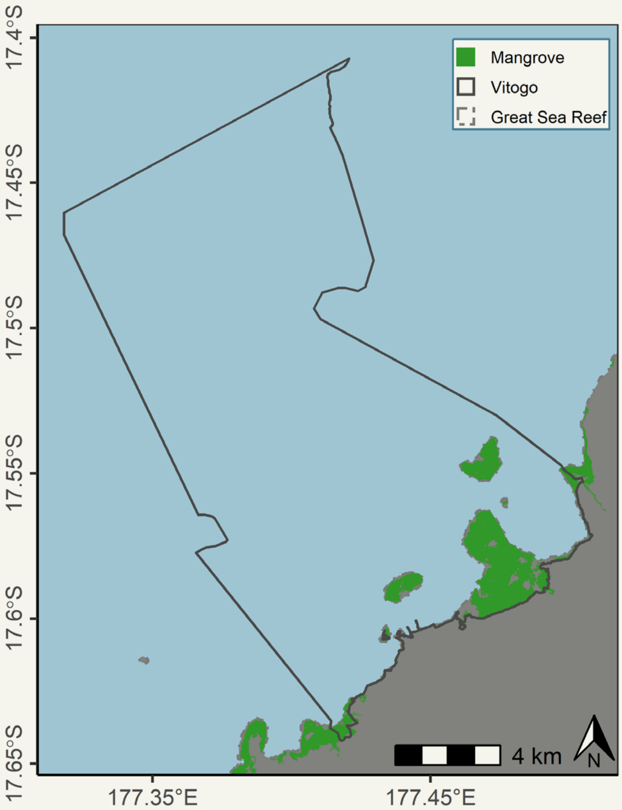


Figure 6.3.5. Mangrove change between 1996-2016 in Vitogo *qoliqoli*.

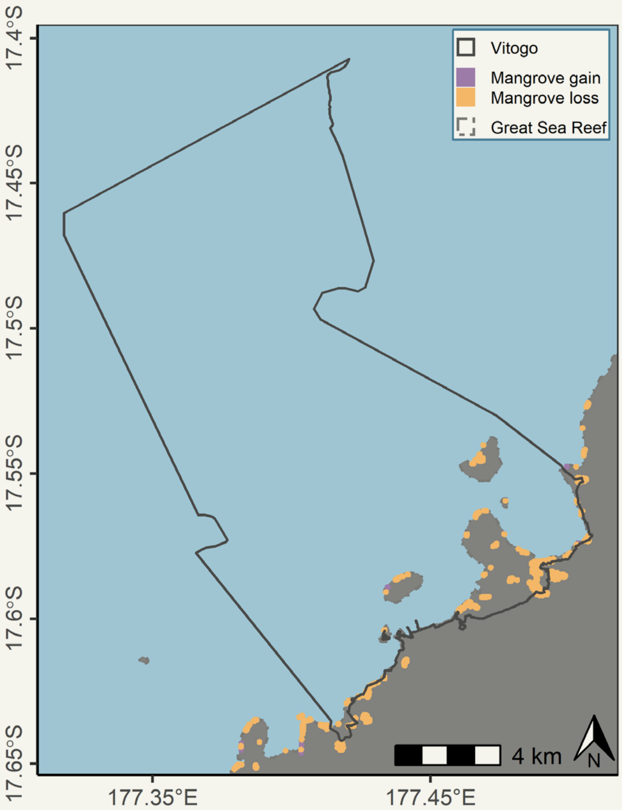
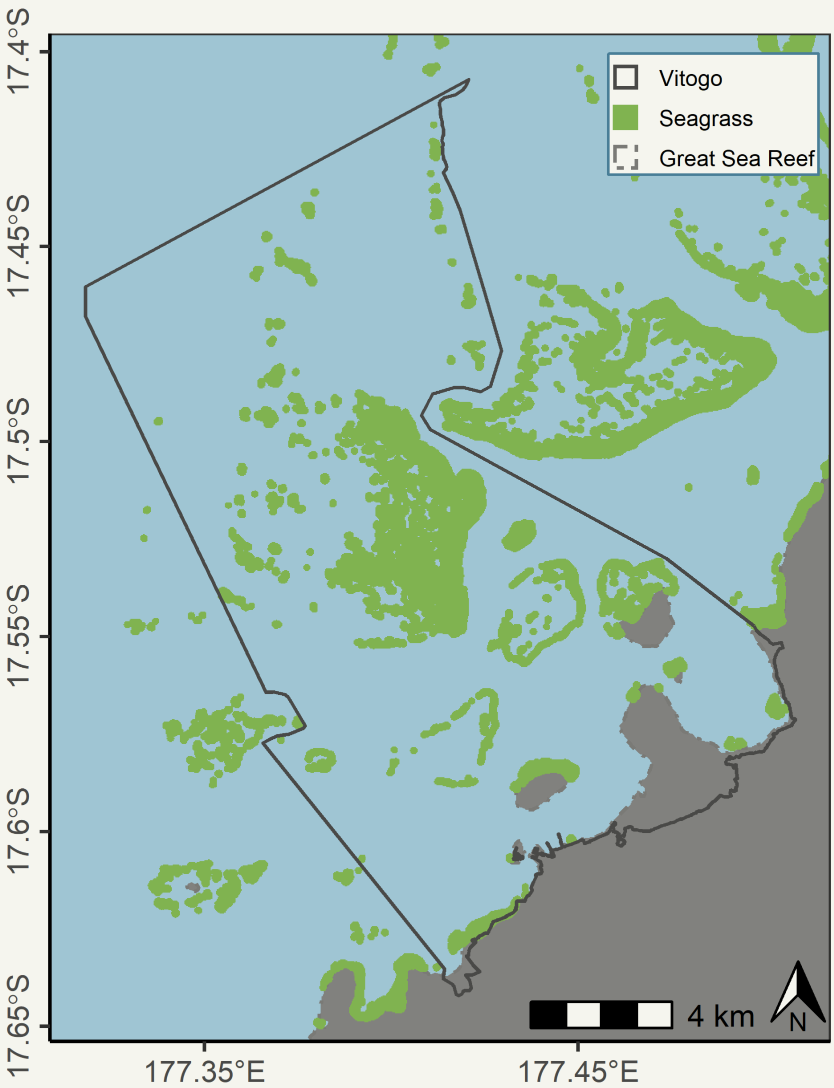


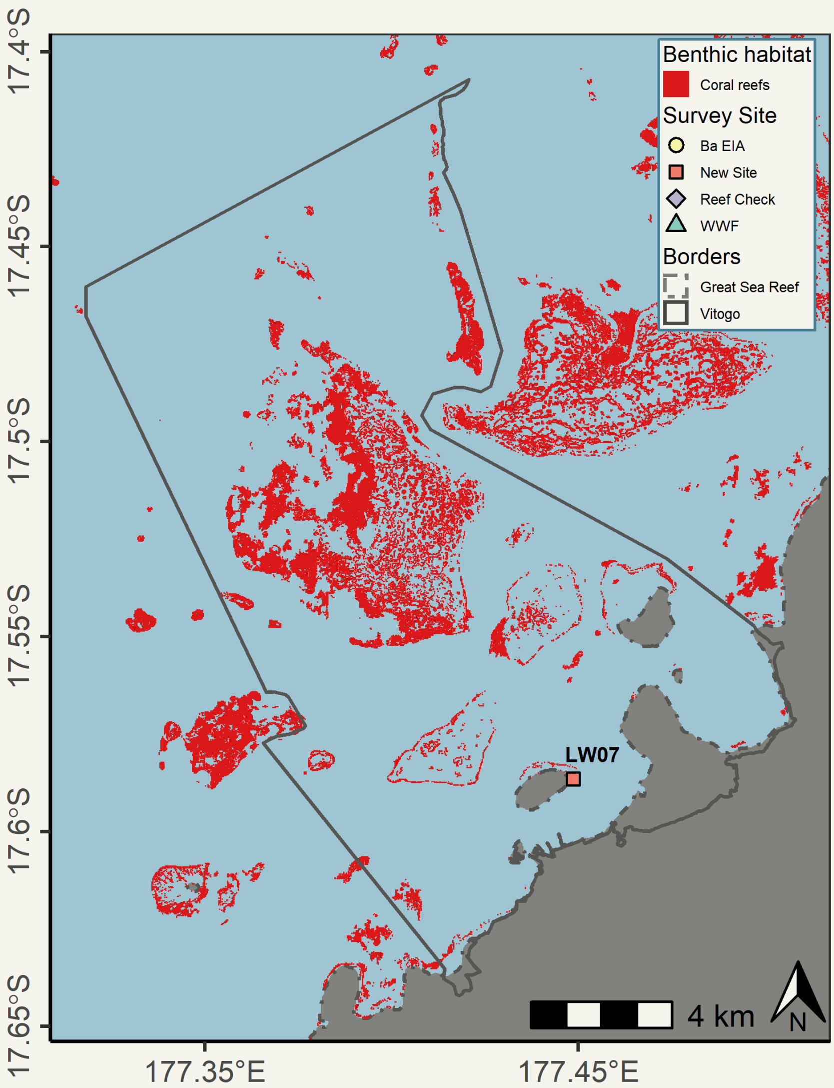
Figure 6.3.6. Seagrass cover in Vitogo *qoliqoli*.



6.3.2 Survey sites

Surveys were completed at one site in Vitogo *qoliqoli* (Figure 6.3.7). This site (LW07) was on a fringing reef on an island immediately adjacent to Lautoka city, so should not be considered representative of the whole Vitogo *qoliqoli*. Instead, this site provides information on coastal ecosystem health immediately adjacent to Lautoka. No previous data has been collected from this site, precluding any temporal comparisons.

Figure 6.3.7. Survey site in Vitogo *qoliqoli*.



6.3.3 Benthic cover

Hard coral cover was 9% at the site in Vitogo in 2019 (Figure 6.3.8). This coral cover was amongst the lowest cover we recorded on the GSR. The second highest live benthic cover on reefs was crustose coralline algae at 2%. Nonliving benthic cover was high, with rubble at 50%, bare substrate at 11%, and sand at 25%. In addition, this site appeared to be highly sedimented when dived. This suggests that these reefs have experienced significant damage in recent years, and the site generally appeared degraded. Previously, concern has been raised about pollution from the Lautoka waste disposal site located in the adjacent mangroves leaching onto this reef area and causing degradation; this is a threat that should be addressed (Andradi-Brown 2020).

6.3.4 Fish communities

A mean fish abundance for the target family/species list of 360 ind/ha was recorded at the survey site in Vitogo, while mean fish biomass was 44 kg/ha. Fish communities were dominated by non-commercially valuable fish families by abundance and by herbivores by biomass (Figure 6.3.9). The most abundant fish family was Chaetodontidae (267 ind/ha) followed by Acanthuridae (40 ind/ha). Chaetodontidae was also the largest fish family by biomass (20 kg/ha), with Acanthuridae the second largest (14 kg/ha). Herbivorous reef fish were surprisingly rare, and at low biomass compared to other sites on the GSR. No carnivorous reef fish were observed at the site. These results suggest that this site is subject to high fisheries pressure.

6.3.5 Rare Species

No humphead wrasse, bumphead parrotfish, Serranidae, or sharks were recorded at the site in Vitogo during the 2019 survey. The lack of even juvenile Serranidae on the reef highlights how heavily fished and degraded this reef site is.

Figure 6.3.8. Benthic cover in 2019 for Vitogo *qoliqoli*.

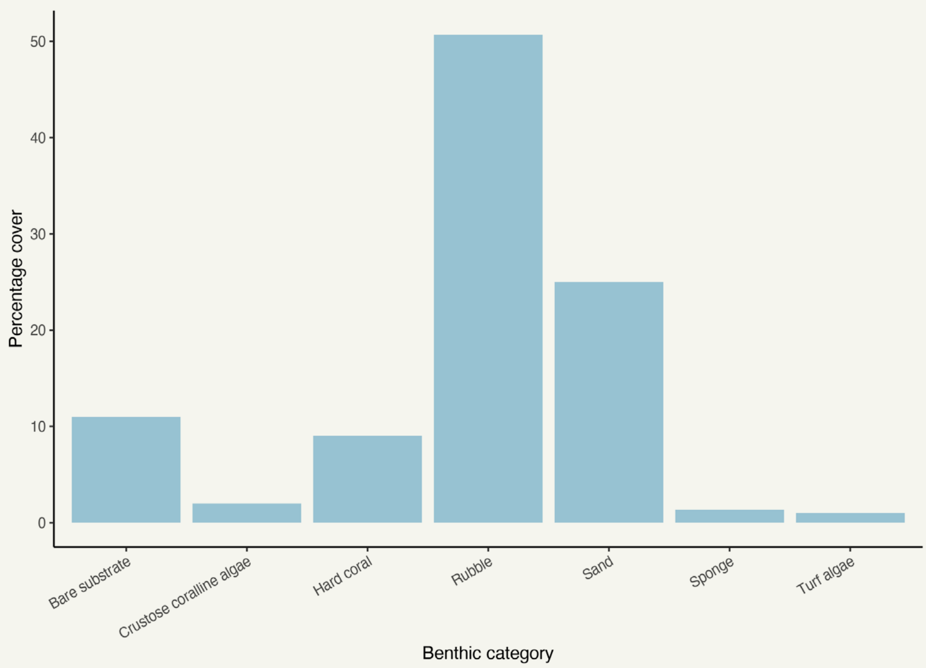
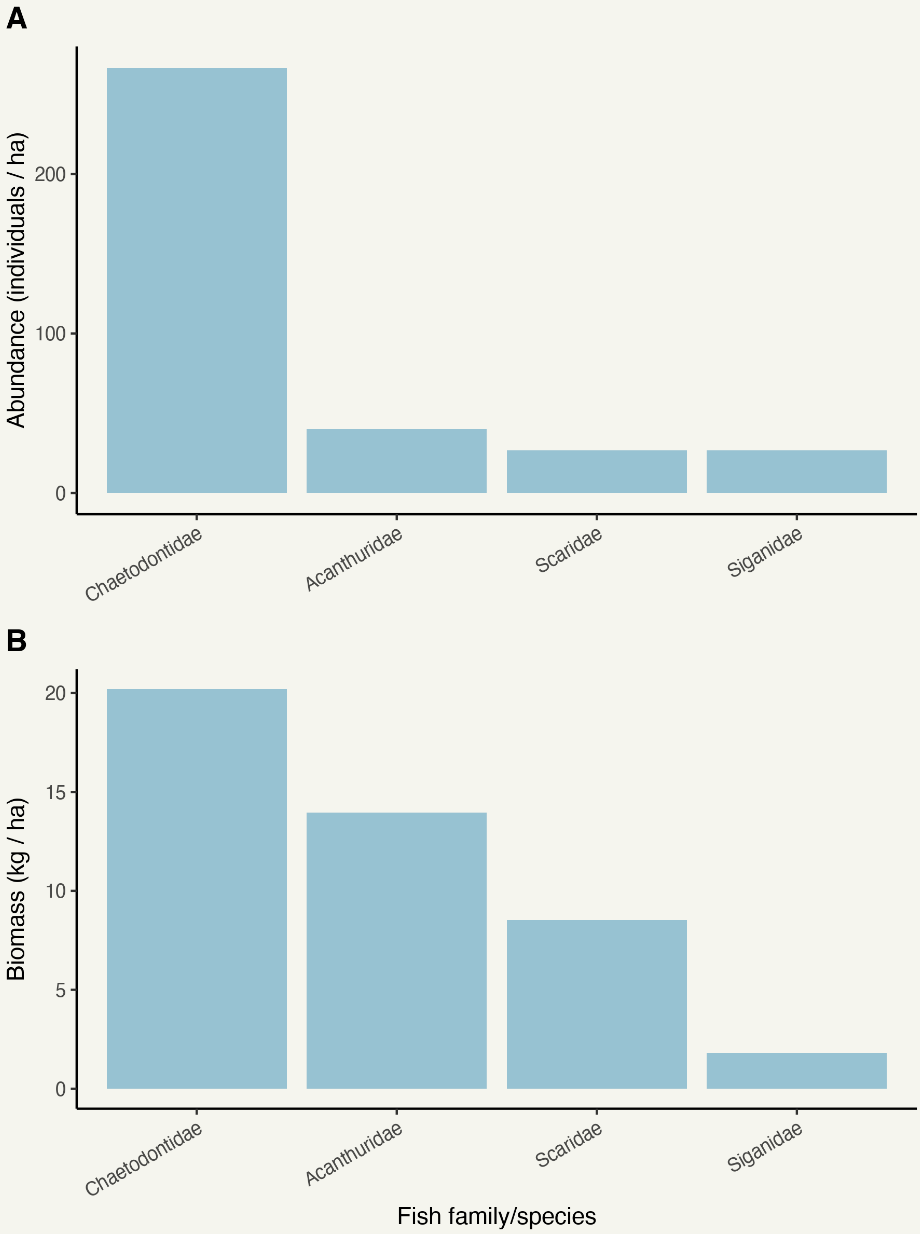


Figure 6.3.9. Fish community structure by (A) abundance and (B) biomass for Vitogo *qoliqoli*.



6.4 Nailaga and Bulu

6.4.1 Introduction and critical habitat coverage

Nailaga and Bulu is a *qoliqoli* in Ba province located on the western coast of Viti Levu and includes several islands and offshore reefs. Nailaga and Bulu marine areas span 205 km² (Figure 6.4.1).

Reefs within Nailaga and Bulu *qoliqoli* are mostly offshore barriers containing lagoons (Figure 6.4.2). In total, coral covers approximately 25 km² within Nailaga and Bulu *qoliqoli*, though summing all Allen Coral Atlas benthic categories that likely contribute to broader coral reef ecosystem composition (i.e. coral/algae, microalgal mats, rock, and rubble) suggests a coverage of 46 km² of shallow reef-related ecosystems. The majority of these reefs are comprised of shallow lagoonal reefs (29 km²), followed by sheltered reef slopes (11 km²), and inner reef flats (10 km²), with many other reef types also present (Figure 6.4.3).

Mangroves cover 3 km² in Nailaga and Bulu *qoliqoli* (Figure 6.4.4) – with 4 ha lost between 1996 and 2016. However, mangroves expanded by 8 ha elsewhere within the *qoliqoli*, giving a net gain of 4 ha of mangrove forest between 1996-2016 (Figure 6.4.5). Mangroves exist as a narrow fringing coastal band in Nailaga and Bulu, associated with the Viti Levu coastline. Seagrass covers approximately 12 km² within Nailaga and Bulu, with much of this growing in the shallow lagoons in the center of the *qoliqoli* (Figure 6.4.6).

Figure 6.4.1. Bathymetry of Nailaga and Bulu *qoliqoli*.

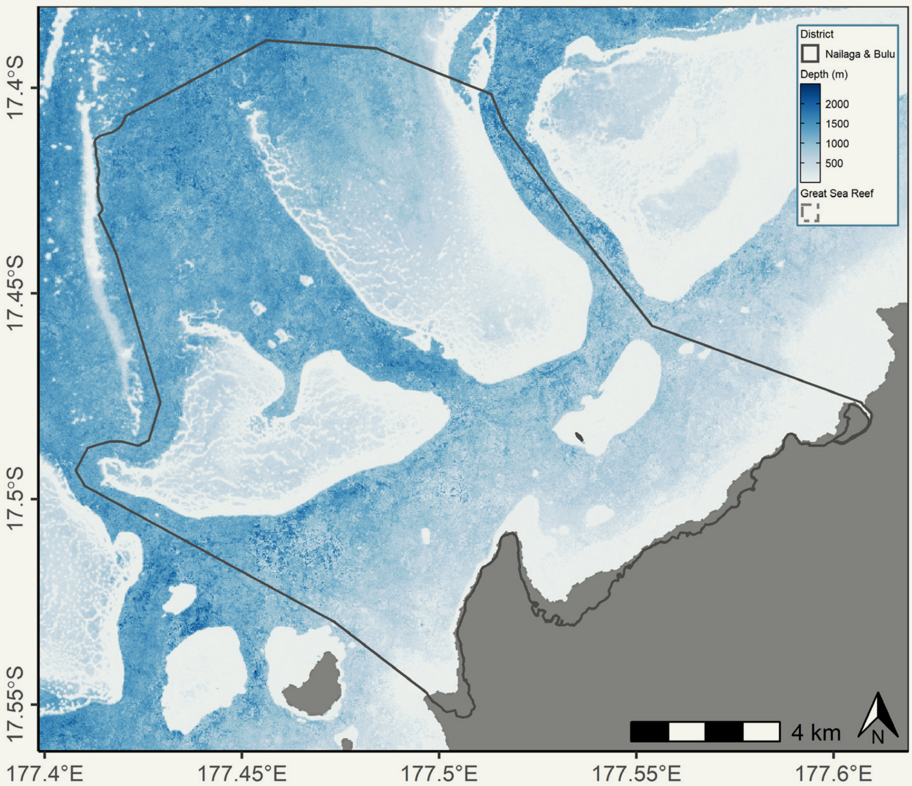


Figure 6.4.2. Coral reef extent in Nailaga and Bulu *qoliqoli*.

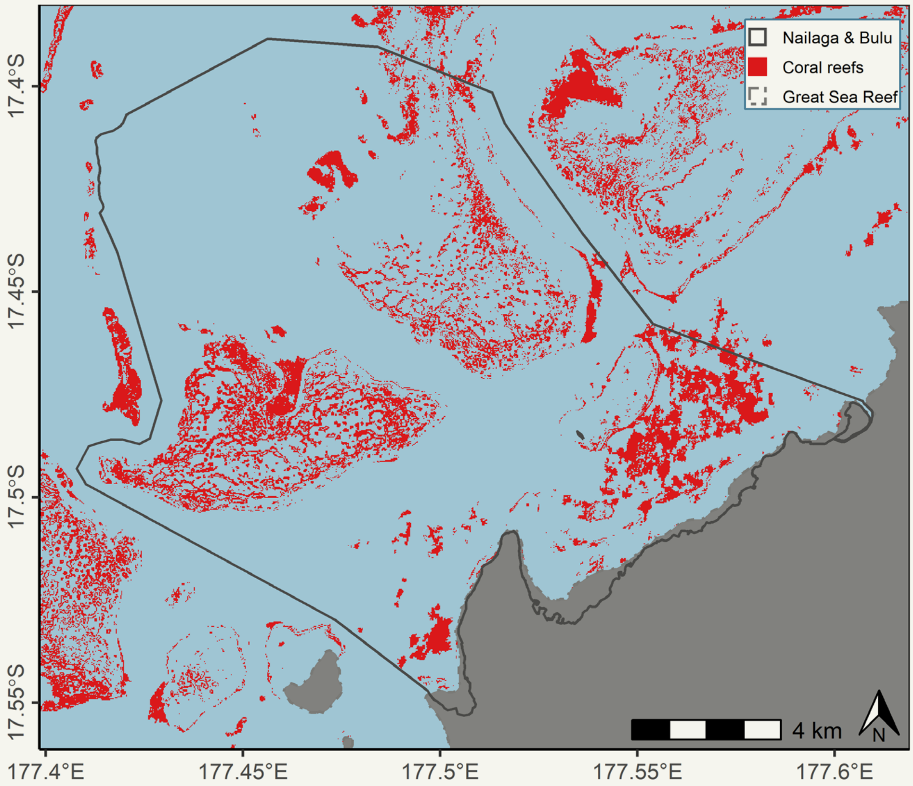


Figure 6.4.3. Reef geomorphic types in Nailaga and Bulu *qoliqoli*.

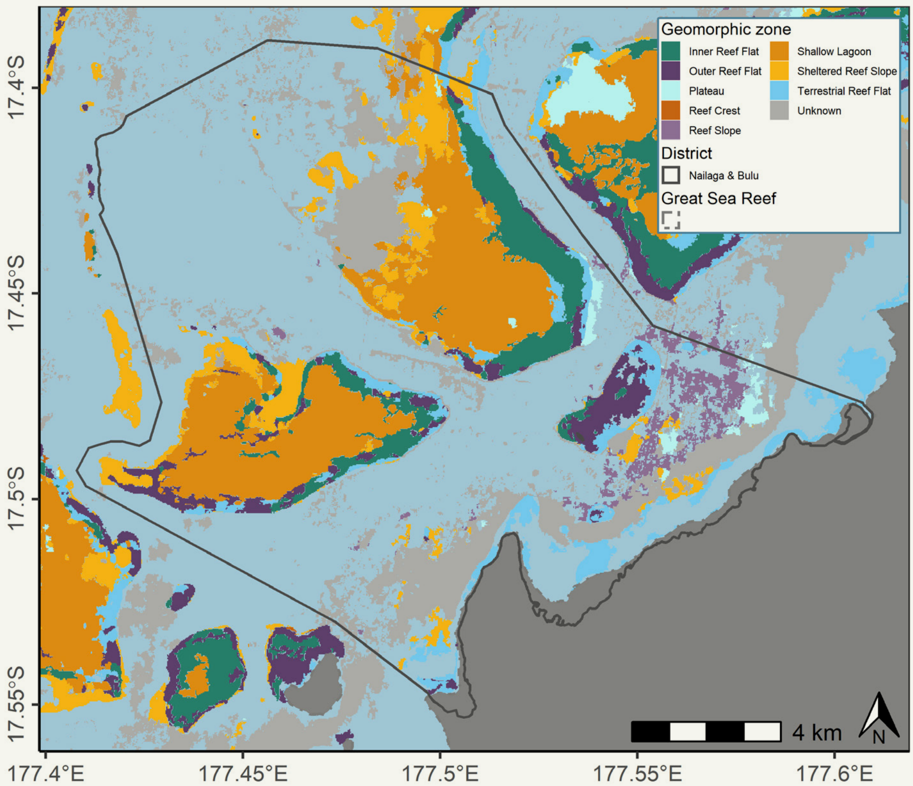


Figure 6.4.4. Mangrove extent in Nailaga and Bulu *qoliqoli*.

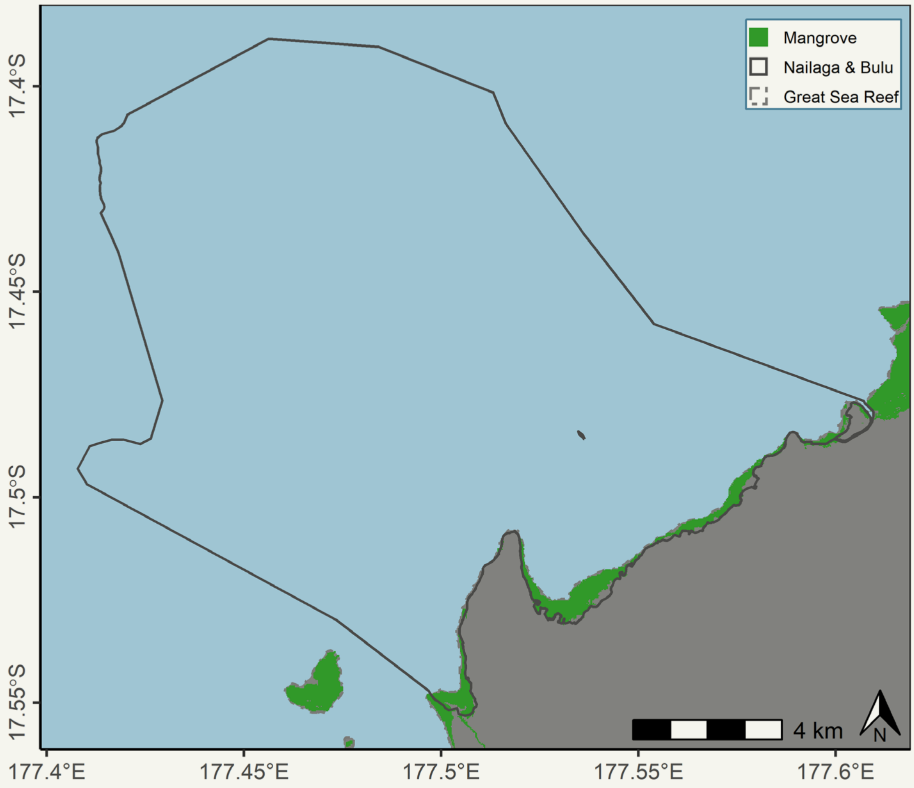


Figure 6.4.5. Mangrove change between 1996-2016 in Nailaga and Bulu *qoliqoli*.

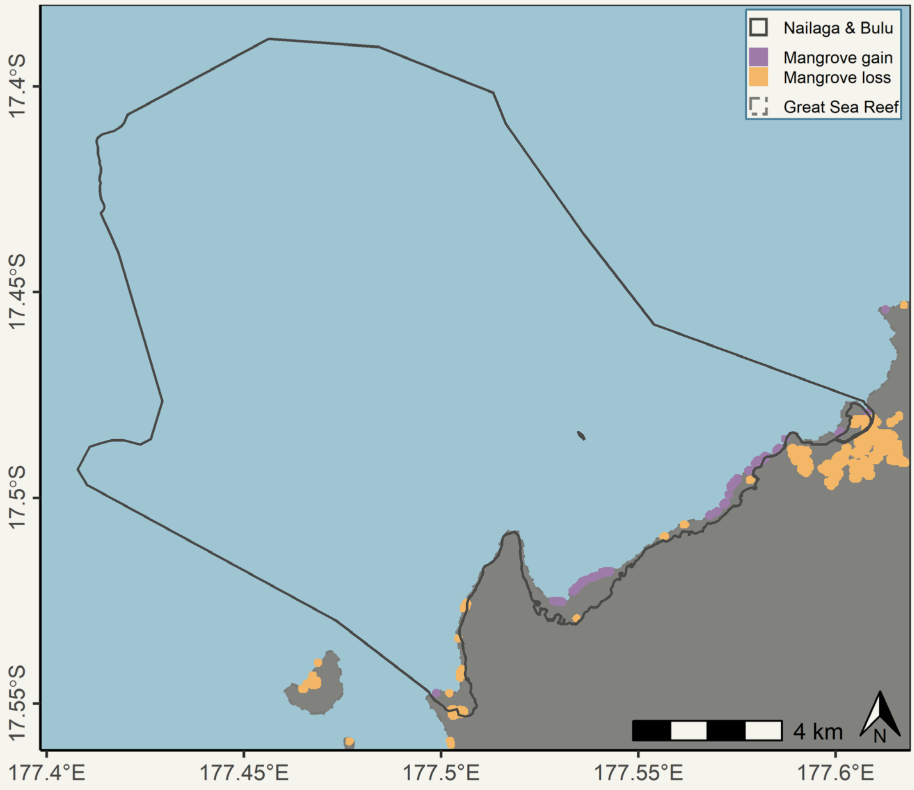
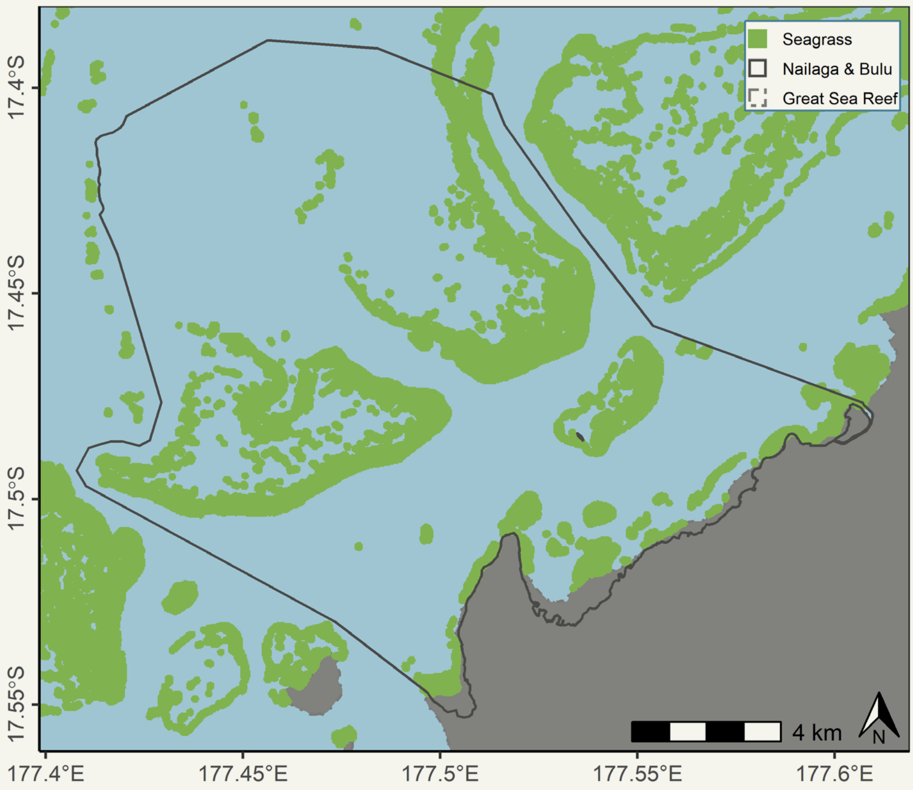


Figure 6.4.6. Seagrass cover in Nailaga and Bulu *qoliqoli*.



6.4.2 Survey sites

Surveys were completed at one site in Nailaga and Bulu *qoliqoli* (Figure 6.4.7). This site (BA07) was on the edge of a channel through the reef in the west of the *qoliqoli*, and so should not be considered representative of the whole Nailaga and Bulu *qoliqoli*. This site is associated with the Ba Estuary, so it provides information on coastal ecosystem health within the estuary and particularly with regards to the sand mining occurring within the area. This site was previously surveyed for fish abundance and biomass in 2010 by the Ba EIA (GREENPAC 2011), allowing temporal comparisons of fish communities. No historic benthic data is available from the site.

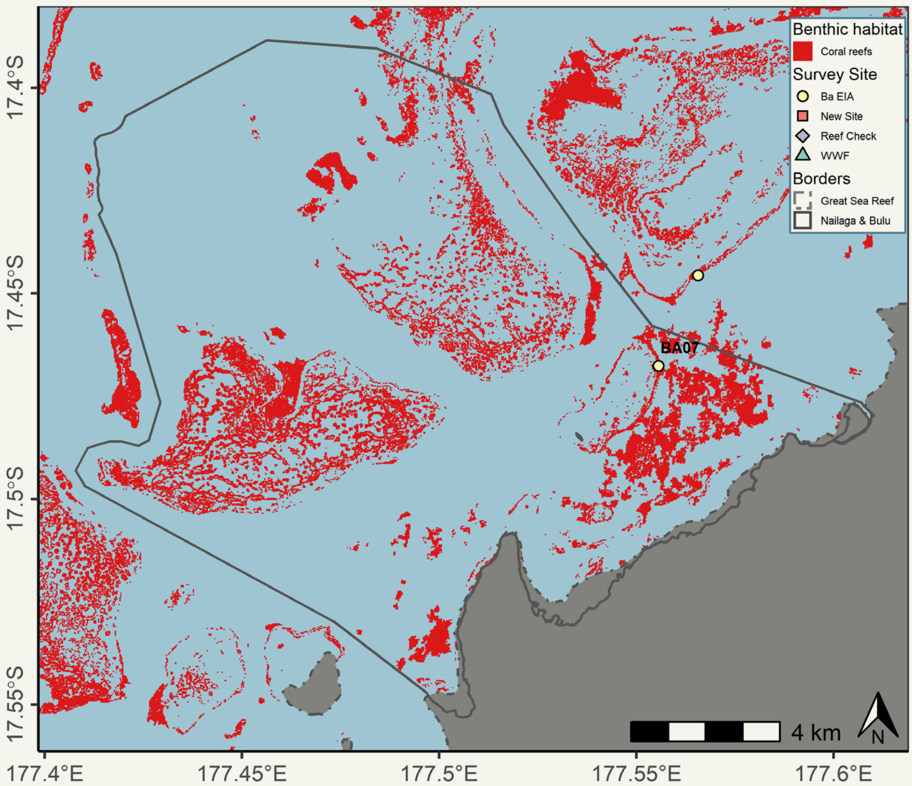


Figure 6.4.7. Survey site in Nailaga and Bulu *qoliqoli*.

6.4.3 Benthic cover

Hard coral cover was 46% at the site in Nailaga and Bulu in 2019 (Figure 6.4.8). The second highest live benthic cover on reefs was sponge at 14%. The reefs associated with Ba Estuary had high turbidity, and uniquely for the GSR sites surveyed had high sponge cover. These sponges exhibited highly diverse growth forms and provided a large component of the structural complexity on the reef. Surprisingly, there was no macroalgae recorded on the transect. Nonliving benthic cover was moderate, with rubble at 26% and bare substrate at 9%.

6.4.4 Fish communities

A mean fish abundance for the target family/species list of 1,693 ind/ha was recorded at the survey site in Nailaga and Bulu, while mean fish biomass was 92 kg/ha. Fish communities were dominated by herbivores in both abundance and biomass (Figure 6.4.9). The most abundant fish family was Scaridae (707 ind/ha), followed by Acanthurdae (387 ind/ha), and Siganidae (293). Scaridae was also the largest fish family by biomass (59 kg/ha), with Acanthuridae the second largest (12 kg/ha). The most abundant carnivorous reef fish family was Lutjanidae at 160 ind/ha, and a biomass of 7 kg/ha. These results suggest that this site is subject to fisheries pressure.

Key fisheries family (Haemulidae, Lutjanidae, Scaridae, Serranidae) abundance was lower at the Nailaga and Bulu site in 2019 than in 2010 – declining from 4,860 ind/ha to 880 ind/ha (Figure 6.4.10). Key fisheries family biomass also appeared to decline – from 983 kg/ha in 2010 to 73 kg/ha in 2019 (Figure 6.4.11).

6.4.5 Rare Species

No humphead wrasse were observed in Nailaga and Bulu during the 2019 survey. The historic survey conducted in 2010 recorded humphead wrasse at site BA07 at a density of 80 ind/ha, translating to a biomass of 31 kg/ha. This very high historic density reflects that only one site was surveyed and four juvenile humphead wrasse, all in the 25-30 cm size range, were observed at this site in 2010. It is doubtful that this high historic density accurately represents the whole *qoliqoli*, and instead probably reflects that by chance the selected survey site had a greater than average density of humphead wrasse.

No Serranidae were observed in Nailaga and Bulu during the 2019 survey. Historic surveys in 2010 recorded grouper abundance of 220 ind/ha and biomass of 68 kg/ha. This rapid decline of Serranidae, and lack of even juvenile Serranidae on the reef highlights how heavily fished this reef site is.

No bumphead parrotfish or sharks were recorded in at the site in Nailaga and Bulu during the 2019 surveys or during the historic surveys in 2010.

Figure 6.4.8. Benthic cover in 2019 for Nailaga and Bulu *qoliqoli*.

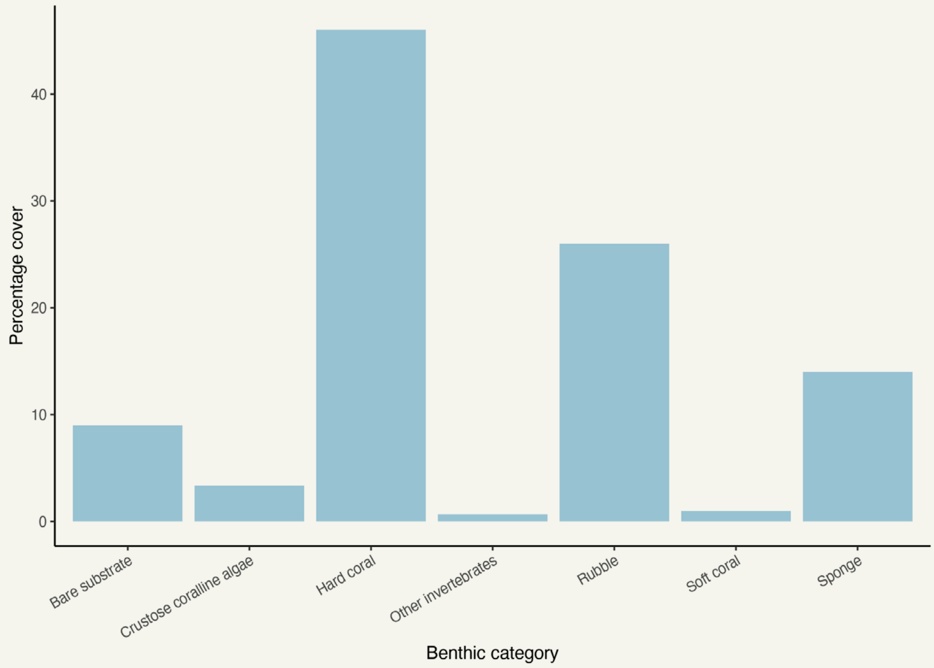


Figure 6.4.9. Fish community structure by (A) abundance and (B) biomass for Nailaga and Bulu *qoliqoli*.

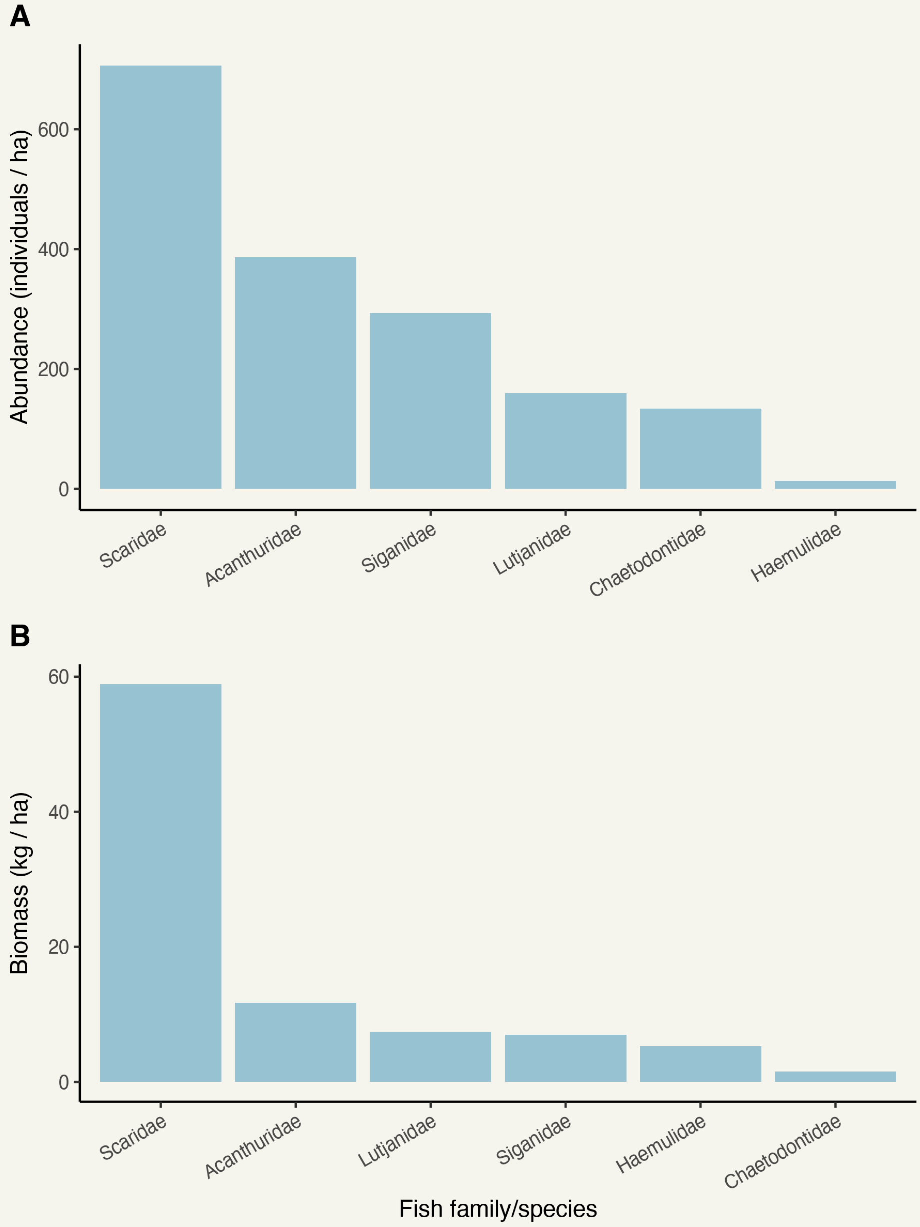


Figure 6.4.10. Change in key fisheries family abundance (Haemulidae, Lutjanidae, Scaridae, and Serranidae) for the Nailaga and Bulu site.

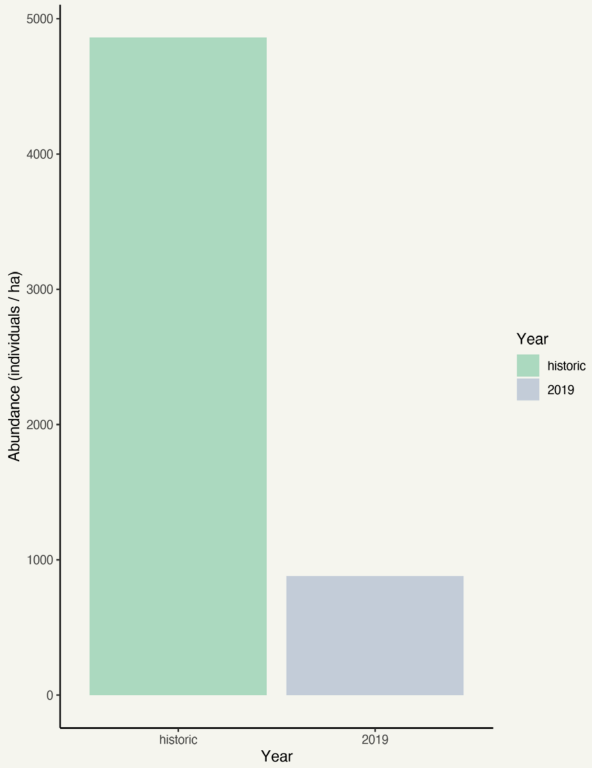
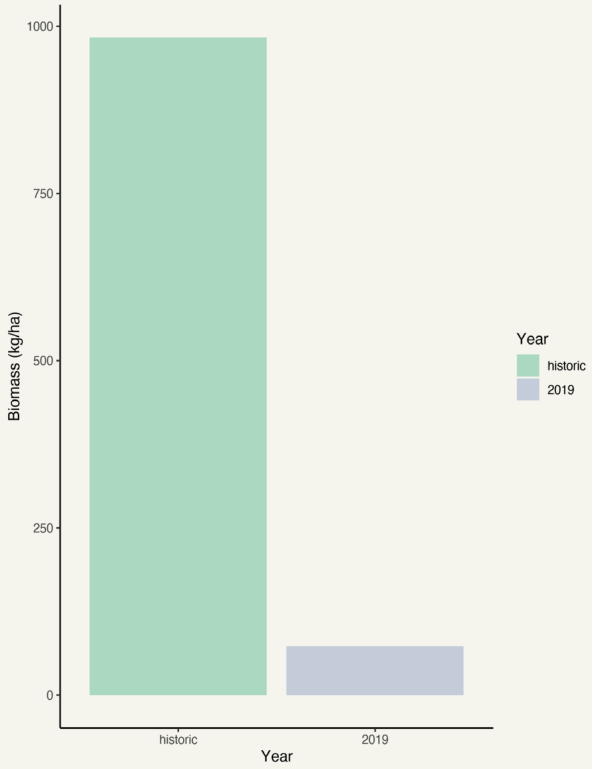


Figure 6.4.11. Change in key fisheries family biomass (Haemulidae, Lutjanidae, Scaridae, and Serranidae) for the Nailaga and Bulu site.



6.5 Votua

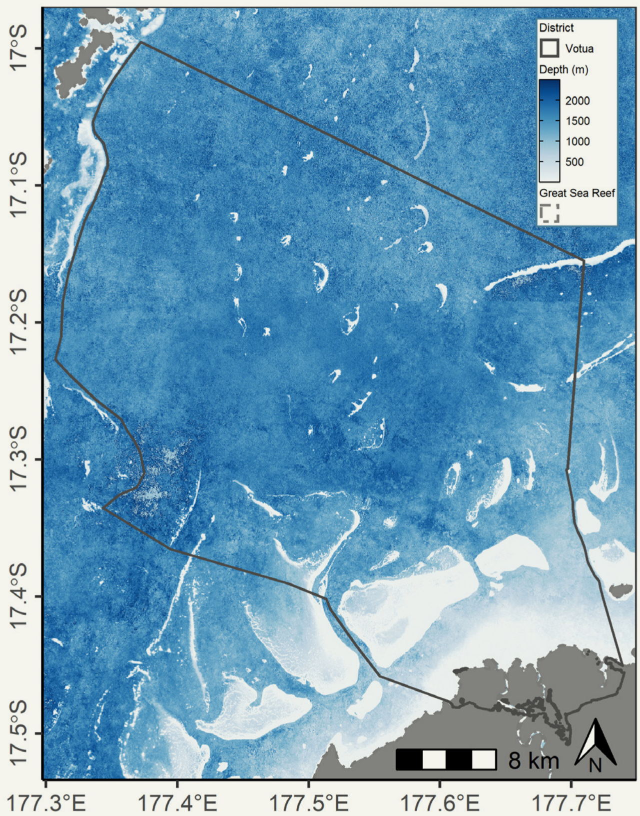
6.5.1 Introduction and critical habitat coverage

Votua *qoliqoli* is located in Ba province off the north western coast of Viti Levu and spans 1,554 km² (Figure 6.5.1). Votua *qoliqoli* falls under the customary ownership of clans within Votua Village, which lies within the district of Nailaga. The *qoliqoli* contains a series of large shallow reefs with channels passing through them, which are heavily influenced by the input from the adjacent Ba river.

Reefs within Votua exist in the offshore area as a large coastal-associated system, and as isolated patch reefs in the center of the *qoliqoli* (Figure 6.5.2). In total, coral covers approximately 26 km2 within the *qoliqoli*, though summing all Allen Coral Atlas benthic categories that likely contribute to broader coral reef ecosystem composition (i.e. coral/algae, microalgal mats, rock, and rubble) suggests a coverage of 64 km² of shallow reef-related ecosystems. The majority of these reefs are comprised of inner reef flats (31 km²), followed by significant areas of outer reef flats (21 km²), with significant shallow lagoons (12 km²) and terrestrial reef flats (12 km²), and other reef types also present (Figure 6.5.3).

Mangrove extent is high in Votua *qoliqoli* at 45 km², with a net loss of 10 ha between 1996 and 2016 (Figures 6.5.4; 6.5.5). This high mangrove cover reflects extensive mangrove stands in the coastal areas of Viti Levu. Seagrass covers approximately 11 km² within the *qoliqoli*, with much of this split associated with the coastal area and reefs of Viti Levu (Figure 6.5.6).

Figure 6.5.1. Bathymetry of Votua *qoliqoli*.



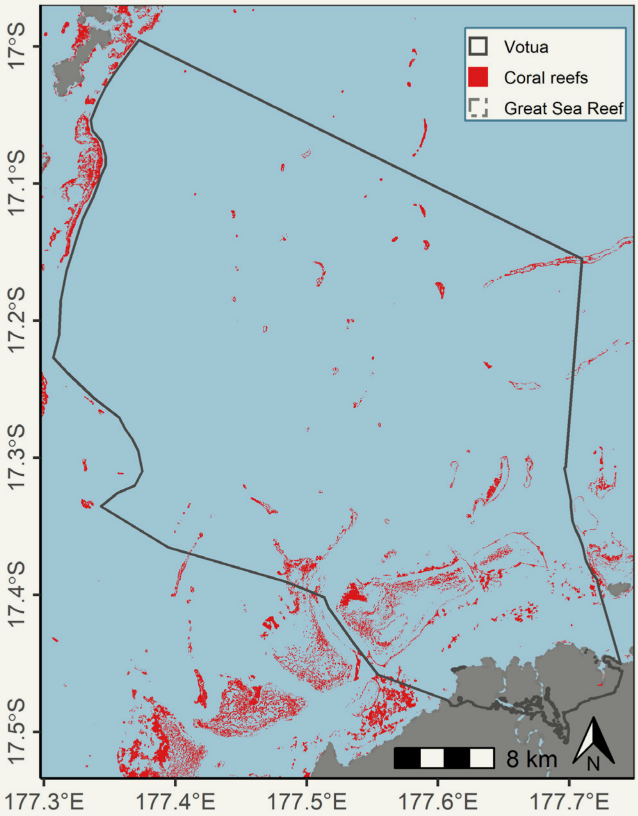


Figure 6.5.2. Coral reef extent in the Votua *qoliqoli*.

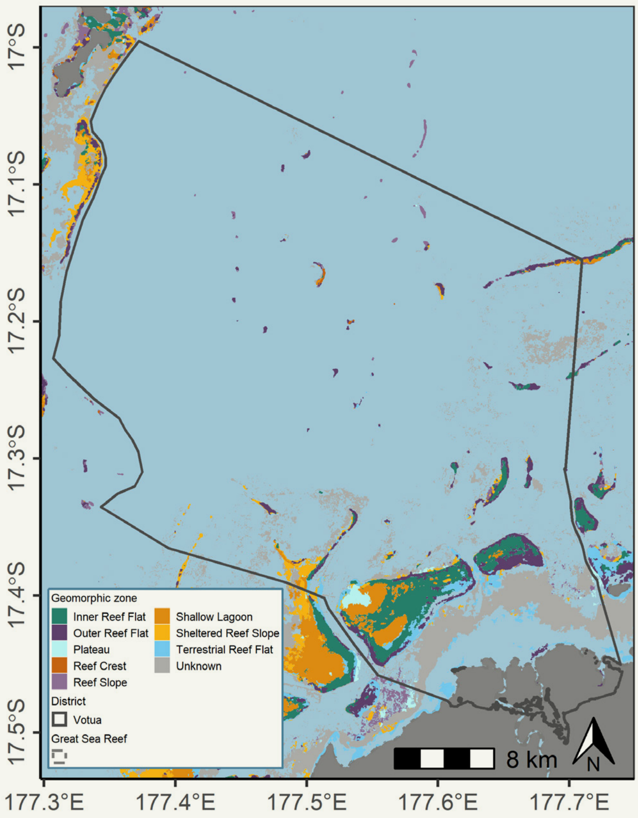


Figure 6.5.3. Reef geomorphic types in Votua *qoliqoli*.

Figure 6.5.4. Mangrove extent in Votua *qoliqoli*.

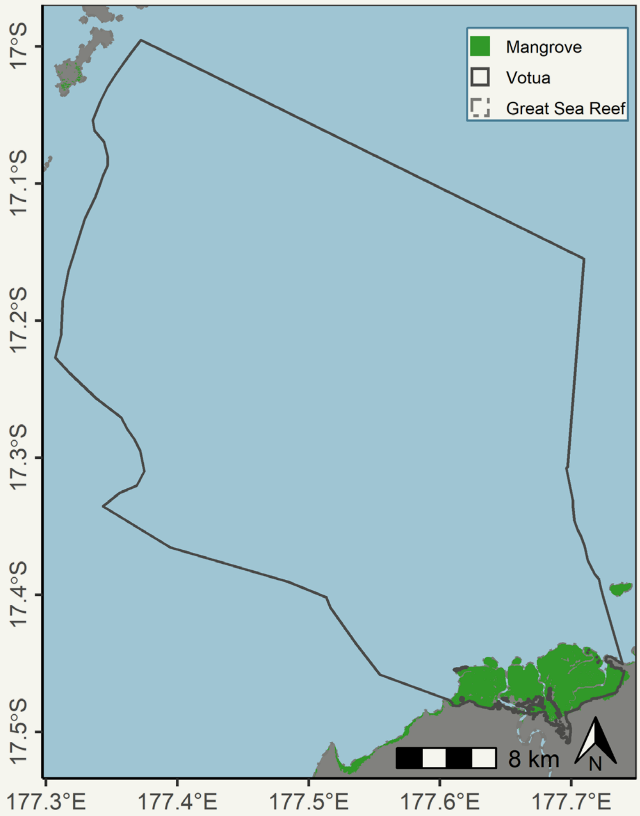


Figure 6.5.5. Mangrove change between 1996-2016 in Votua *qoliqoli*.

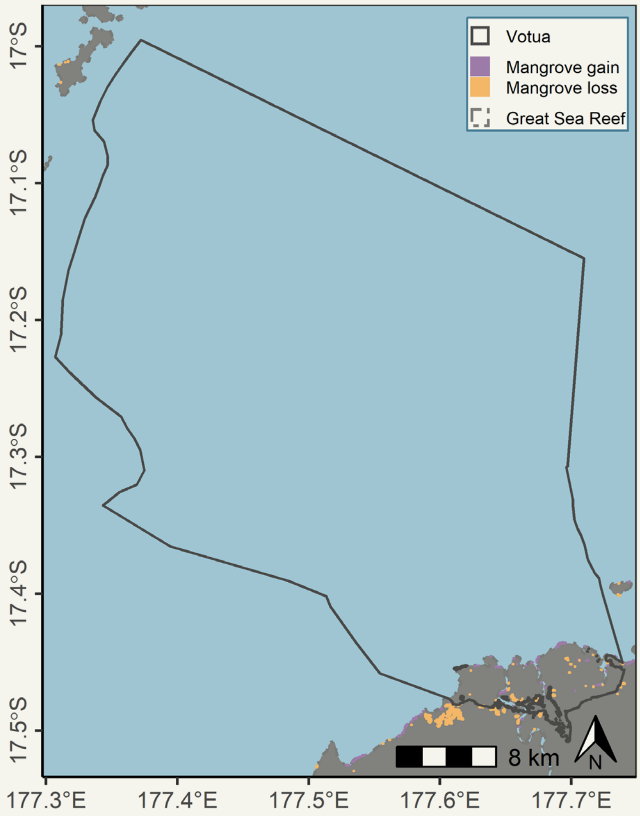
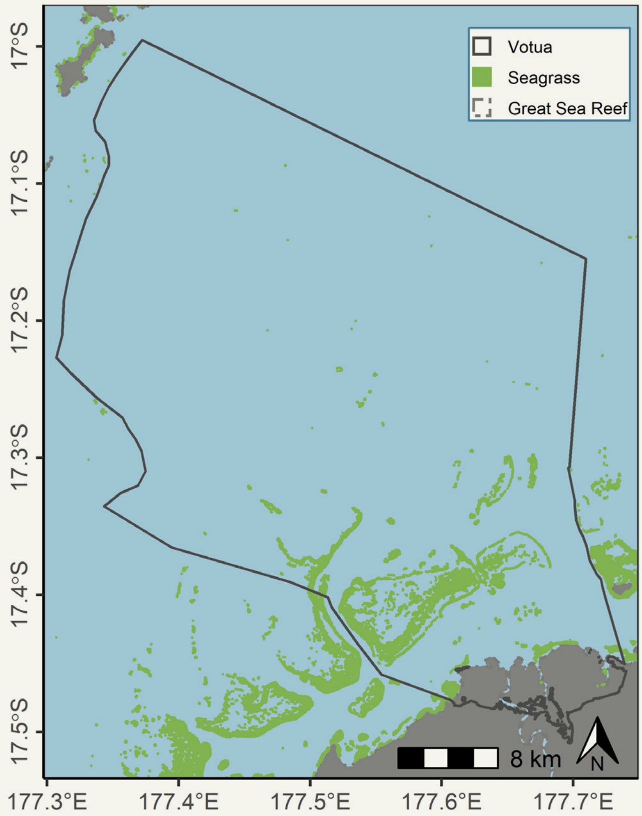


Figure 6.5.6. Seagrass cover in Votua *qoliqoli*.



6.5.2 Survey sites

Surveys were completed at 11 sites within Votua (Figure 6.5.7). Seven of these sites were located in the coastal area close to the Ba Estuary, while four of the sites were located on the patch reefs further offshore in the center of the *qoliqoli*. Historic fish abundance and biomass data from 2010 is available for six of the Ba Estuary sites from the Ba EIA (GREENPAC 2011). No historic benthic data is available for sites in Votua, and no historic fish data is available for sites in central Ba.

6.5.3 Benthic cover

Hard coral cover was 31 ± 6% across reefs in Votua in 2019 (Figure 6.5.8). The second highest live benthic cover on reefs was macroalgae, at 10 ± 2%. Soft coral and sponge were low, at 3 ± 1% and 2 ± 1%, respectively.

Sites surveyed in Votua split into two group based on reef type and geographic location – (i) Ba River estuary, and (ii) central Ba. Hard coral cover and macroalgae cover was variable between sites within each of these two groups, though Ba Estuary had greater mean hard coral cover and macroalgae cover than central Ba (Figure 6.5.9). No historic benthic data is available for Votua *qoliqoli*.

Figure 6.5.7. Survey sites in Votua *qoliqoli*.

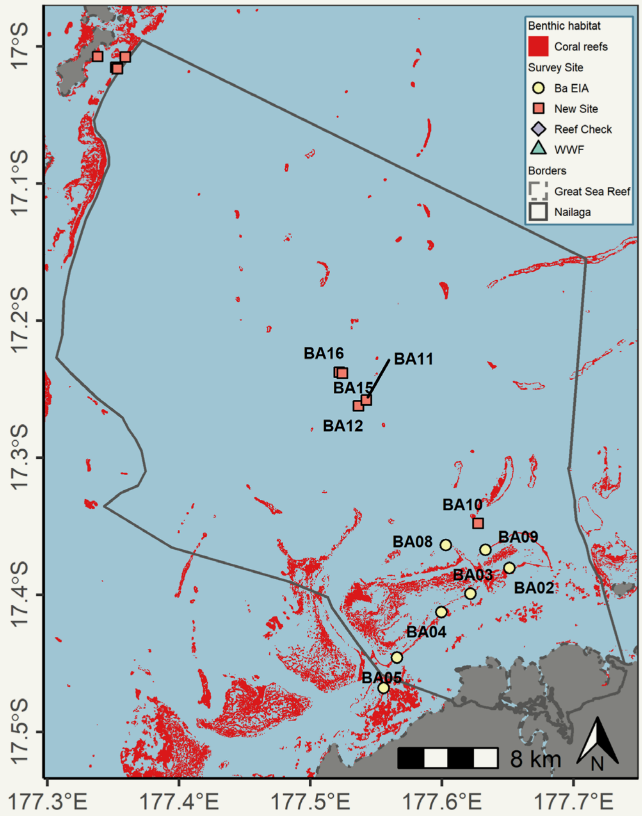


Figure 6.5.8. Benthic cover in 2019 for Votua *qoliqoli*.

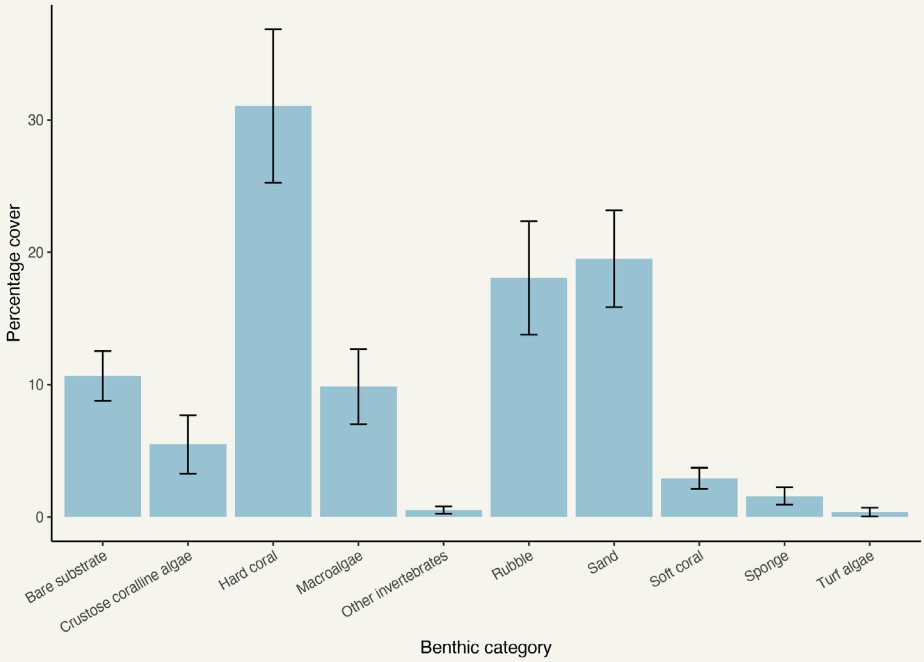
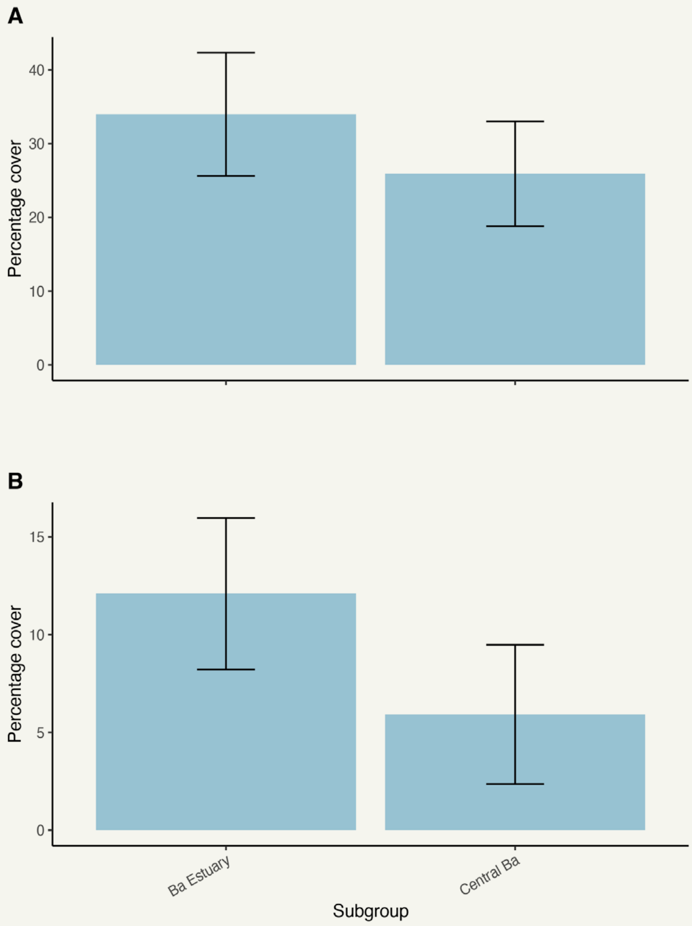


Figure 6.5.9. (A) Hard coral cover and (B) macroalgae cover by subgroup for sites within Votua *qoliqoli*.



6.5.4 Fish communities

A mean fish abundance for the target family/species list of 2,213 ± 227 ind/ha was recorded across all Votua sites, while mean fish biomass was 208 ± 29 kg/ha. Fish communities were dominated by herbivores by both abundance and biomass (Figure 6.5.10). The most abundant fish family was Scaridae (1,027 ± 205 ind/ha), followed by Acanthuridae (315 ± 41 ind/ha) and Siganidae (295 ± 44 ind/ha). Scaridae was also the largest fish family by biomass (96 ± 23 kg/ha), with acanthids the third largest (24 ± 5 kg/ha). The greatest carnivorous family by both abundance and biomass was Lutjanidae (214 ± 84 ind/ha; 31 ± 15 kg/ha) – though this was low abundance and biomass compared to elsewhere in the GSR. Fish abundance and biomass were similar between Ba Estuary and central Ba (Figure 6.5.11).

It was *very likely* (V=20, p=0.06) that key fisheries family abundance declined for the six sites in Ba Estuary with historic data available (Figure 6.5.12). Key fisheries family abundance at these six sites in 2010 was 2,593 ± 410 ind/ha, which fell to 1,313 ± 323 ind/ha in 2019. It was *extremely likely* (V=21, p=0.03) that key fisheries family biomass declined at the six Ba Estuary sites with historic data (Figure 6.5.13). Key fisheries family biomass was 586 ± 107 kg/ha in 2010, declining to 163 ± 55 kg/ha in 2019.

Figure 6.5.10. Fish community structure by (A) abundance and (B) biomass for Votua *qoliqoli*.

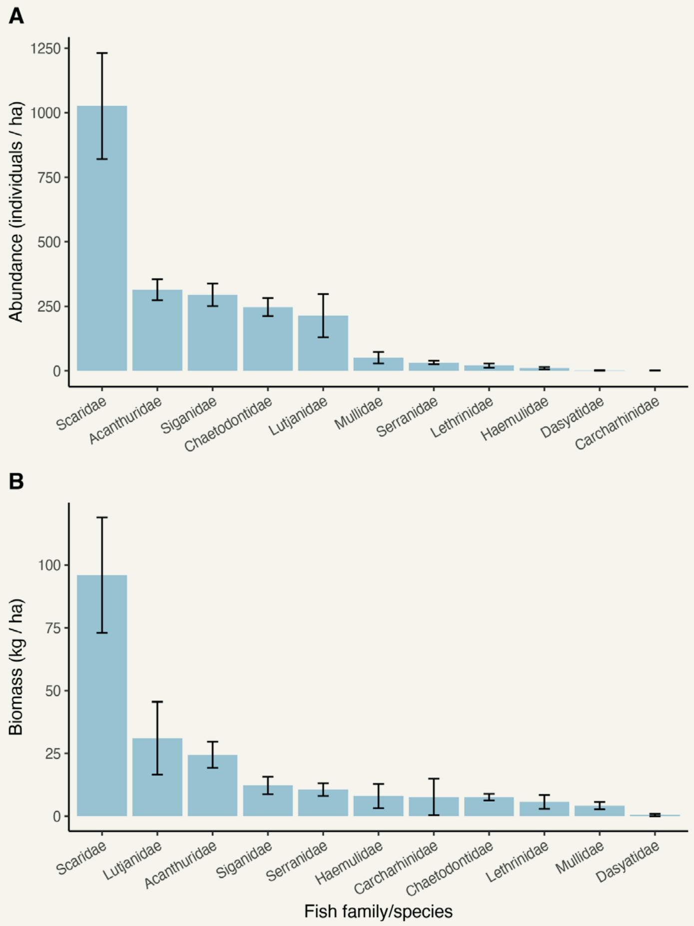


Figure 6.5.11. Overall fish (A) abundance and (B) biomass for sites surveyed in 2019 in Votua *qoliqoli*. Results divided by subgroups representing broad reef types.

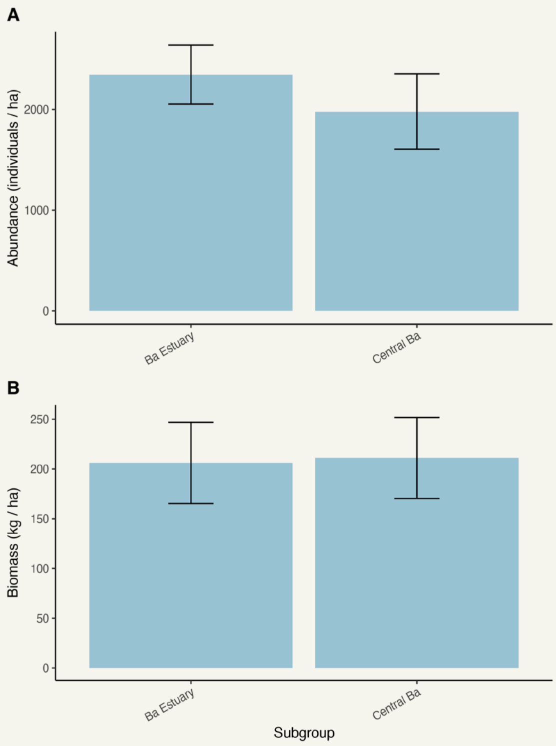


Figure 6.5.12. Change in key fisheries family abundance (Haemulidae, Lutjanidae, Scaridae, and Serranidae) for Ba Estuary in Votua *qoliqoli* for six sites with historic data.

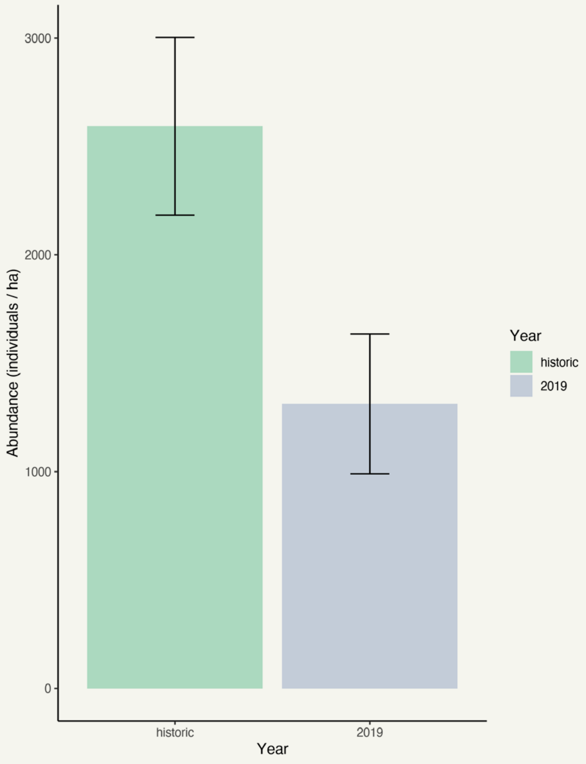


Figure 6.5.13. Change in key fisheries family biomass (Haemulidae, Lutjanidae, Scaridae, and Serranidae) for Ba Estuary in Votua *qoliqoli* for six sites with historic data. Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.

6.5.5 Rare Species

No humphead wrasse or bumphead parrtofish were recorded within Votua during the 2019 survey. Historic fish surveys at the six sites in Ba Estuary observed both humphead wrasse and bumphead parrotfish. Humphead wrasse were recorded at 3.33 ± 3.33 ind/ha and 1.21 ± 1.31 kg/ha, while bumphead parrotfish were recorded at 27 ± 27 ind/ha and 23 ± 23 kg/ha. This high density and abundance of bumphead parrotfish represents a single school of eight bumphead parrotfish that were all in the 35-40 cm size range encountered at a single site.

Serranidae abundance and biomass was 32 ± 6 ind/ha and 11 ± 3 kg/ha, respectively, across all Votua sites surveyed in 2019. For the six Ba Estuary sites with historic data, it was *very likely* (V=20, p=0.06) that Serranidae abundance declined, from 113 ± 45 ind/ha in 2010 to 19 ± 7 ind/ ha in 2019 (Figure 6.5.14). It was also *likely* (V=18, p=0.16) that Serranidae biomass declined, from 38 ± 17 kg/ha in 2010 to 6 ± 2 kg/ha in 2019 (Figure 6.5.14).

Sharks in the family Carcharhinidae were recorded at an abundance of 0.01 ± 0.65 ind/ha and biomass of 7.65 ± 7.25 kg/ha across all Votua sites in 2019. Historic surveys around the six Ba Estuary sites suggest that it is *exceptionally unlikely* (V=2, p>0.99) that shark abundance or biomass changed within Ba Estuary (Figure 6.5.15).

Figure 6.5.14. Serranidae (grouper) (A) abundance and (B) biomass for Votua *qoliqoli*. For each panel, data on the left of the dashed line represents all sites surveyed in 2019, while data on the right of the dashed line only represents the six sites in Ba Estuary with historic data. Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.

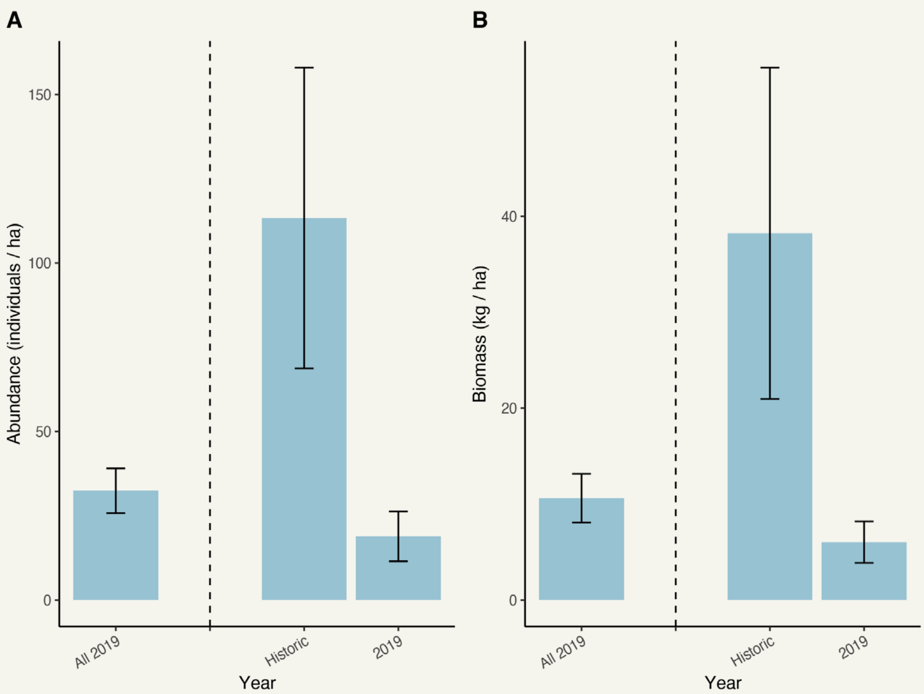
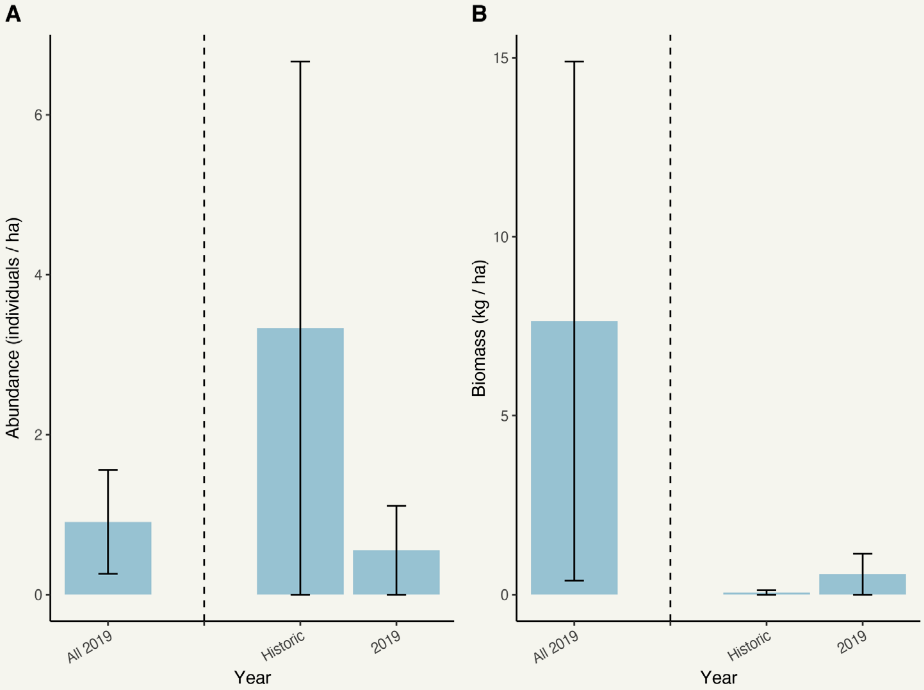


Figure 6.5.15. Carcharhinidae (shark) (A) abundance and (B) biomass for Votua *qoliqoli*. For each panel, data on the left of the dashed line represents all sites surveyed in 2019, while data on the right of the dashed line only represents the six sites in Ba Estuary with historic data. Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.



6.6 Nacula

6.6.1 Introduction and critical habitat coverage

Nacula *qoliqoli* is located in the center of the Yasawa Islands in Ba province off the north western coast of Viti Levu. The *qoliqoli* spans 131 km² (Figure 6.6.1), including deeper water areas and several narrow channels between the islands. Given the lack of major rivers on the Yasawa Islands, there is limited impacts of sedimentation from land use change, though coastal development has caused more localized pollution in some areas.

Nacula *qoliqoli* contains a series of fringing shallow reefs around the Yasawa Islands, as well as a barrier reef running along the eastern edge of the *qoliqoli* and some offshore reefs at the far western edge (Figure 6.6.2). In total, coral covers approximately 9 km² within the *qoliqoli*, though summing all Allen Coral Atlas benthic categories that likely contribute to broader coral reef ecosystem composition (i.e. coral/algae, microalgal mats, rock, and rubble) suggests a coverage of 14 km² of shallow reef-related ecosystems. The majority of these reefs are comprised of inner reef flats (4 km²), reef slopes (4 km²), and sheltered reef slopes (4 km²). However, there are also significant outer reef flats present (3 km²), and other reef types (Figure 6.6.3).

Mangrove extent is low in Nailaga *qoliqoli* at approximately 1 ha, with a net loss of 1 ha between 1996 and 2016 (Figures 6.6.4; 6.6.5). This low mangrove cover reflects that mangroves exist as a narrow coastal fringe around the islands, rather than in extensive stands as elsewhere in the GSR. Seagrass covers approximately 28 ha within the *qoliqoli*, with much of this associated with the coastline around the islands (Figure 6.6.6).

Figure 6.6.1. Bathymetry of Nacula *qoliqoli*.

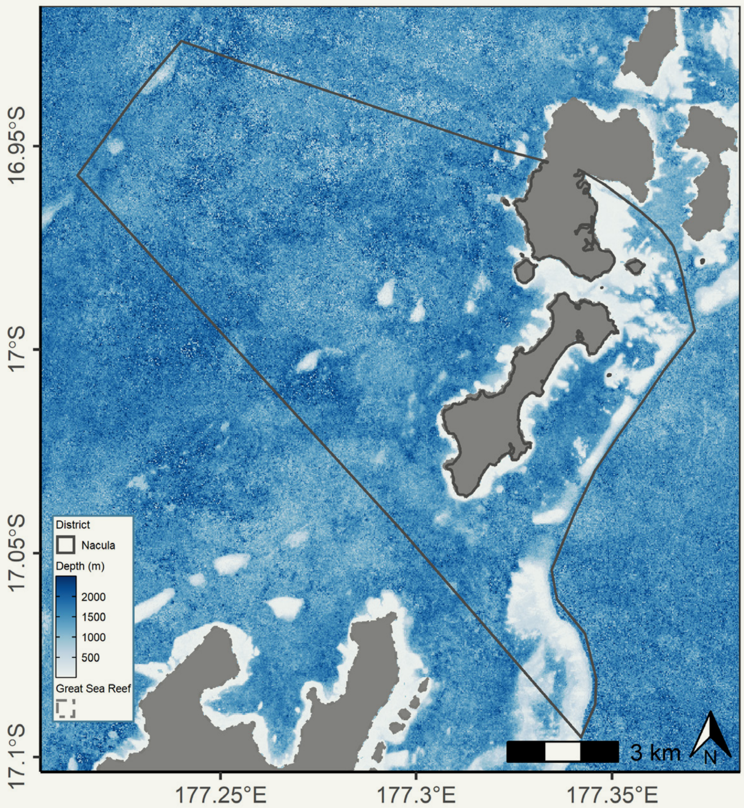


Figure 6.6.2. Coral reef extent in Nacula *qoliqoli*.

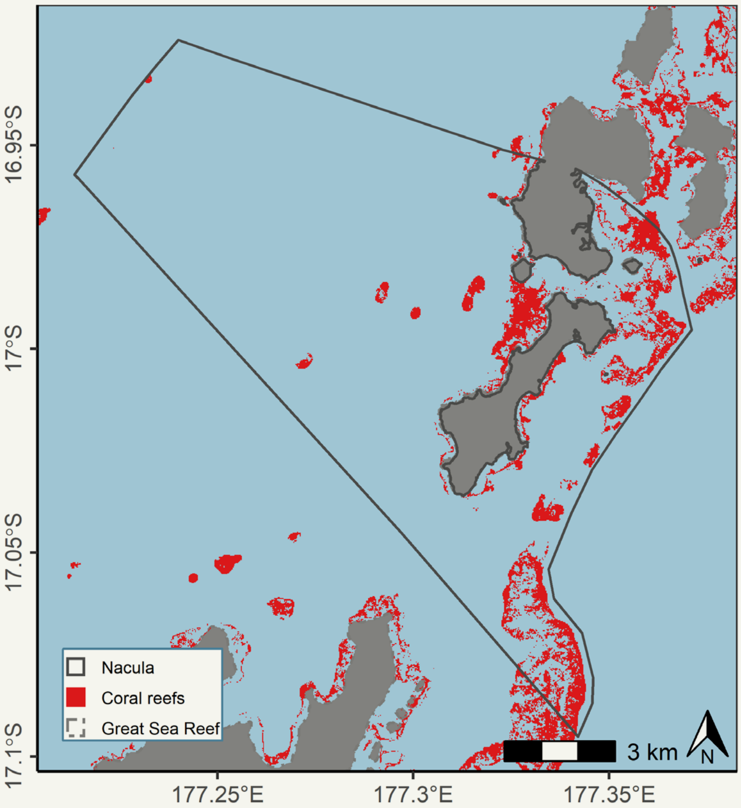


Figure 6.6.3. Coral reef geomorphic types in Nacula *qoliqoli*.

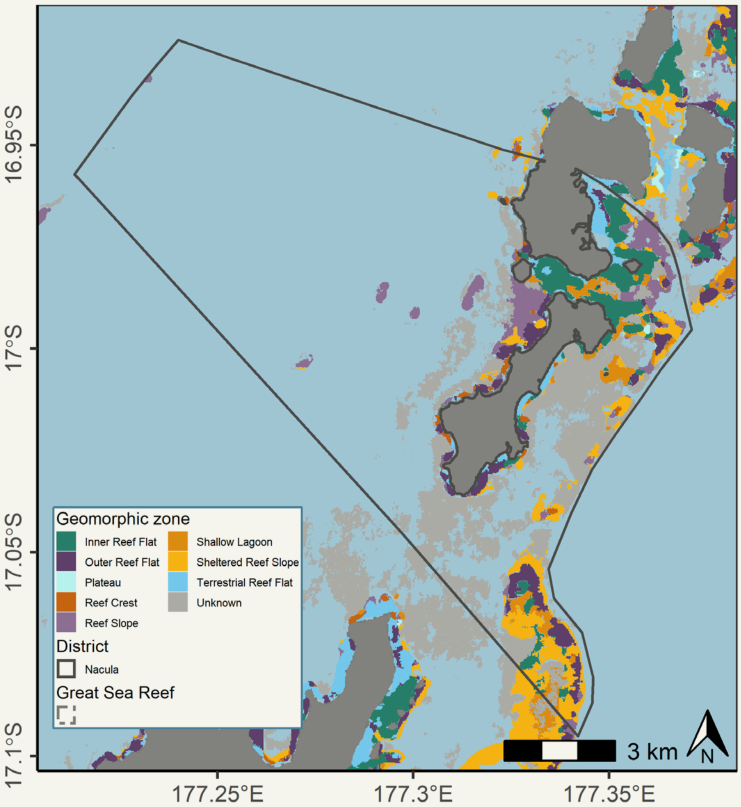


Figure 6.6.4. Mangrove extent in Nacula *qoliqoli*.

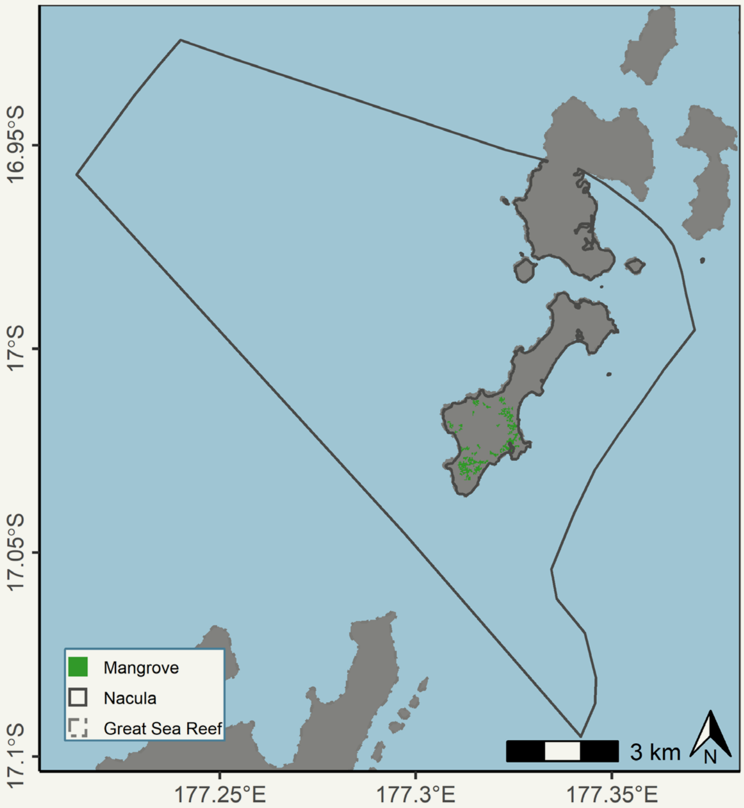


Figure 6.6.5. Mangrove change between 1996-2016 in Nacula *qoliqoli*.

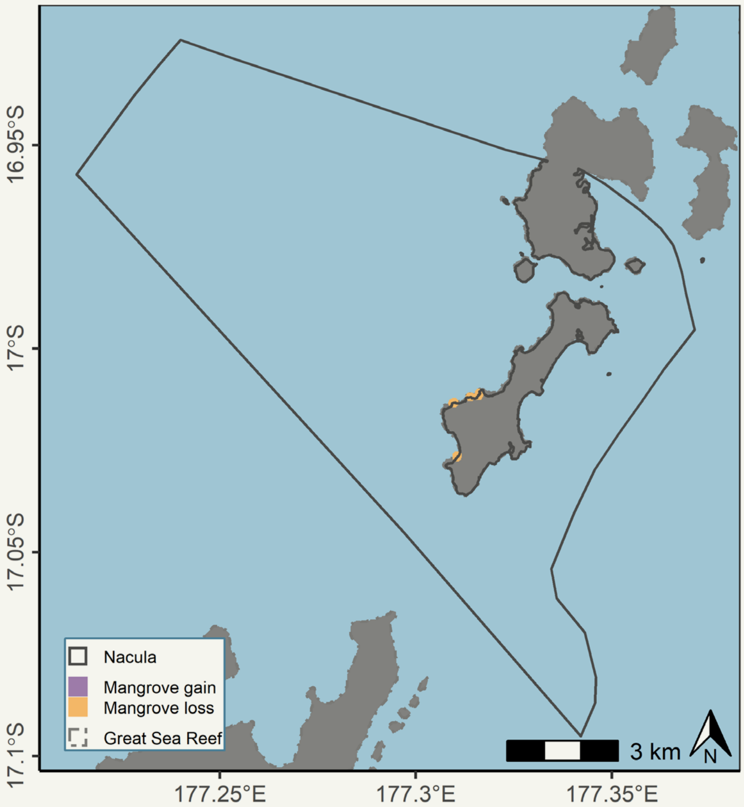
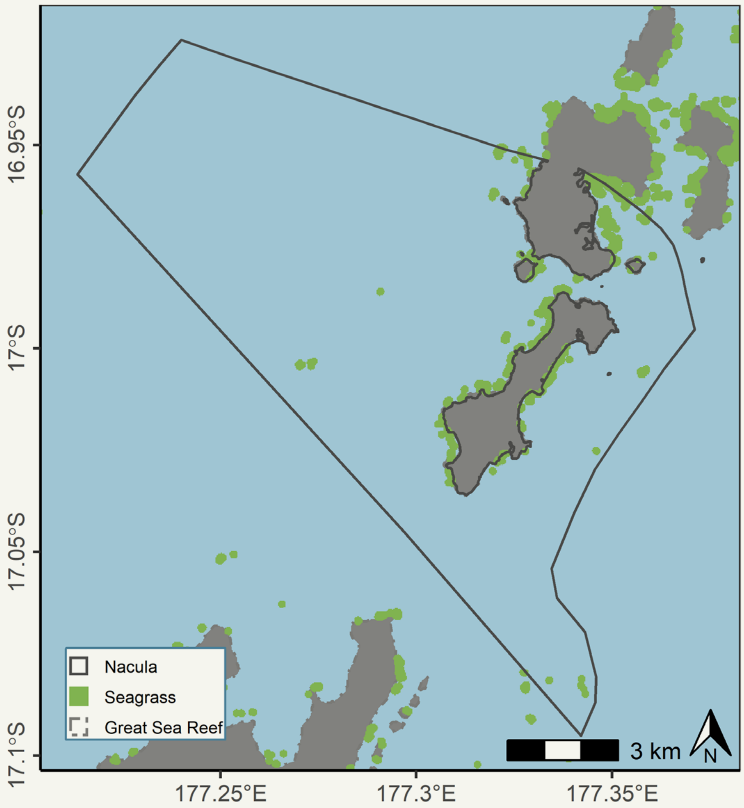


Figure 6.6.6. Seagrass cover in Nacula *qoliqoli*.



6.6.2 Survey sites

Surveys were completed at six sites within Nacula (Figure 6.6.7). Two of these sites were located on the coastal fringing reefs in the north of the *qoliqoli*, while four of the sites were located on the fringing reefs and barrier reef in the east. Historic benthic surveys and fish abundance data is available from Reef Check for the two sites in the north. Site YA01 was surveyed in 2003, while site YA02 was surveyed in 2006. No historic fish biomass data is available.

6.6.3 Benthic cover

Hard coral cover was 23 ± 4% across reefs in Nacula in 2019 (Figure 6.6.8). The second highest live benthic cover on reefs was macroalgae, at 10 ± 3%. Soft coral was higher than in many other GSR sites, at 8 ± 1%. There was substantial non-living benthic cover as well, with bare substrate covering 23 ± 4%, sand at 16 ± 4%, and rubble at 14 ± 6%.

Based on the two sites with historic benthic data, it was *exceptionally unlikely* (W=2, p>0.99) that hard coral cover had changed between historic surveys in 2003,2006, and 2019. It was *about as likely as not* (W=0, p=0.33) that algae cover has increased.

Figure 6.6.7. Survey sites in Nacula *qoliqoli*.

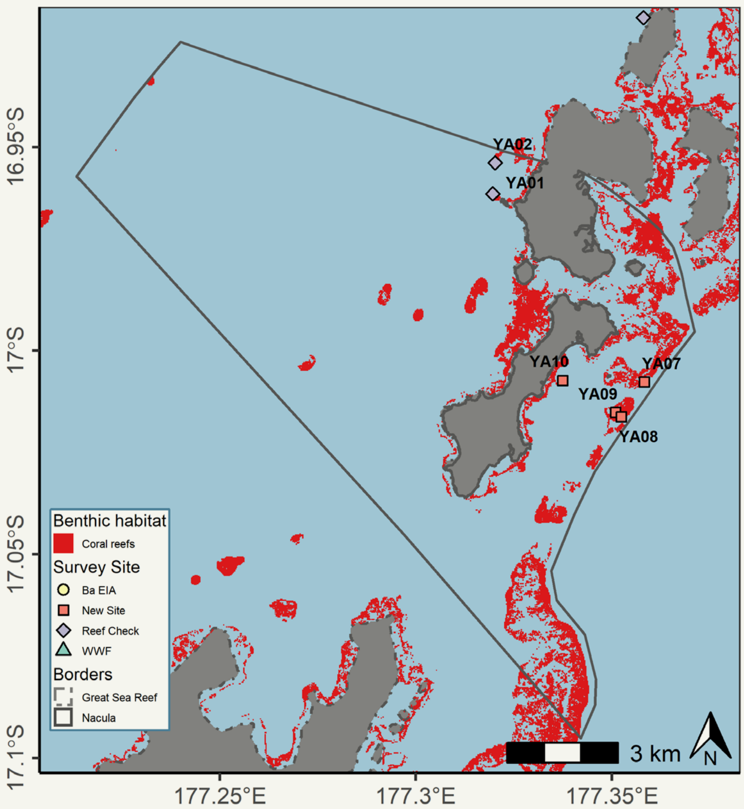


Figure 6.6.8. Benthic cover in 2019 for Nacula *qoliqoli*.

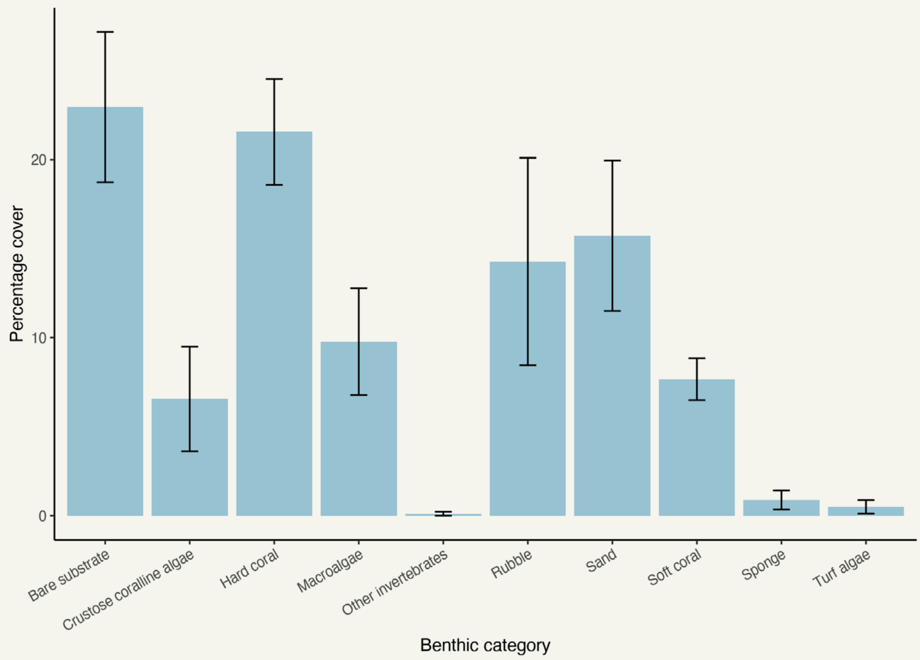
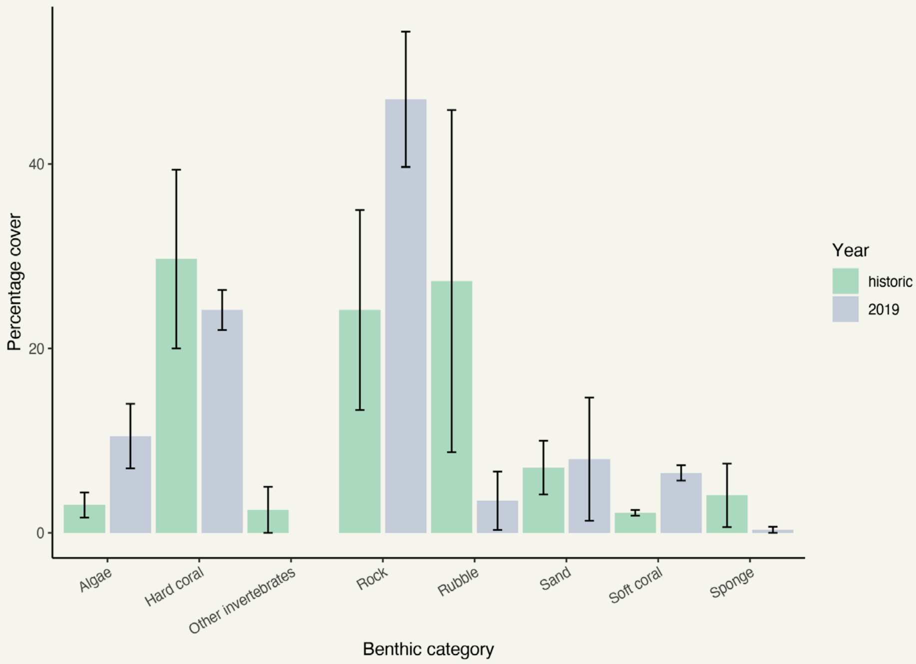


Figure 6.6.9. Change in benthic communities for two sites in Nacula *qoliqoli* with historic benthic data.



6.6.4 Fish communities

A mean fish abundance for the target family/species list of 2,259 ± 912 ind/ha was recorded across all Nacula sites, while mean fish biomass was 248 ± 172 kg/ha. Fish communities were dominated by herbivores by both abundance and biomass (Figure 6.6.10). The most abundant fish family was Acanthuridae (1,251 ± 758 ind/ha) followed by Scaridae (512 ± 174 ind/ha). Acanthuridae was also the largest fish family by biomass (132 ± 0.8 kg/ha), with Scaridae the second largest (86 ± 58 kg/ha). The greatest carnivorous family by both abundance and biomass was Lethrinidae (13 ± 8 ind/ha; 0.74 ± 0.47 kg/ha) – with carnivores having very low abundance and biomass compared to elsewhere in the GSR. It was *exceptionally unlikely* (V=2, p>0.99) that key fisheries family abundance changed for the two sites in Nacula *qoliqoli* with historic data available (Figure 6.2.11).

6.6.5 Rare Species

No humphead wrasse, bumphead parrtofish, or sharks were recorded within Nacula during 2019 surveys. Historic fish surveys at the two sites in Nacula observed humphead wrasse at 6.25 ± 6.25 ind/ha. Historic surveys did not record any bumphead parrotfish or sharks at these sites.

Serranidae abundance and biomass was 2.67 ± 2.67 ind/ha and 1.85 ± 1.85 kg/ha, respectively, across all surveyed Nacula sites in 2019. For the two sites with historic data, no Serranidae were recorded in past surveys, compared to an abundance of 6.67 ± 6.67 ind/ha we recorded in 2019 (Figure 6.6.12).

Figure 6.6.10. Fish community structure by (A) abundance and (B) biomass for Nacula *qoliqoli*.

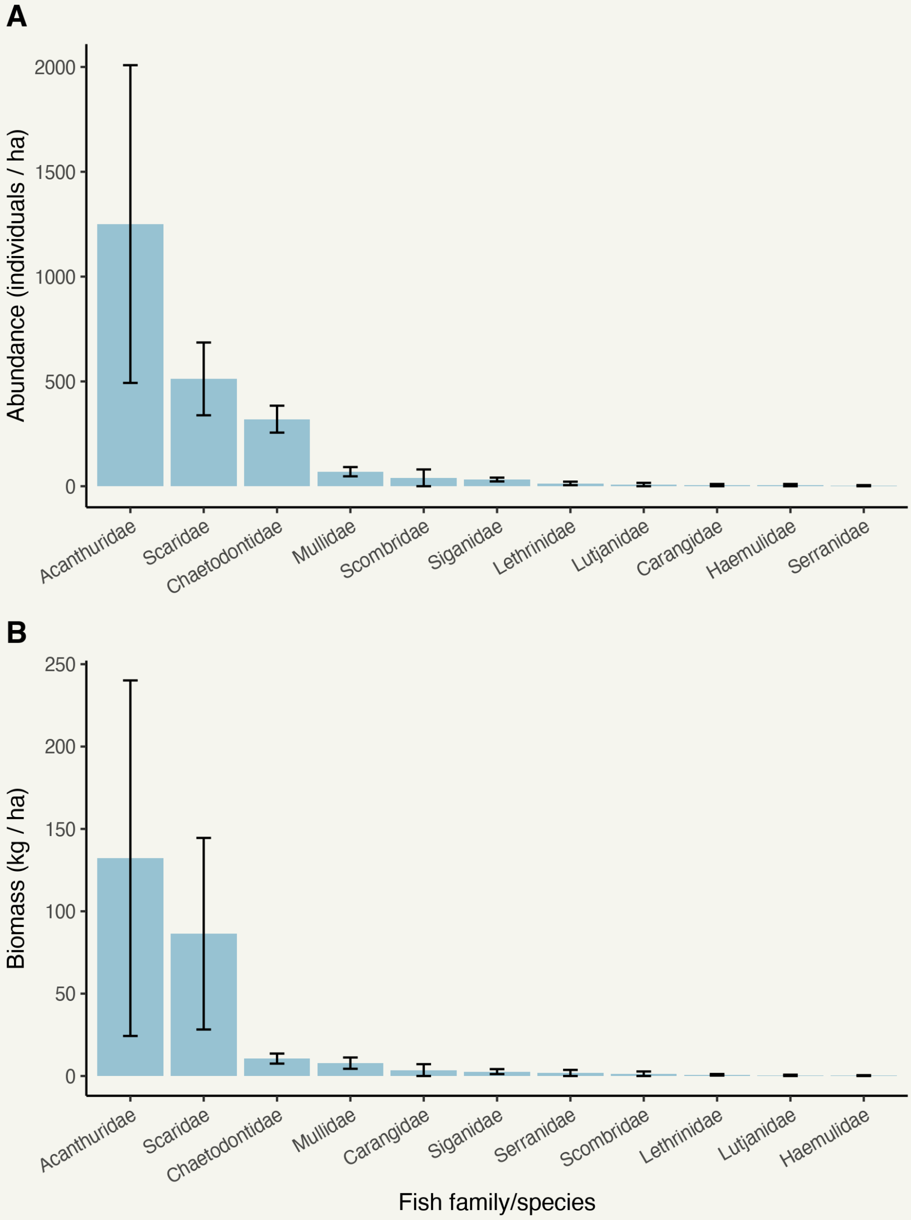
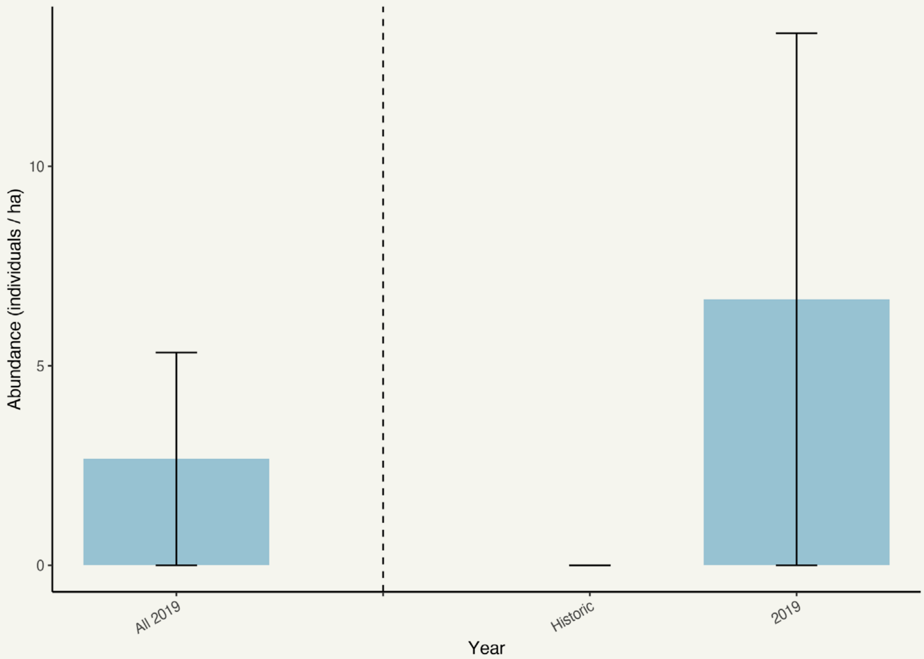


Figure 6.6.11. Change in key fisheries family abundance (Haemulidae, Lutjanidae, Scaridae, and Serranidae) for Nacula *qoliqoli* for two sites with historic data.

Figure 6.6.12. Serranidae (grouper) abundance for Nacula *qoliqoli*. Data on the left of the dashed line represents all sites surveyed in 2019, while data on the right of the dashed line only represents two sites with historic data.



6.7 Yasawa and Nacula

6.7.1 Introduction and critical habitat coverage

Yasawa and Nacula *qoliqoli* is located in the northern Yasawa Islands in Ba province off the north western coast of Viti Levu. The *qoliqoli* spans 3,459 km² (Figure 6.7.1), including deeper water areas and several narrow channels between the islands. Given the lack of major rivers on the Yasawa Islands, there are limited impacts of sedimentation from land use change, though coastal development has caused more localized pollution in some areas.

Yasawa and Nacula *qoliqoli* contains multiple coral reefs. There are extensive fringing shallow reefs around the Yasawa Islands, as well as a barrier reef running along the eastern edge of the islands. The *qoliqoli* also includes some offshore reefs at the far western edge and several patch reefs in the shallow seas to the east of the Yasawa Islands (Figure 6.7.2). In total, coral covers approximately 32 km² within the *qoliqoli*, though summing all Allen Coral Atlas benthic categories that likely contribute to broader coral reef ecosystem composition (i.e. coral/algae, microalgal mats, rock, and rubble) suggests a coverage of 51 km² of shallow reef-related ecosystems. The majority of these reefs are comprised of reef slopes (18 km²), outer reef flats (14 km²), and inner reef flats (10 km²). Though, there are other reef types present (Figure 6.7.3).

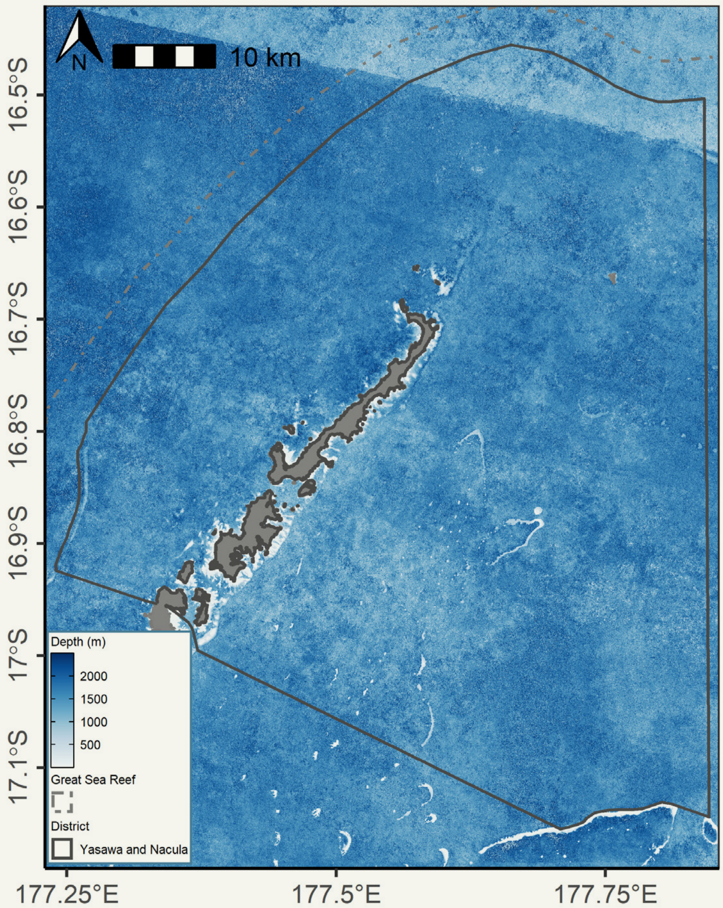


Figure 6.7.1. Bathymetry of Yasawa and Nacula *qoliqoli*.

Figure 6.7.2. Coral reef extent in Yasawa and Nacula *qoliqoli*.

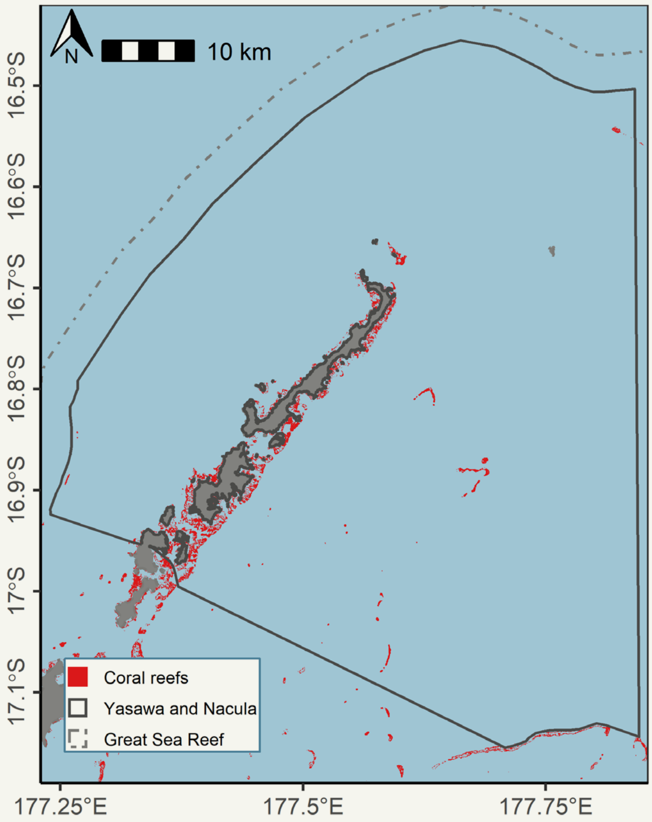
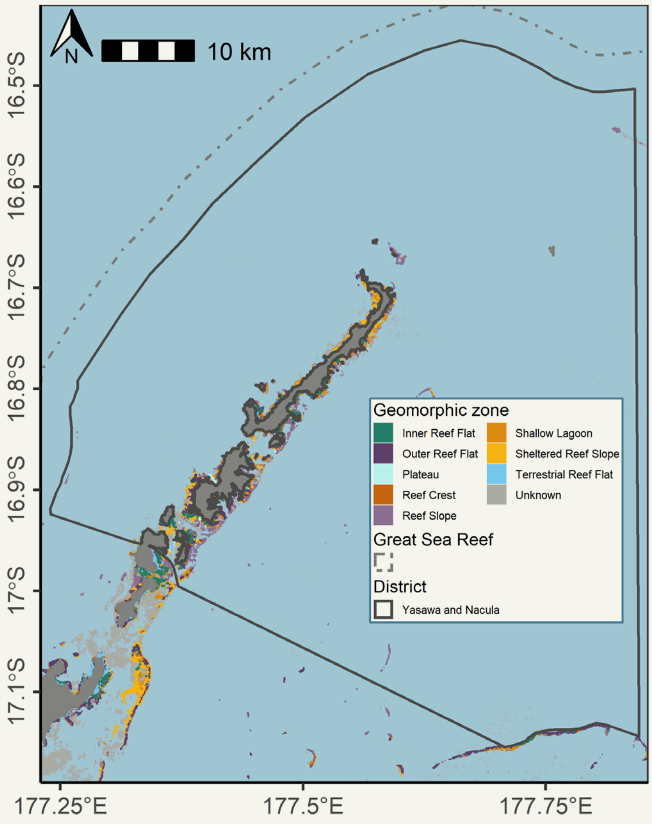


Figure 6.7.3. Coral reef geomorphic types in Yasawa and Nacula *qoliqoli*.

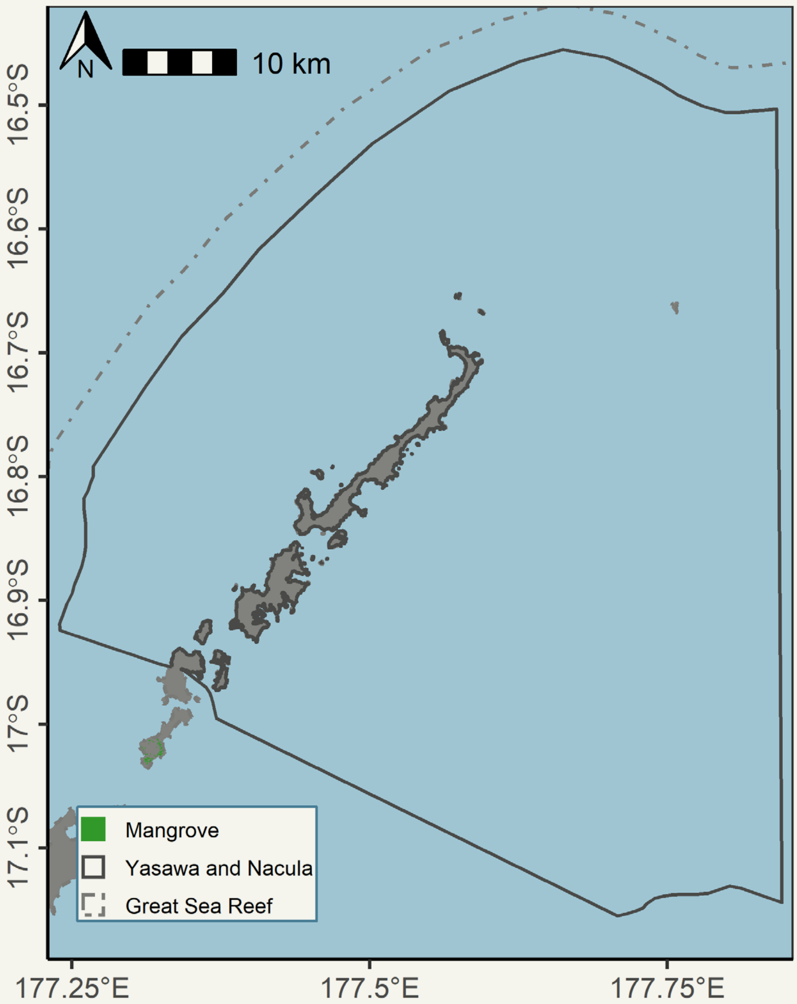


Mangrove extent is low in Yasawa and Nacula *qoliqoli*, with none recorded by remote sensing (Figures 6.7.4; 6.7.5). This reflects that mangroves exist as a narrow coastal fringe around the islands, making them hard to detect by satellites, instead of in extensive stands as elsewhere in the GSR. Despite having low mangrove coverage, the narrow band of mangroves around coastlines plays an important role for both biodiversity and ecosystem services. Seagrass covers approximately 83 ha within the *qoliqoli*, with much of this associated with the coastline around the islands (Figure 6.7.6).

6.7.2 Survey sites

Surveys were completed at four sites within Yasawa and Nacula (Figure 6.7.7). All four of these sites were located on the coastal fringing reefs along the west coast of the Yasawa Islands. Historic benthic surveys and fish abundance data is available from Reef Check for three of the sites. Site YA03 was surveyed in 2003, while sites YA05 and YA05 were surveyed in 2006. No historic fish biomass data is available.

Figure 6.7.4. Mangrove extent in Yasawa and Nacula *qoliqoli*.



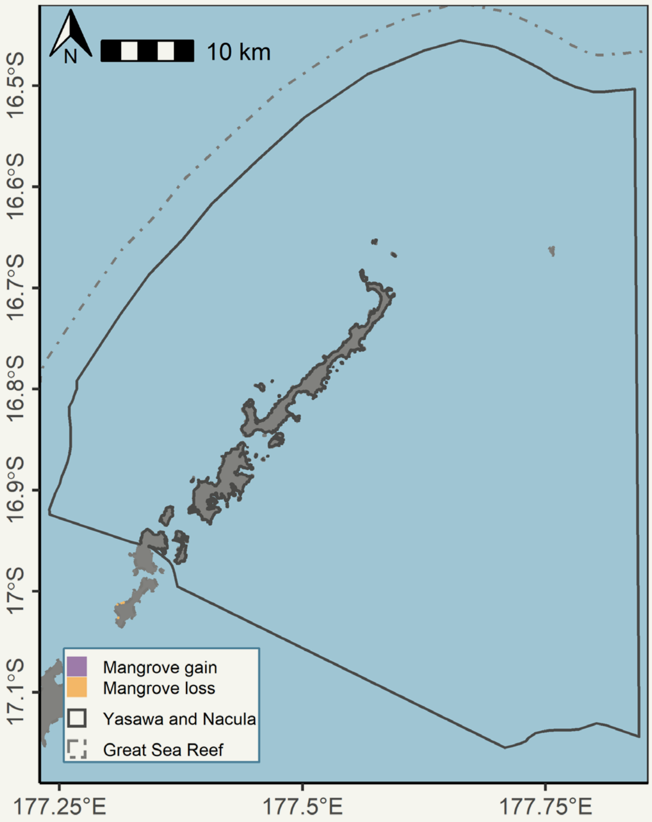


Figure 6.7.5. Mangrove change between 1996-2016 in Yasawa and Nacula *qoliqoli*.

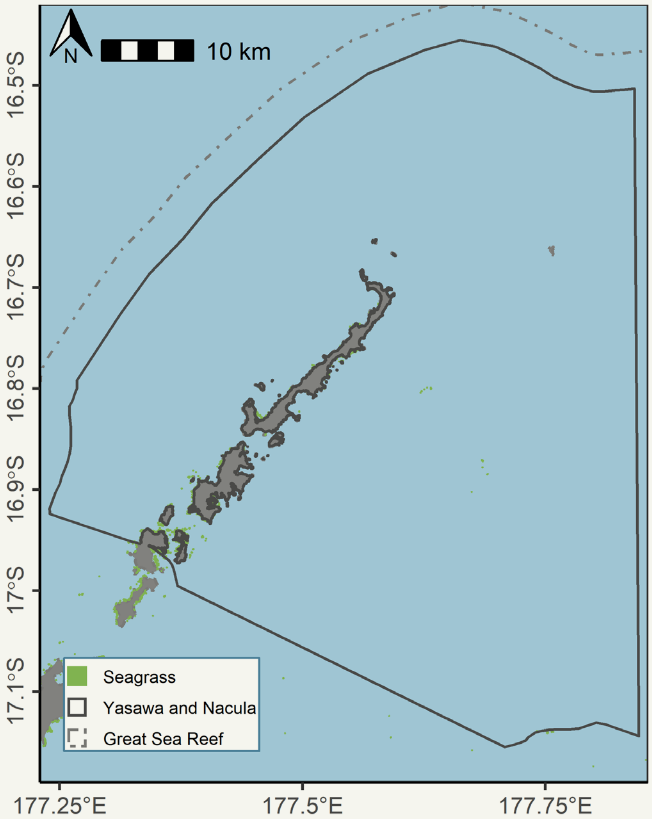
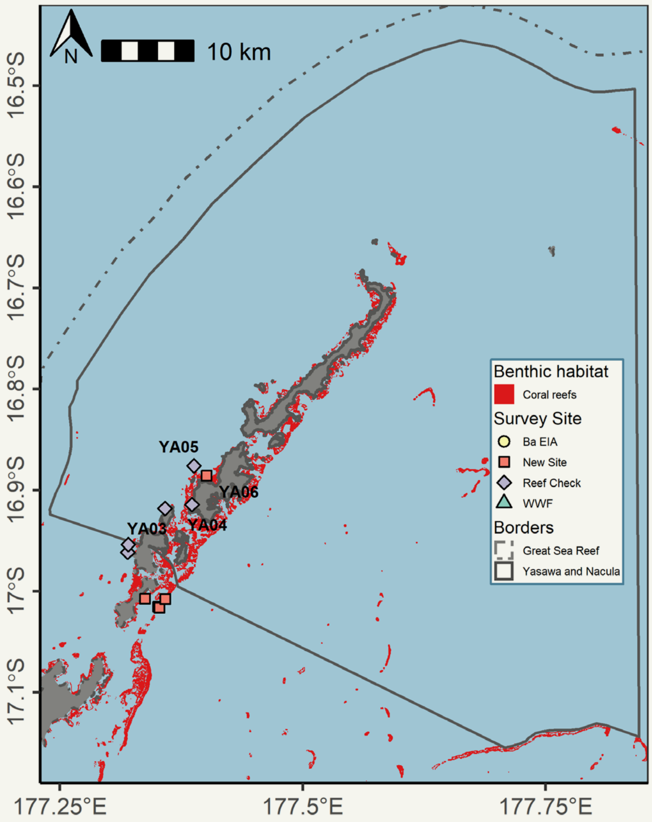


Figure 6.7.6. Seagrass cover in Yasawa and Nacula *qoliqoli*.

Figure 6.7.7. Survey sites in Yasawa and Nacula *qoliqoli*.



6.7.3 Benthic cover

Hard coral cover was 26 ± 5% across reefs in Yasawa and Nacula in 2019 (Figure 6.7.8). The second highest live benthic cover on reefs was soft coral, at 16 ± 4%. Macroalgae was higher than at many other GSR sites, at 13 ± 4%. There was also substantial non-living benthic cover compared to other sites, with bare substrate covering 7 ± 1%, sand at 19 ± 2%, and rubble at 12 ± 3%.

Based on the two sites with historic benthic data (Figure 6.7.9), it was *unlikely* (W=6, p=0.70) that hard coral cover had changed between historic surveys in 2003, 2006, and 2019. It was also *unlikely* (W=6, p=0.70) that algae cover has changed. However, it was *likely* (W=1, p=0.20) that soft coral cover increased, from 6 ± 3% to 14 ± 5%. It was also *likely* (W=8, p=0.18) that sponge cover declined, from 2.1 ± 0.8% to 0.3 ± 0.3%.

6.7.4 Fish communities

A mean fish abundance for the target family/species list of 3,691 ± 458 ind/ha was recorded across all Yasawa and Nacula sites, while mean fish biomass was 296 ± 56 kg/ha. Fish communities were dominated by herbivores by both abundance and biomass (Figure 6.7.10). The most abundant fish family was Acanthuridae (1,543 ± 181 ind/ha) followed by Scaridae (960 ± 191 ind/ha). Scaridae was the largest fish family by biomass (106 ± 24 kg/ha), with Acanthuridae the second largest (103 ± 34 kg/ha). The greatest carnivorous family by both abundance and biomass was Lutjanidae (157 ± 96 ind/ha; 12 ± 8 kg/ha) – with carnivores having low abundance and biomass compared to elsewhere in the GSR. It was *likely* (V=0, p=0.25) that key fisheries family abundance increased for the three sites in Yasawa and Nacula *qoliqoli*, with historic data available (Figure 6.7.11). Historic surveys recorded key fisheries family abundance at 225 ± 101 ind/ha, while we recorded 906 ± 142 ind/ha in 2019.

Figure 6.7.8. Benthic cover in 2019 for Yasawa and Nacula *qoliqoli*.

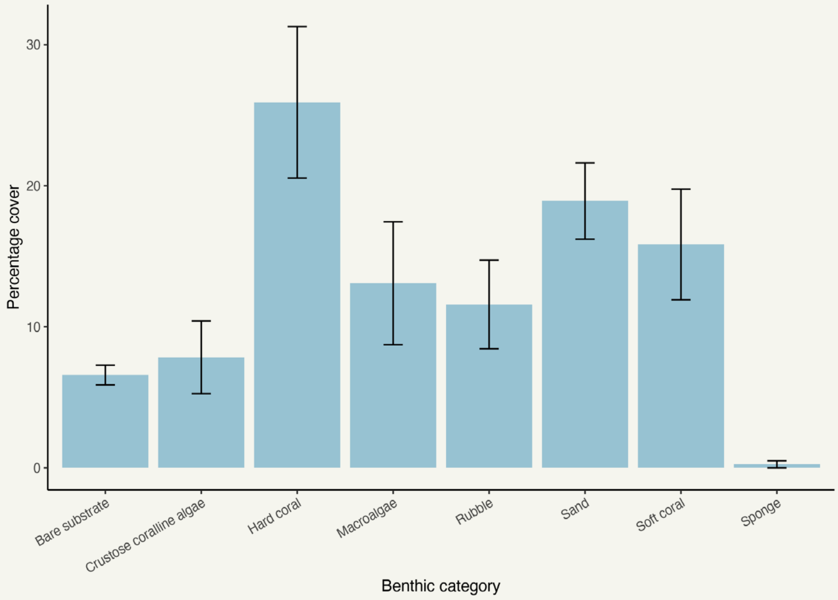


Figure 6.7.9. Change in benthic communities for three sites in Yasawa and Nacula *qoliqoli* with historic benthic data.

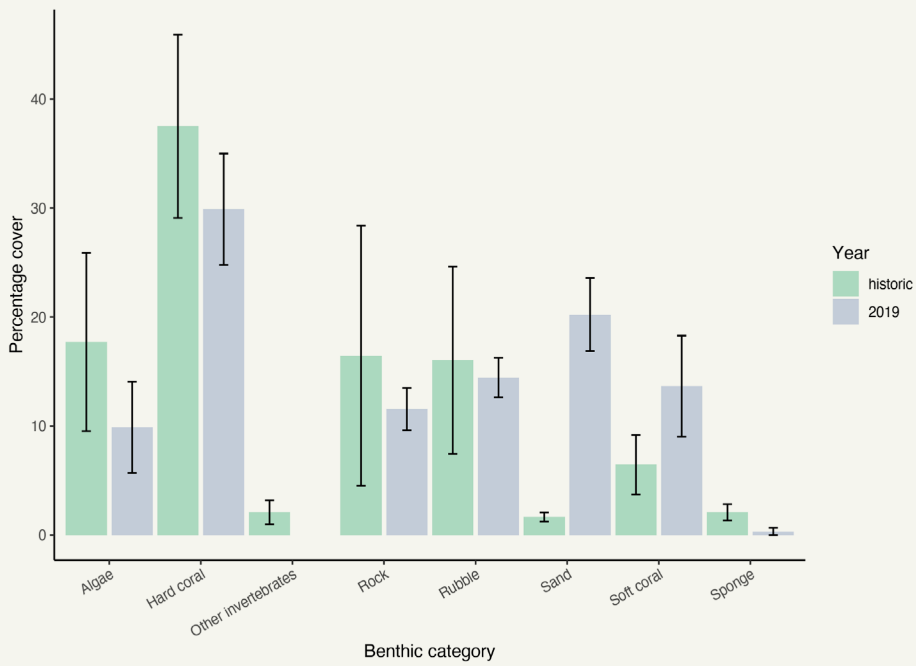


Figure 6.7.10. Fish community structure by (A) abundance and (B) biomass for Yasawa and Nacula *qoliqoli*.

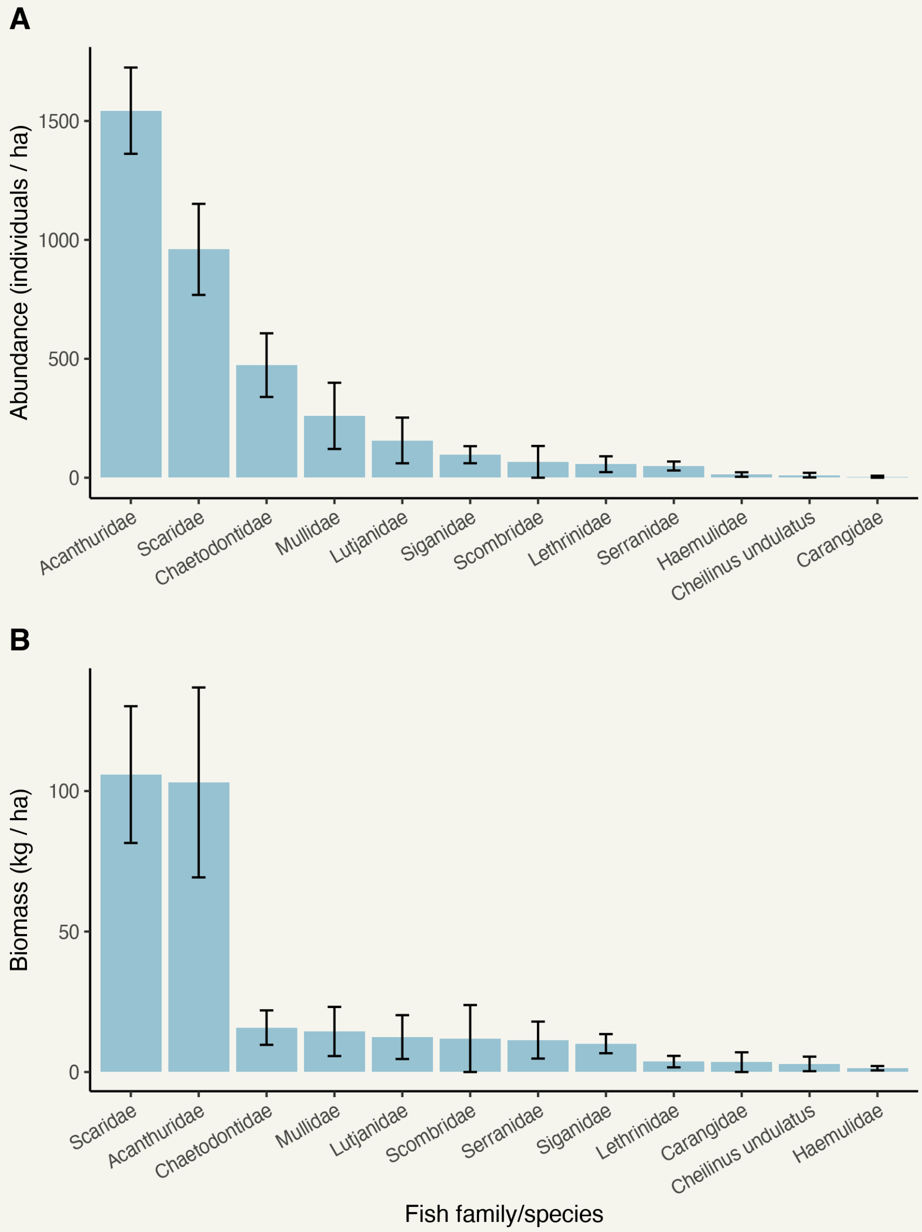
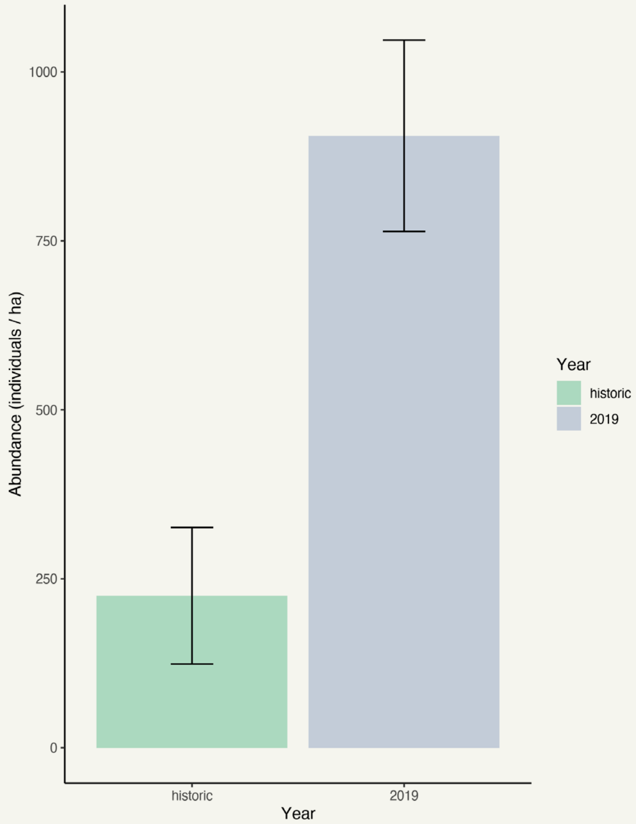


Figure 6.7.11. Change in key fisheries family abundance (Haemulidae, Lutjanidae, Scaridae, and Serranidae) for Yasawa and Nacula *qoliqoli* for three sites with historic data.



6.7.5 Rare Species

Humphead wrasse abundance and biomass were recorded at 10.83 ± 9.75 ind/ha and 2.88 ± 2.59 kg/ha, respectively, across all surveyed Yasawa and Nacula sites in 2019. For the three sites with historic data, no humphead wrasse were recorded in past surveys, compared to an abundance of 1.11 ± 1.11 ind/ha we recorded in 2019 (Figure 6.7.12).

No bumphead parrtofish or sharks were recorded within Yasawa and Nacula during 2019 surveys. Historic surveys at the three sites did not record any bumphead parrotfish or sharks either.

Serranidae abundance and biomass was 49 ± 19 ind/ha and 11 ± 7 kg/ha, respectively, across all surveyed Yasawa and Nacula sites in 2019. For the three sites with historic data, it was *about as likely as not* (V=1, p=0.50) that Serranidae abundance increased. Historic surveys at the three sites recorded Serranidae at 4 ± 4 ind/ha compared to 2019 where we recorded 52 ± 26 ind/ha (Figure 6.7.13).

Figure 6.7.12. Humphead wrasse (*Cheilinus undulatus*) abundance for Yasawa and Nacula *qoliqoli*. Data on the left of the dashed line represents all sites surveyed in 2019 in Yasawa and Nacula *qoliqoli*, while data on the right of the dashed line only represents the three sites with historic data.

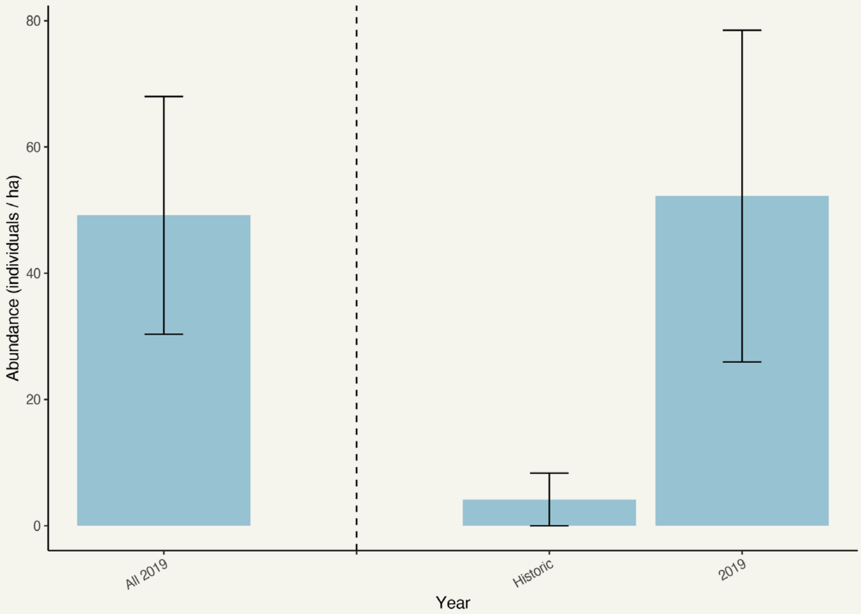
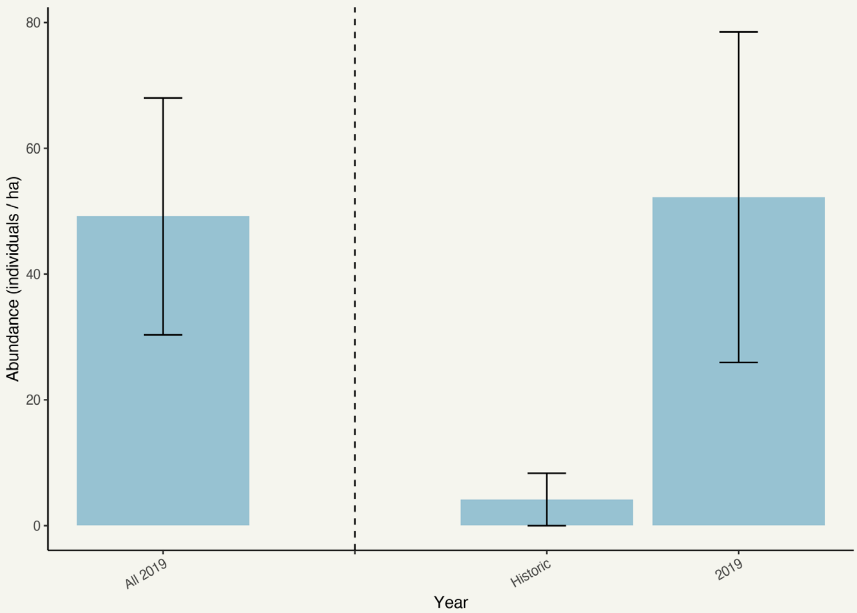
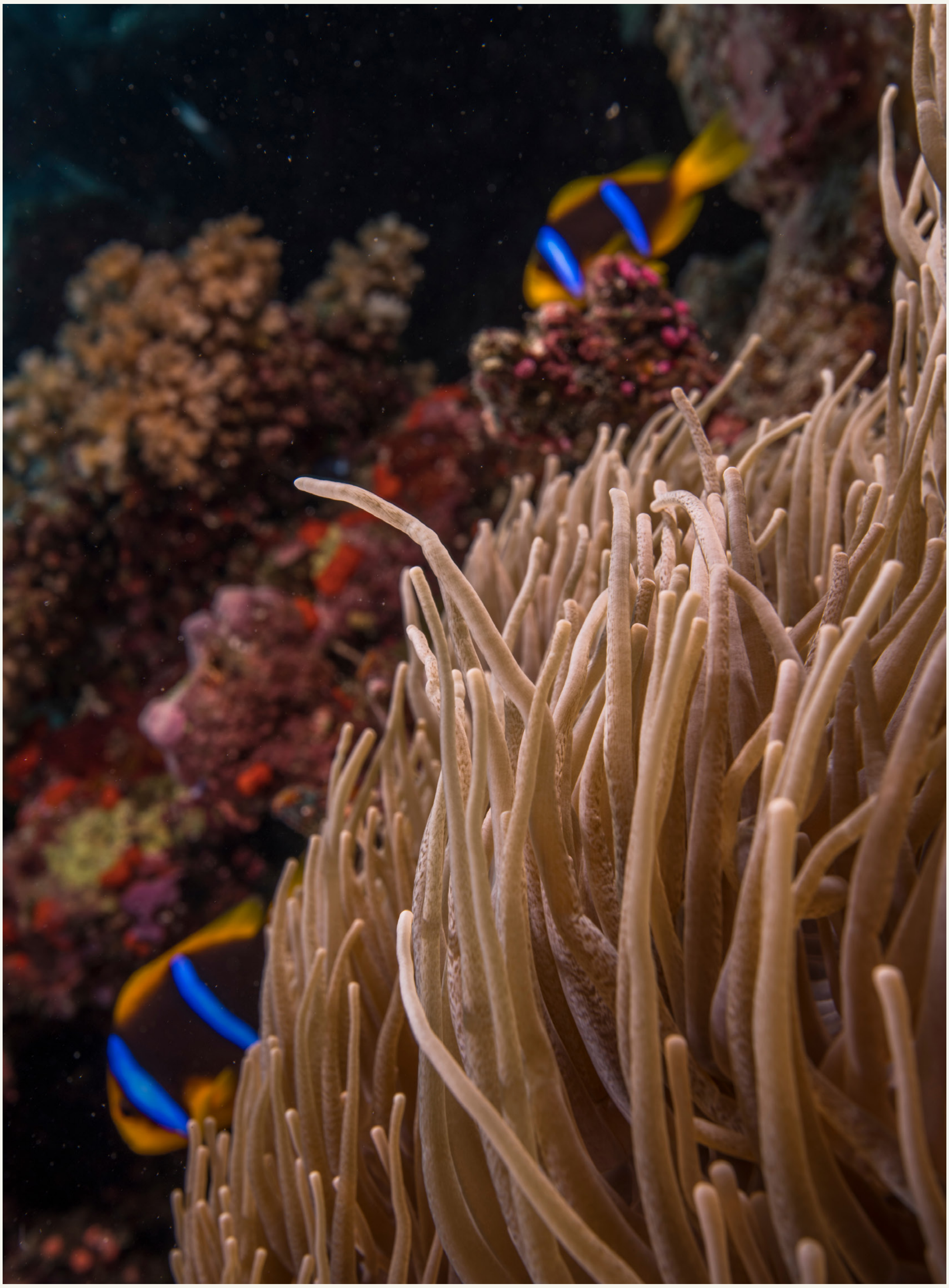


Figure 6.7.13. Serranidae (grouper) abundance for Yasawa and Nacula *qoliqoli*. Data on the left of the dashed line represents all sites surveyed in 2019, while data on the right of the dashed line only represents the three sites with historic data.





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Close-up of an anemone with two anemonefish in the background. Photographed on the coral reefs north of Kia Island, Fiji.

7 BUA

7.1 Bua province

7.1.1 Introduction and critical habitat coverage

Bua province lies at the western end of Vanua Levu. It has a land area of approximately 1,380 km^2 and a population of approximately 15,500 people – making it one of the least populous provinces in the GSR region and in Fiji. The waters of Bua are divided into eight *qoliqoli*, and span 6,191 km^2 (Figure 7.1.1). The province is bounded to the north by the main Cakaulevu barrier reef, which drops off into deep ocean to the north. Within this large area enclosed by the barrier reef there are many small patch reefs rising up from the seabed. Nearer to the Vanua Levu coastline are many mangrove-fringed reef islands. These islands enclose lagoons that are accessible by boats at high tide, and local communities fish within. Several major rivers flow into Bua coastal waters, including the Lekutu River, which carry substantial sediment to coastal inner reefs, increasing the turbidity (Figure 7.2.2).

Reefs take multiple forms within Bua province, with shallow fringing reefs along the coastline of Vanua Levu and Yadua Island, and extensive fringing reefs and reef flats around coastal mangrove islands. Part of the main Cakaulevu barrier reef, as well as several small reefs contained within Cakaulevu are also present (Figure 7.1.3). In total, coral covers approximately 177 km^2 within Bua province, though summing all Allen Coral Atlas benthic categories that likely contribute to broader coral reef ecosystem composition (i.e. coral/algae, microalgal mats, rock, and rubble) suggests a coverage of 312 km^2 of shallow reef-related ecosystems. The majority of these reefs are comprised of inner reef flats (90 km^2), closely followed by outer reef flats (86 km^2) and terrestrial reef flats (72 km^2), with many other reef types also present (Figure 7.1.4).

Mangrove extent is high and stable in Bua province at 79 km^2, with no change between 1996 and 2016 (Figures 7.1.5; 7.1.6). This high mangrove cover reflects the extensive coastline with rivers providing sediment input for mangroves. The shallow coastal waters with many small islands also provides suitable substrate for extensive mangrove forests to form. Seagrass covers approximately 46 km^2 within Bua province, with much of this split in the coastal areas of Vanua Levu and the small islands adjacent to the shoreline (Figure 7.1.7). However, some narrow bands of seagrass are found associated with the Cakaulevu offshore reef.

7.1.2 Survey sites

Surveys were completed at 17 sites within Bua province (Figure 7.1.8). Four of these sites were located in the Vanua Levu coastal area – sites associated with the reefs of three of the coastal island reefs and a small ribbon reef adjacent to the islands. Seven were on the Cakaulevu offshore barrier reef, with six at the western end and one at the eastern end of Bua province. The remaining six sites were located around Yadua Island off the western tip of Vanua Levu. Two sites were surveyed by the WWF 2004 GSR survey (CH1, IB1) and six sites (Yadua Island) were surveyed by Reef Check in 2001 and 2003, and so have historic benthic and fish data available (Figure 7.1.8).

Figure 7.1.1. Bathymetry of Bua province.

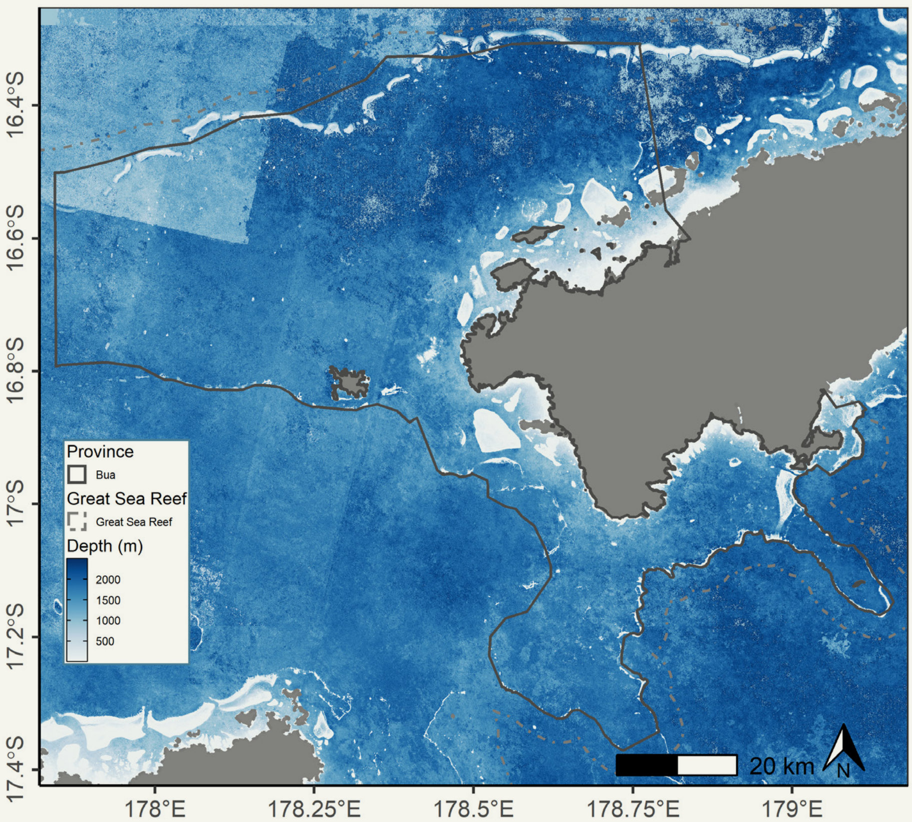


Figure 7.1.2. Sedimentation rates inside and adjacent to Bua province.

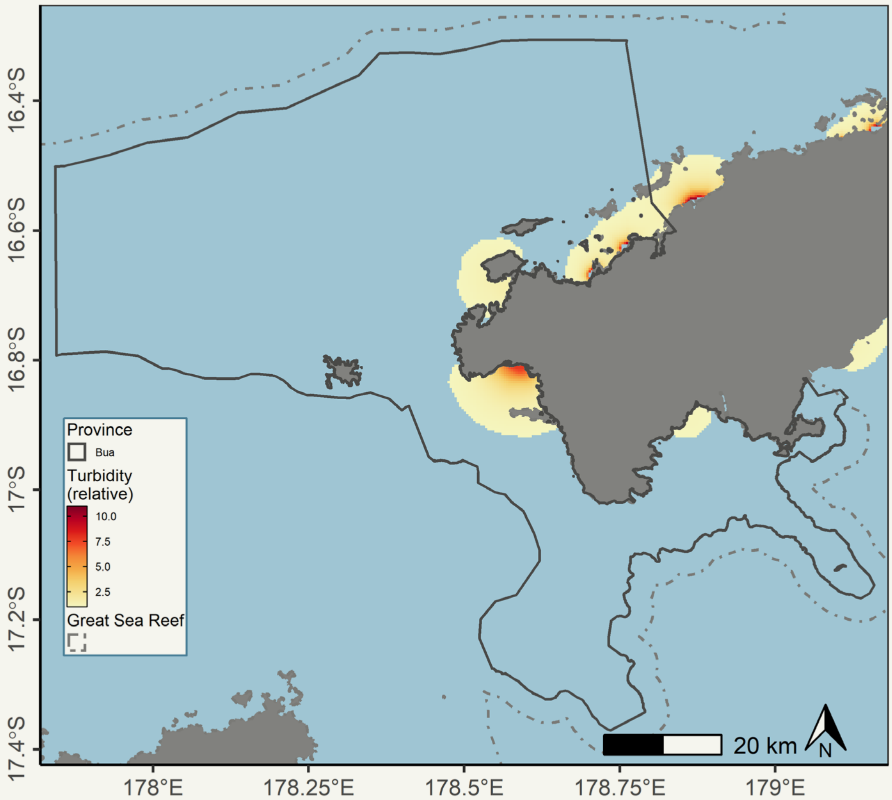


Figure 7.1.3. Coral reef extent in Bua province.

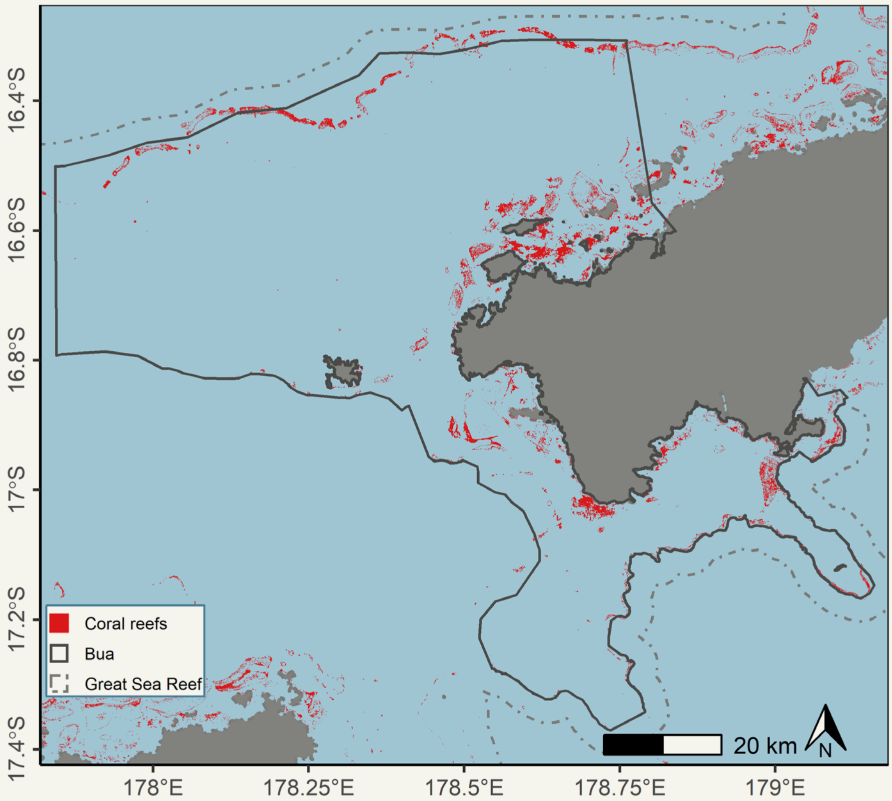


Figure 7.1.4. Coral reef geomorphic types in Bua province.

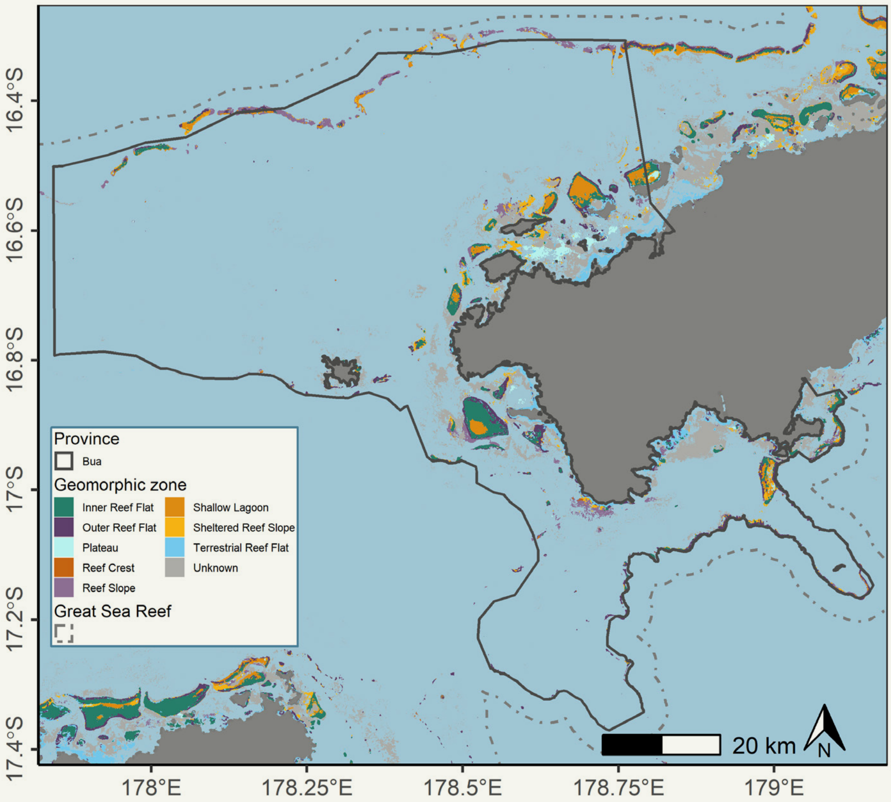
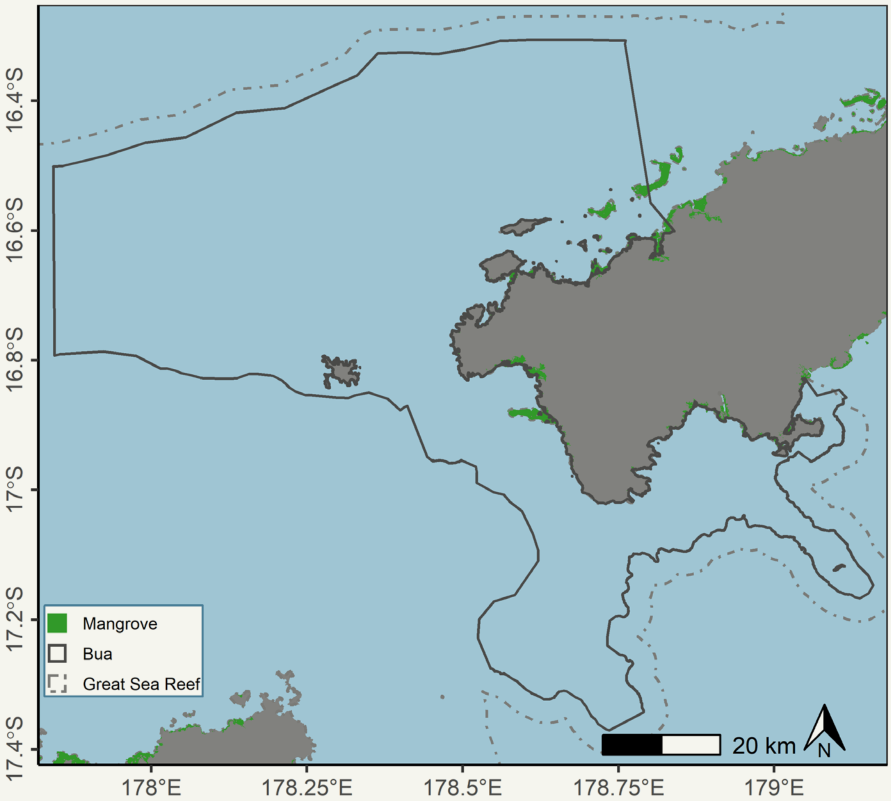


Figure 7.1.5. Mangrove extent in Bua province.



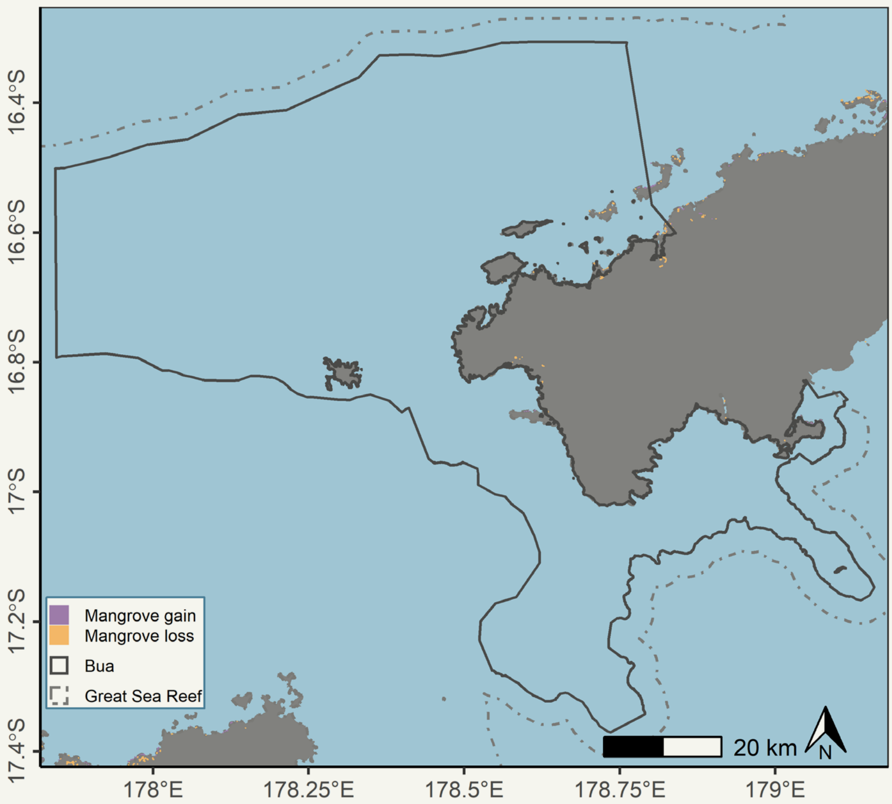


Figure 7.1.6. Mangrove change between 1996-2016 in Bua province.

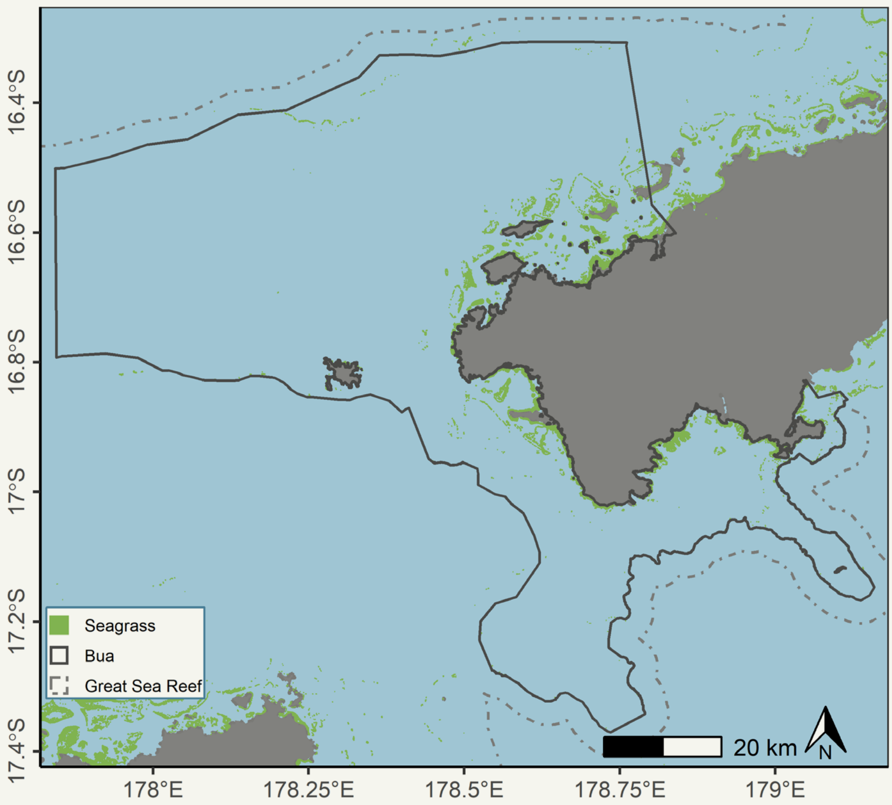


Figure 7.1.7. Seagrass cover in Bua province.

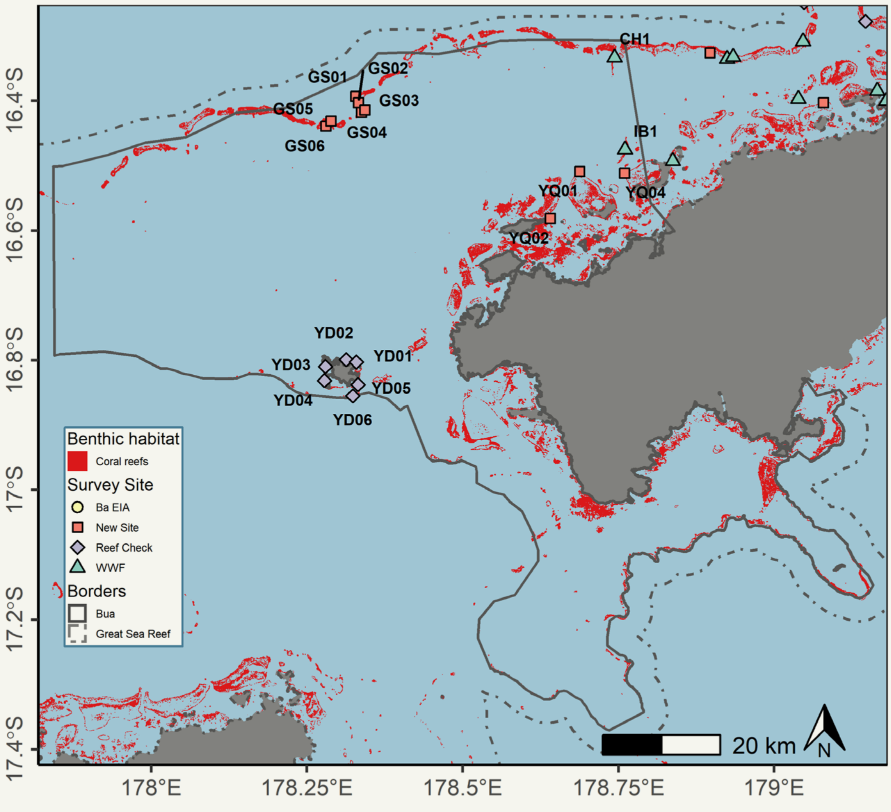


Figure 7.1.8. Survey sites in Bua province.

7.1.3 Benthic cover

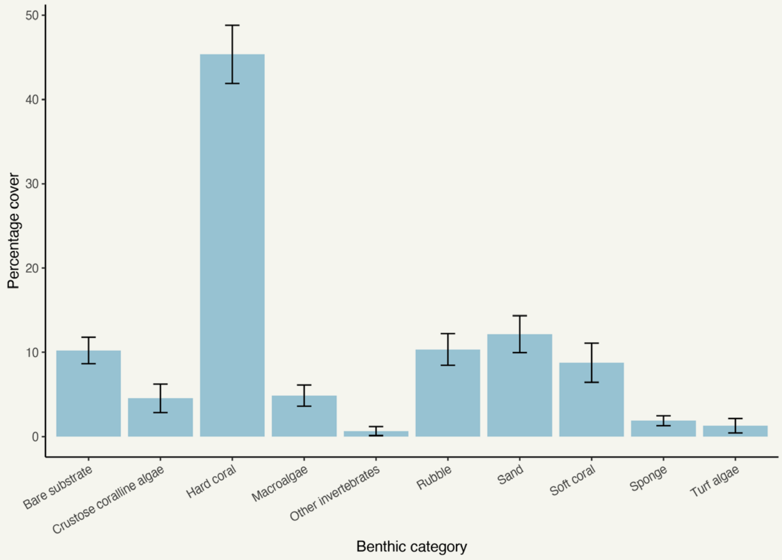
Hard coral cover was 45 ± 3% across reefs in Bua province in 2019 (Figure 7.1.9). This is high coral cover, suggesting the benthic cover on these reefs is currently generally healthy. The second highest live benthic cover on reefs was soft coral, at 9 ± 2%. Non-living benthic cover was high in the province, with sand at 12 ± 2%, rubble at 10 ± 2%, and bare substrate at 10 ± 2% cover.

Sites surveyed in Bua province split into three subgroups based on reef type and geographic location – (i) inner reefs along the coastline, (ii) the offshore barrier reef, and (iii) Yadua Island. The greatest hard coral cover was found on the offshore barrier reef at 48 ± 7%, though hard coral cover was above 40% at all three subgroups (Figure 7.1.10). Macroalgae cover was similar between the offshore barrier reef (7 ± 2%) and the inner reefs of Vanua Levu (6 ± 3%), while Yadua had low macroalgae cover (2 ± 1%; Figure 7.1.10).

Historic survey data for Bua province was based on eight sites, one inner reef site on Vanua Levu, one outer barrier reef site, and six sites around Yadua Island. Based on these sites, it was *extremely likely* (W=13, p=0.05) that hard coral cover increased, from 27 ± 5% in baseline surveys in 2001, 2003, and 2004 to 41 ± 4% in 2019 (Figure 7.1.11). It was very likely (W=15, p=0.08) that algae cover increased, from 2 ± 1% to 5 ± 2%. There was also changes in non-living benthic cover. For example, it was *virtually certain* (W=62, p<0.01) that bare rock declined from 30 ± 5% in historic surveys to 14 ± 2%. There have been limited changes in other benthic groups (Figure 7.1.11). Breaking apart the data between the different subgroups for the barrier reef, the Vanua Levu inner reef, and Yadua Island suggests that coral cover increased across all parts of the province (Figure 7.1.12). However, results show that the greatest gain in macroalgae cover was on the inner reef site adjacent to Vanua Levu, where macroalgae increased from none recorded in 2004 to 12% in 2019.

Figure 7.1.9 (left). Benthic cover in 2019 for Bua province.

Figure 7.1.10 (right). (A) Hard coral cover and (B) macroalgae cover by subgroup for sites within Bua province.



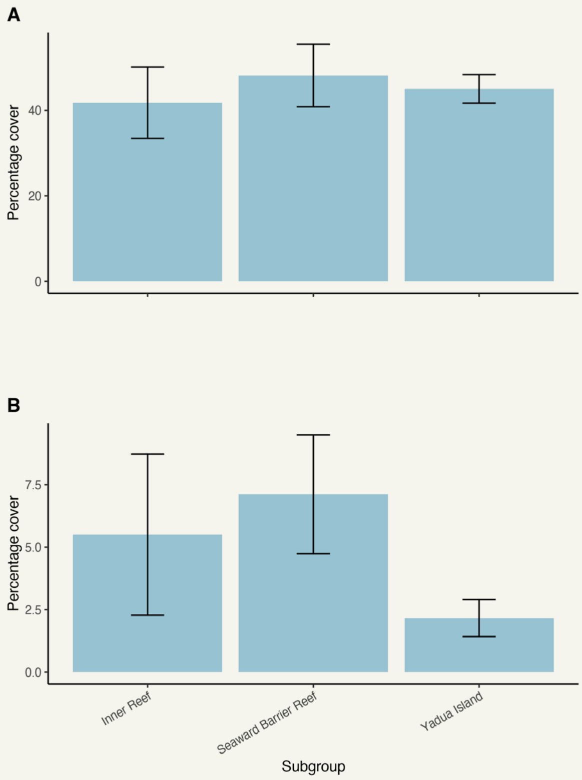


Figure 7.1.11. Change in benthic communities for Bua province.

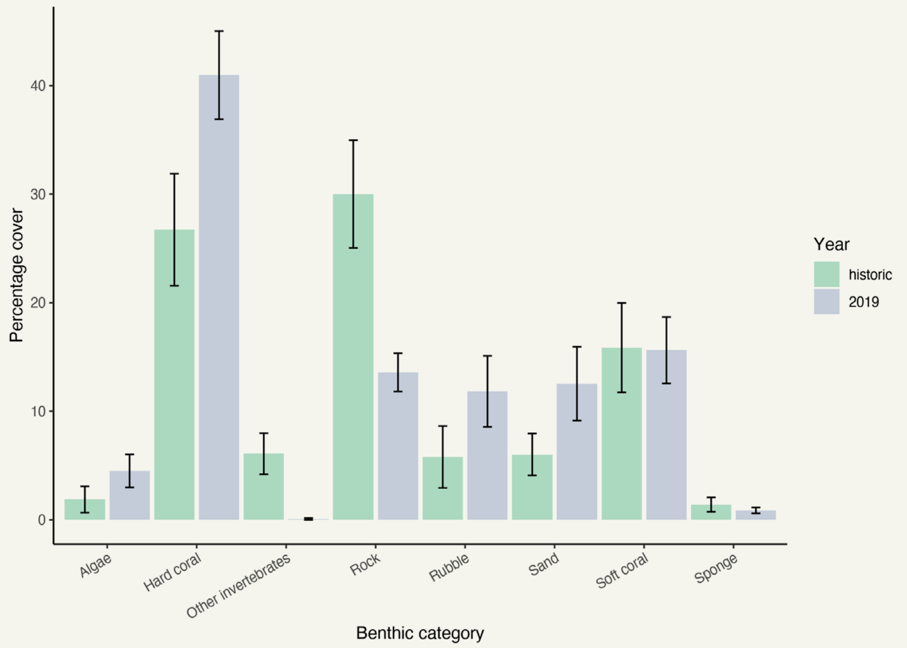
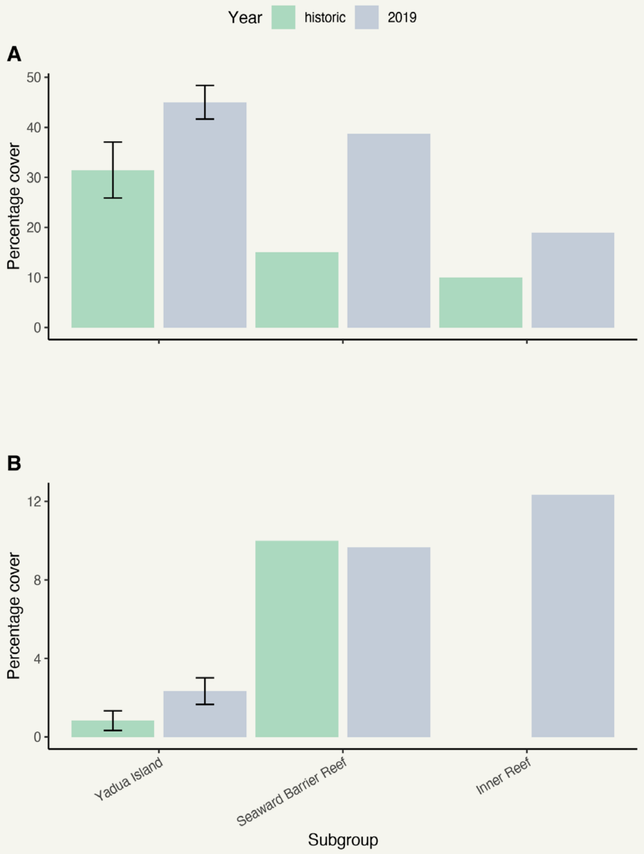


Figure 7.1.12. Change in (A) hard coral and (B) algae cover for sites with historic data in Bua province. Note data for the seaward barrier reef and inner reef each are represented by one site, and no algae was recorded on the inner reef site in historic surveys.



7.1.4 Fish communities

A mean fish abundance for the target family/species list of 3,155 ± 340 ind/ha was recorded across all Bua province sites, while mean fish biomass was 434 ± 71 kg/ha. Fish communities were dominated by herbivores by abundance, but with a more even split between herbivores and carnivores by biomass (Figure 7.1.13). The most abundant fish family was Acanthuridae (1039 ± 179 ind/ha) followed by Scaridae (850 ± 129 ind/ha). Scaridae was the largest fish family by biomass (122 ± 15 kg/ha), with Acanthuridae the third largest (58 ± 10 kg/ha). Carnivores made up a substantial proportion of the fish community by biomass, with Lutjanidae the second largest group (112 ± 40 kg/ha) and Carcharhinidae the fourth largest group (50 ± 28 kg/ha). The outer barrier reef had greater mean fish abundance and biomass than the inner reef sites and Yadua Island (Figure 7.1.14).

Figure 7.1.13. Fish community structure by (A) abundance and (B) biomass for Bua province.

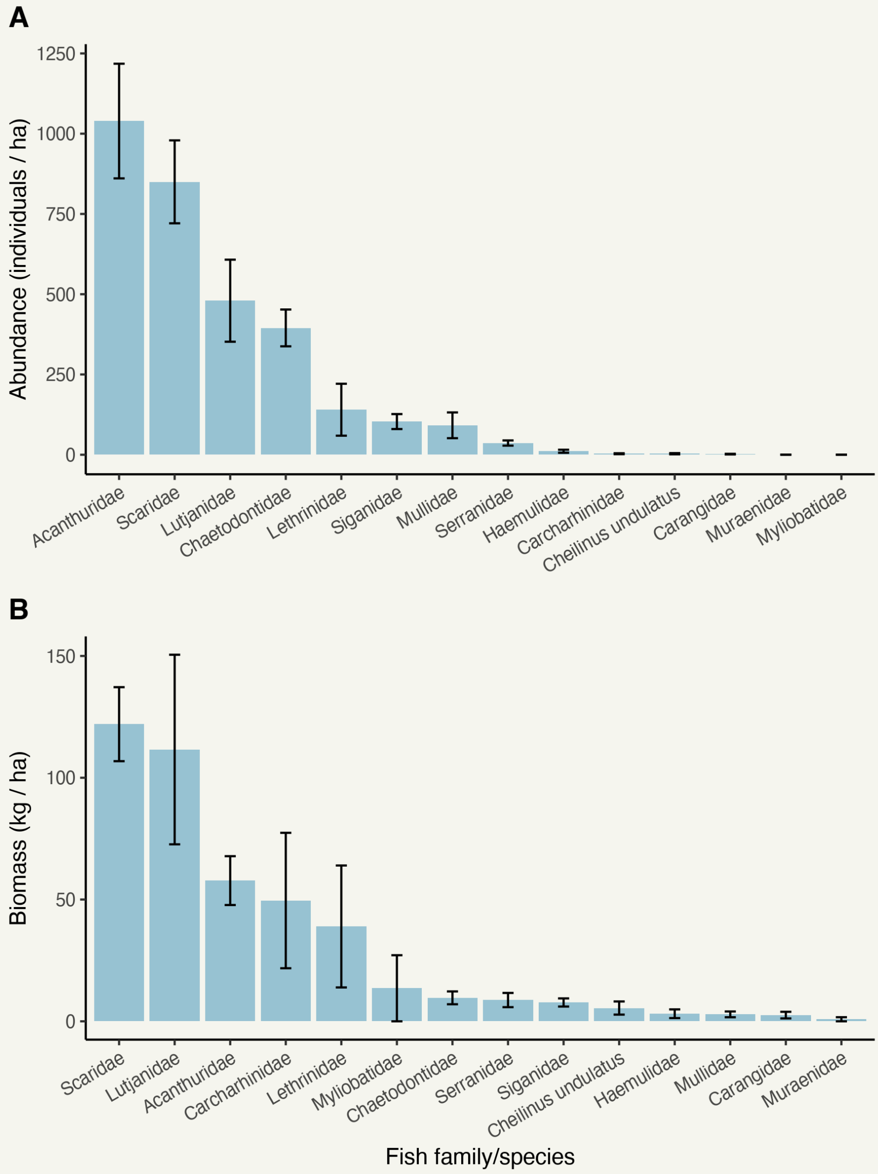
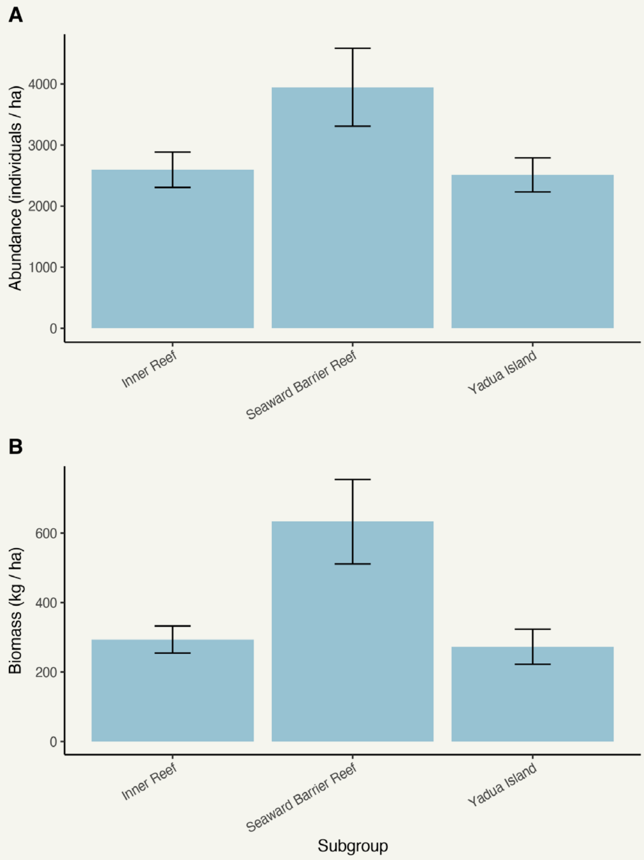


Figure 7.1.14. Overall fish (A) abundance and (B) biomass for sites surveyed in 2019 in Bua province. Results divided by subgroups representing broad reef types.



It was *unlikely* (V=15, p=0.74) that key fisheries family abundance changed between the historic surveys and 2019 in Bua province (Figure 7.1.15A). However, this lack of change marked differing trends based on different reef areas within the province. Yadua Islands fish abundance increased, while fish abundance on the inner coastal reefs of Vanua Levu and the main offshore barrier reef declined (Figure 7.1.15B). It was *about as likely as not* (V=3, p=0.50) that key fisheries family fish biomass declined, though biomass was recorded at 1,242 ± 723 kg/ha in 2004 and 230 ± 40 kg/ha in 2019 (Figure 7.1.16). Biomass changes should be treated with caution, as biomass data is only available from the two sites with historic WWF survey data.

Figure 7.1.15. Change in key fisheries family abundance (Haemulidae, Lutjanidae, Scaridae, and Serranidae) for Bua province for (A) all sites with historic data and (B) sites with historic data by subgroup.

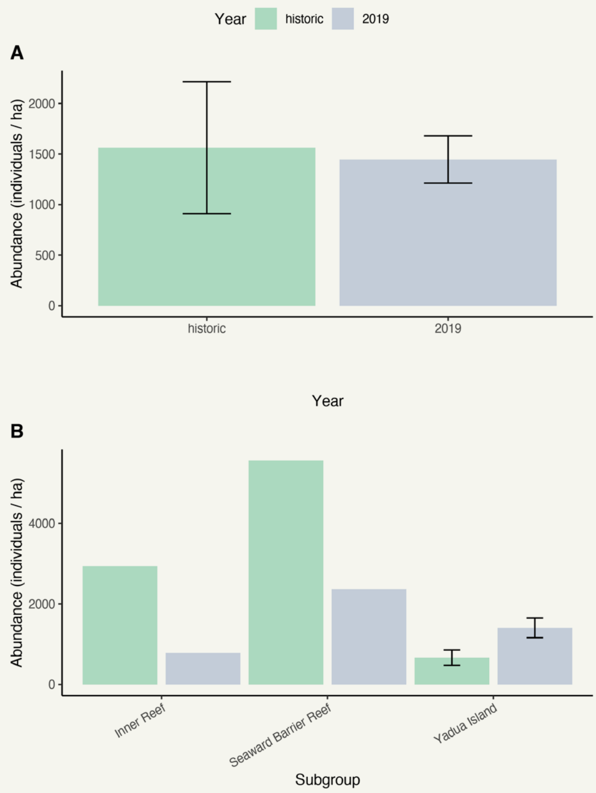
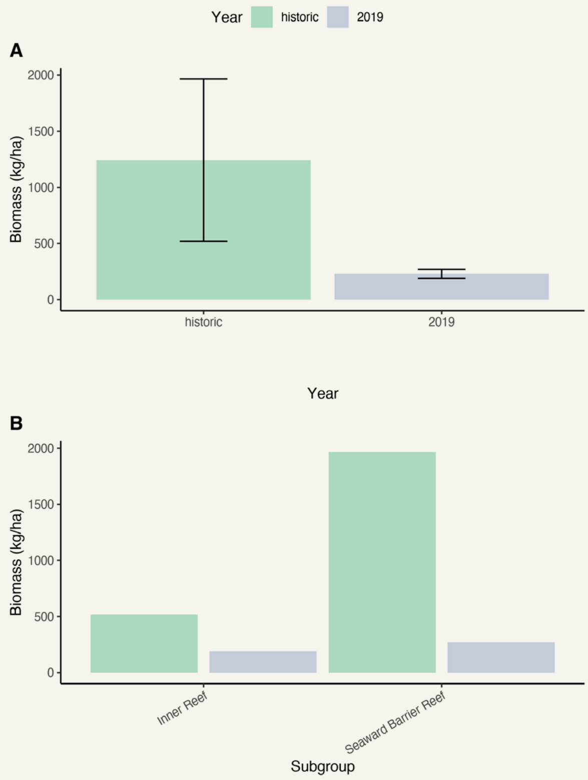


Figure 7.1.16. Change in key fisheries family biomass (Haemulidae, Lutjanidae, Scaridae, and Serranidae) for Bua province for (A) sites with historic data and (B) sites with historic data by subgroup. Note biomass data is only available for the two sites with historic WWF survey data. Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.



7.1.5 Rare Species

Humphead wrasse were recorded at a density of 3.12 ± 1.89 ind/ha with a biomass of 5.45 ± 2.70 kg/ha across all sites surveyed in 2019 in Bua province (Figure 7.1.17). The eight historic surveys sites did not record any humphead wrasse, while the 2019 survey recorded their abundance at 2.50 ± 2.07 ind/ha – representing an increase. No bumphead parrotfish were recorded in Bua province during the historic or 2019 GSR surveys.

Serranidae abundance and biomass was 36 ± 8 ind/ha and 9 ± 3 kg/ha, respectively, across all surveyed Bua sites in 2019 (Figure 7.1.18). For the eight sites with historic data, it was *extremely likely* (V=1, p=0.02) that Serranidae abundance increased, with historic surveys recording 11 ± 3 ind/ha and 2019 surveys recording 41 ± 8 ind/ha (Figure 7.1.18).

Sharks in the family Carcharhinidae were recorded at an abundance of 3.12 ± 1.44 ind/ha and biomass of 50 ± 28 kg/ha across all Bua sites in 2019. Historic surveys did not recorded any sharks, while at these eight sites in 2019 we recorded shark density as 3.94 ± 3.94 ind/ha (Figure 7.1.19).

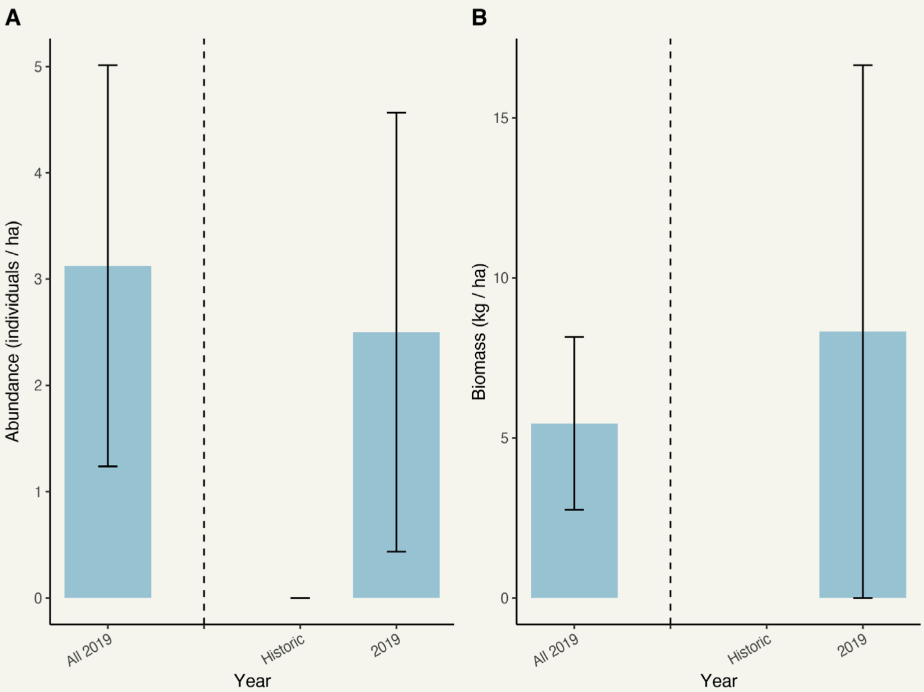


Figure 7.1.17. Humphead wrasse (*Cheilinus undulatus*) (A) abundance and (B) biomass for Bua province. Both panels show data for all 2019 sites to the left of dashed vertical line, and only the sites with historic data available to the right of dashed vertical line. Abundance data was available from eight historic sites, while biomass data was limited to two WWF historic sites. Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.

Figure 7.1.18. Serranidae (grouper) (A) abundance and (B) biomass for Bua province. Each panel shows data for all sites (left of dashed vertical line) and only two sites with historic data available (right of dashed vertical line). Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.

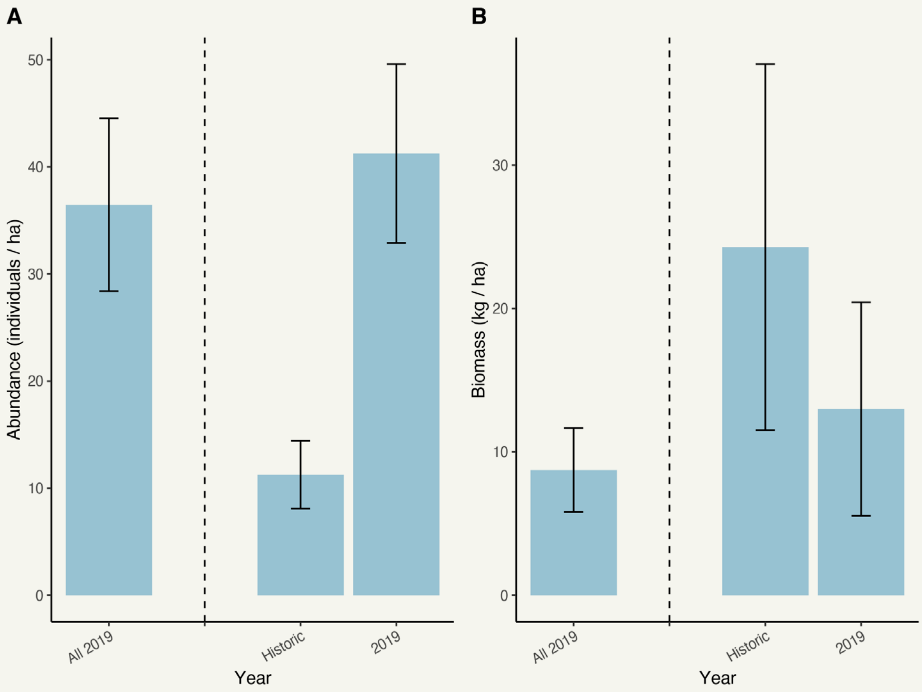
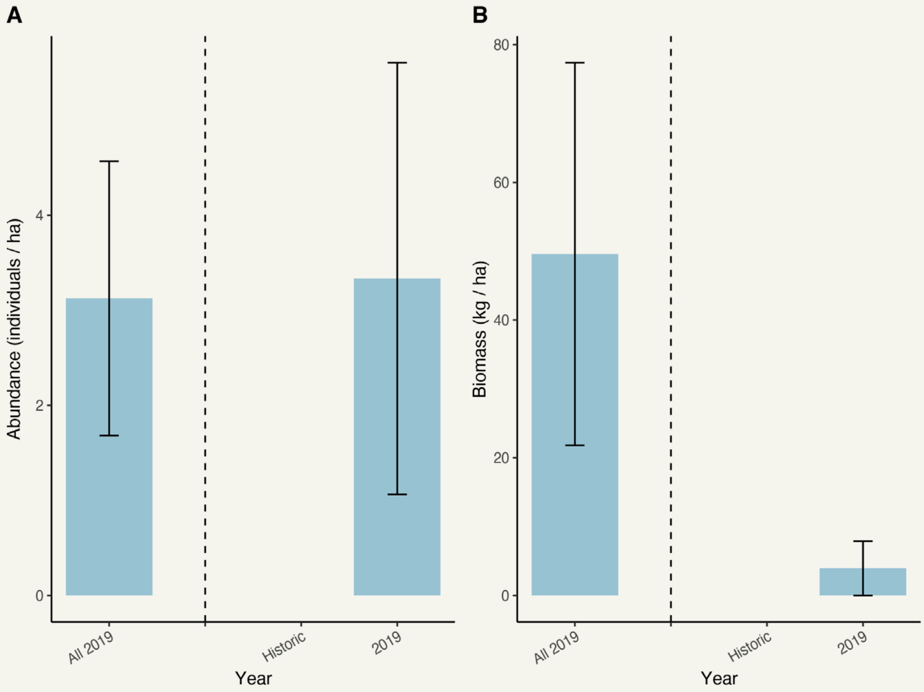


Figure 7.1.19. Carcharhinidae (shark) (A) abundance and (B) biomass for Bua province. Each panel shows data for all sites (left of dashed vertical line) and only two sites with historic data available (right of dashed vertical line). Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.



7.2 Vuya and Bua

7.2.1 Introduction and critical habitat coverage

Vuya and Bua *qoliqoli* is comprised of two areas located in Bua province off the north western coast of Vanua Levu and spanning 2,442 km² (Figure 7.2.1). The *qoliqoli* contains a mix of shallow water and deeper water areas. While adjacent to Vanua Levu, there is limited sedimentation impact in Vuya and Bua as none of the major rivers from Vanua Levu flow out into this *qoliqoli* (Figure 7.2.2).

Reefs of shallow fringing and barrier reefs are found around Yadua Island, part of the main Cakaulevu barrier reef, as well as many small reefs contained behind Cakaulevu (Figure 7.2.3). In total, coral covers approximately 21 km² within the *qoliqoli*, though summing all Allen Coral Atlas benthic categories that likely contribute to broader coral reef ecosystem composition (i.e. coral/ algae, microalgal mats, rock, and rubble) suggests a coverage of 29 km² of shallow reef-related ecosystems. The majority of these reefs are comprised of reef slopes (13 km²), followed by significant areas of outer reef flats (8 km²) and inner reef flats (7 km²), with other reef types also present (Figure 7.2.4).

Mangrove extent is low, but stable in the *qoliqoli* at 65 ha, with no change between 1996 and 2016 (Figures 7.2.5; 7.2.6). This low mangrove cover reflects that much of the *qoliqoli* covers open water areas with offshore reefs and limited coastlines. Seagrass covers approximately 2 km² within the *qoliqoli*, with much of this split between the coastal area of Vanua Levu and a narrow offshore band associated with the Cakaulevu offshore reef.

Figure 7.2.1. Bathymetry of Vuya and Bua *qoliqoli*.

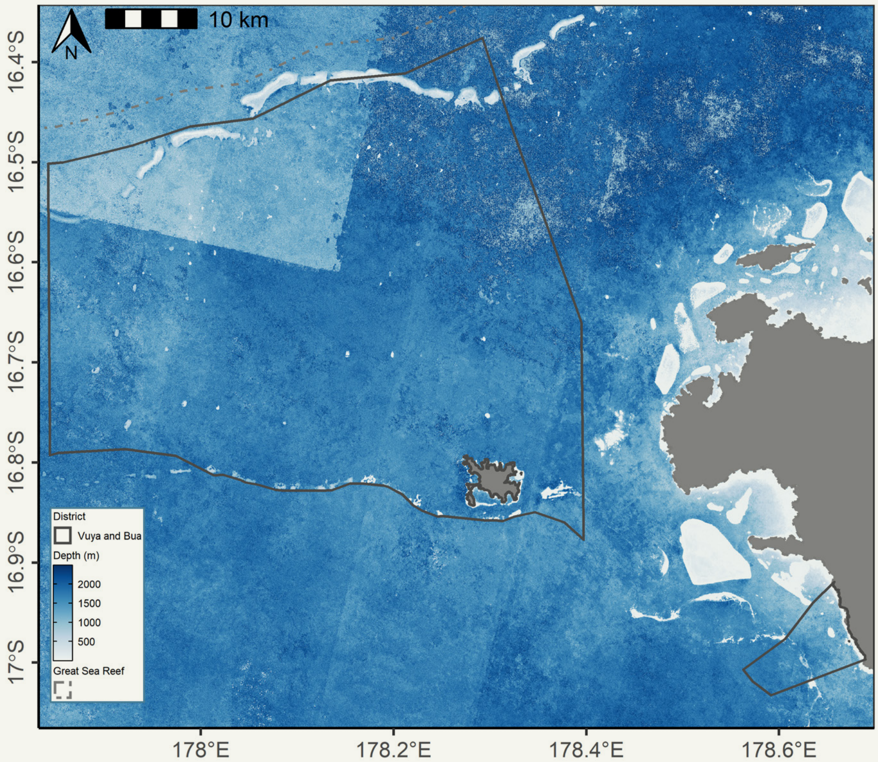


Figure 7.2.2. Sedimentation rates inside and adjacent to Vuya and Bua *qoliqoli*.

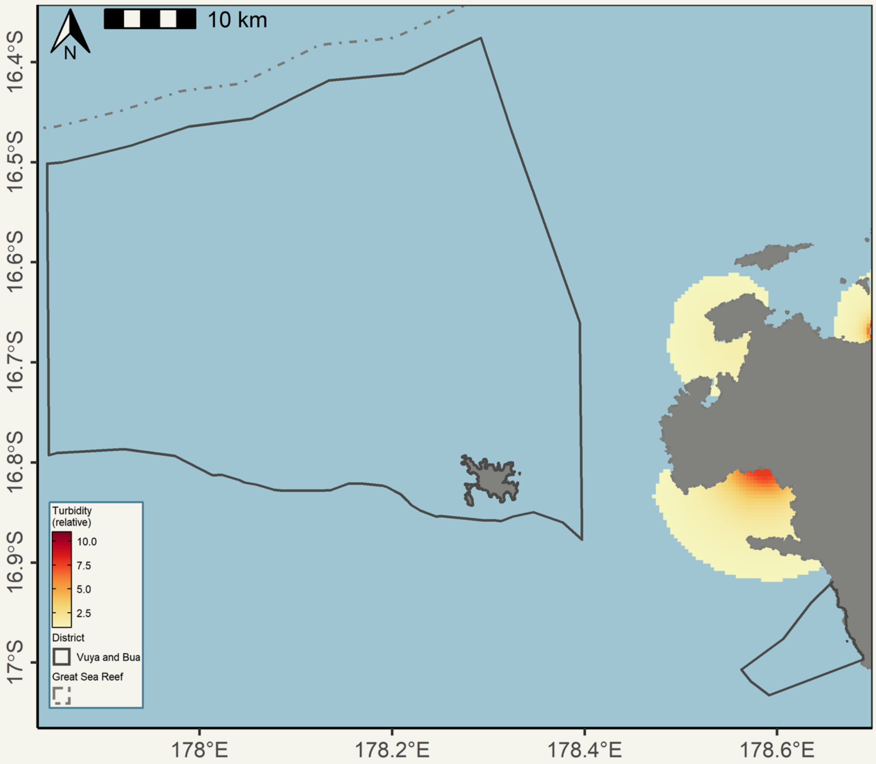


Figure 7.2.3. Coral reef extent in Vuya and Bua *qoliqoli*.

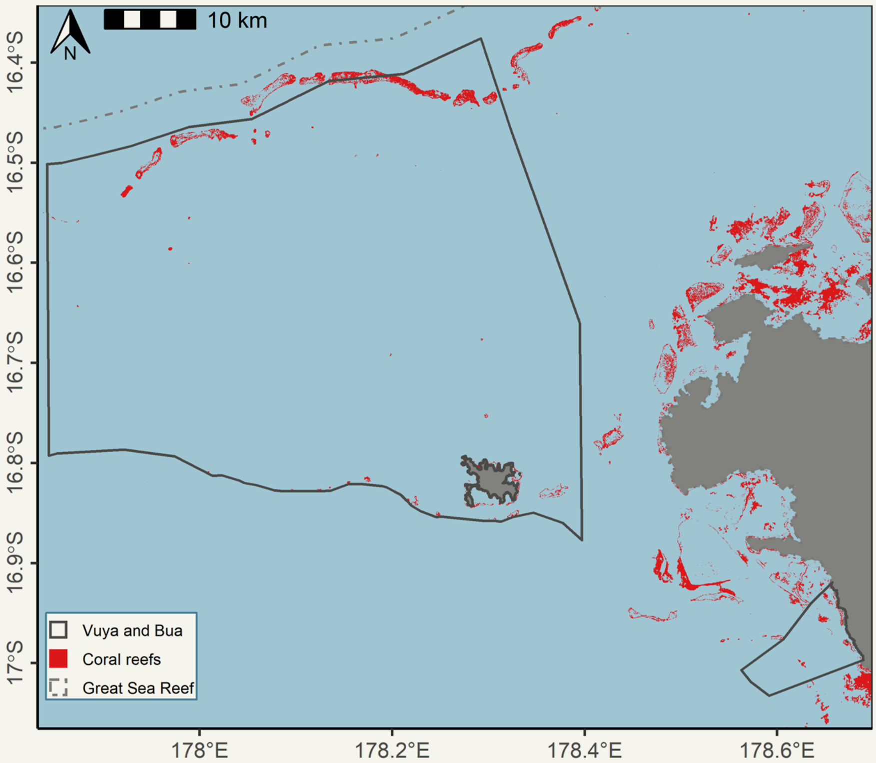


Figure 7.2.4. Coral reef geomorphic types in Vuya and Bua *qoliqoli*.

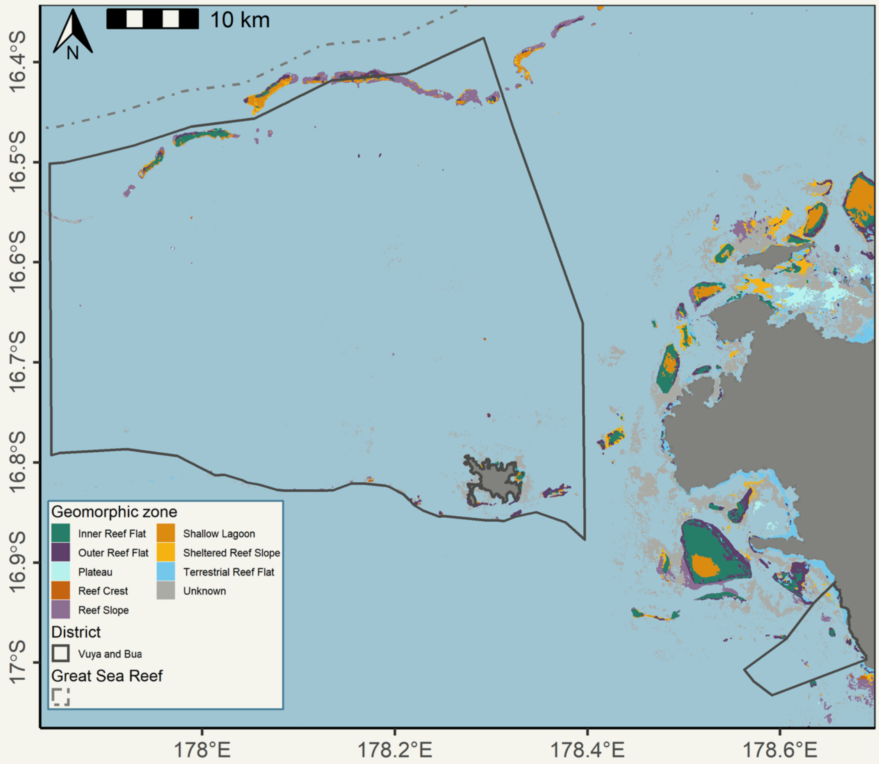
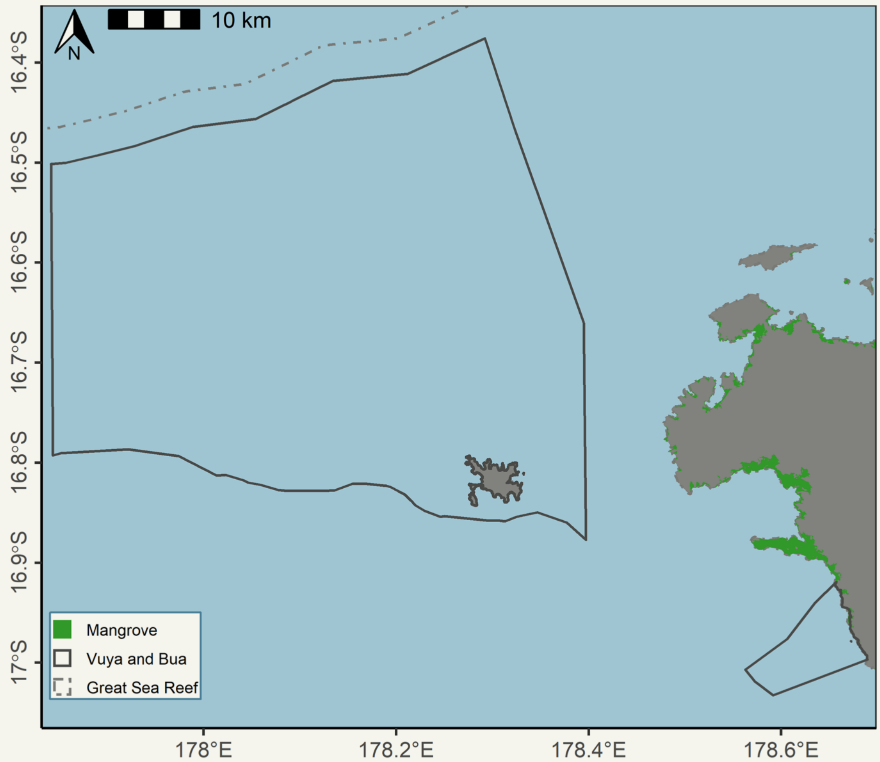


Figure 7.2.5. Mangrove extent in Vuya and Bua *qoliqoli*.



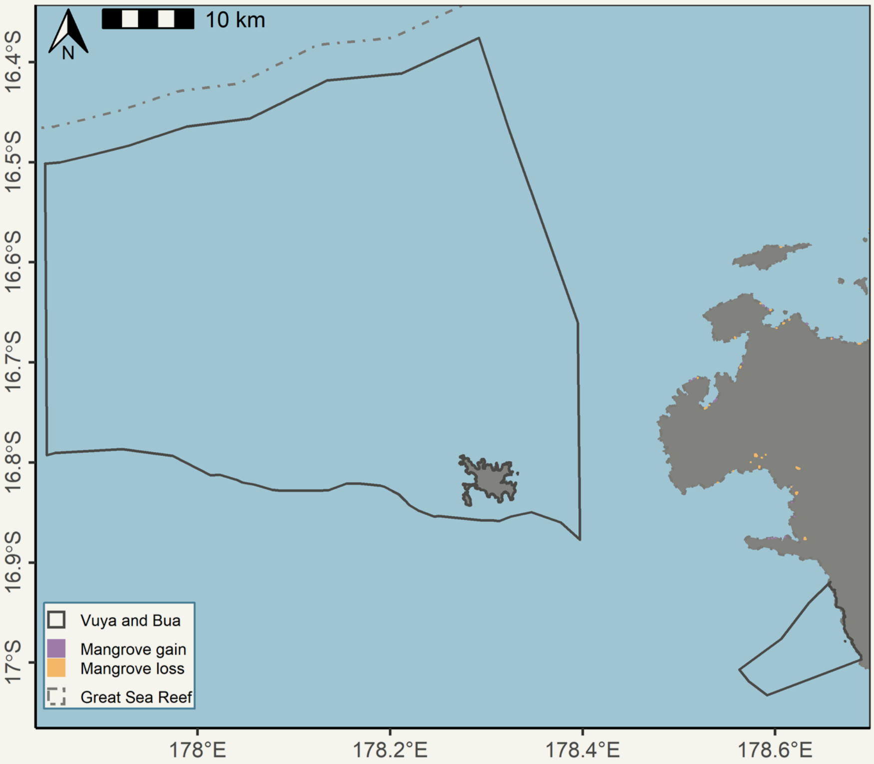


Figure 7.2.6. Mangrove change between 1996-2016 in Vuya and Bua *qoliqoli*.

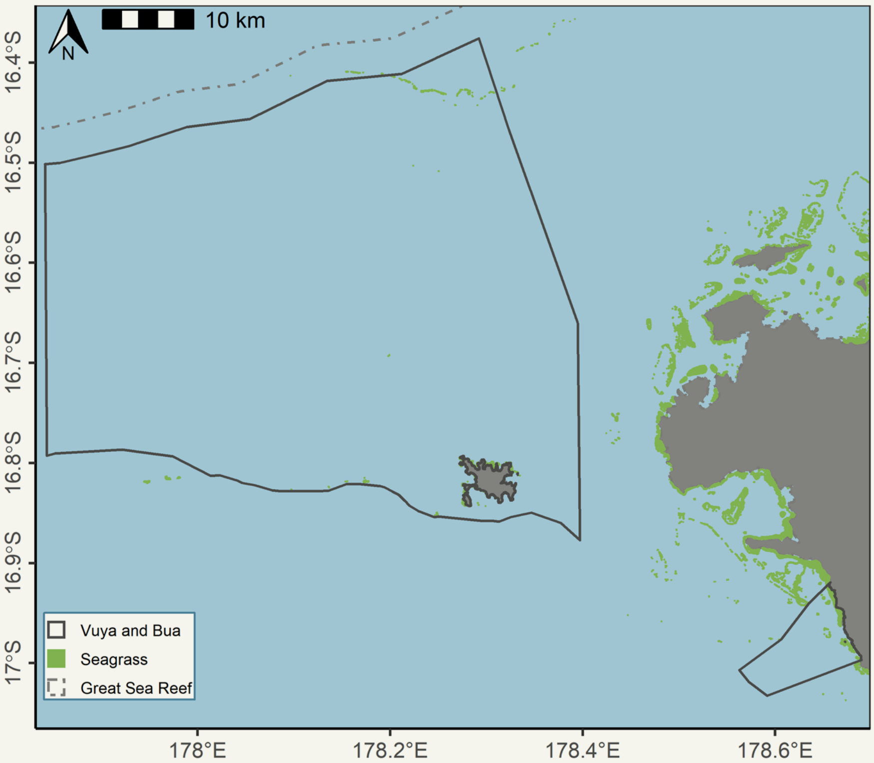


Figure 7.2.7. Seagrass cover in Vuya and Bua *qoliqoli*.

7.2.2 Survey sites

Surveys were completed at eight sites within Vuya and Bua (Figure 7.1.8). Six of these sites were located around Yadua Island – with five of these on the fringing reefs of Yadua and one on the barrier reef to the south of Yadua. The remaining two sites within Vuya and Bua were on the Cakaulevu offshore main reef – with both of these sites adjacent to a channel, with one site on the outer side and one site on the inner side of the reef.

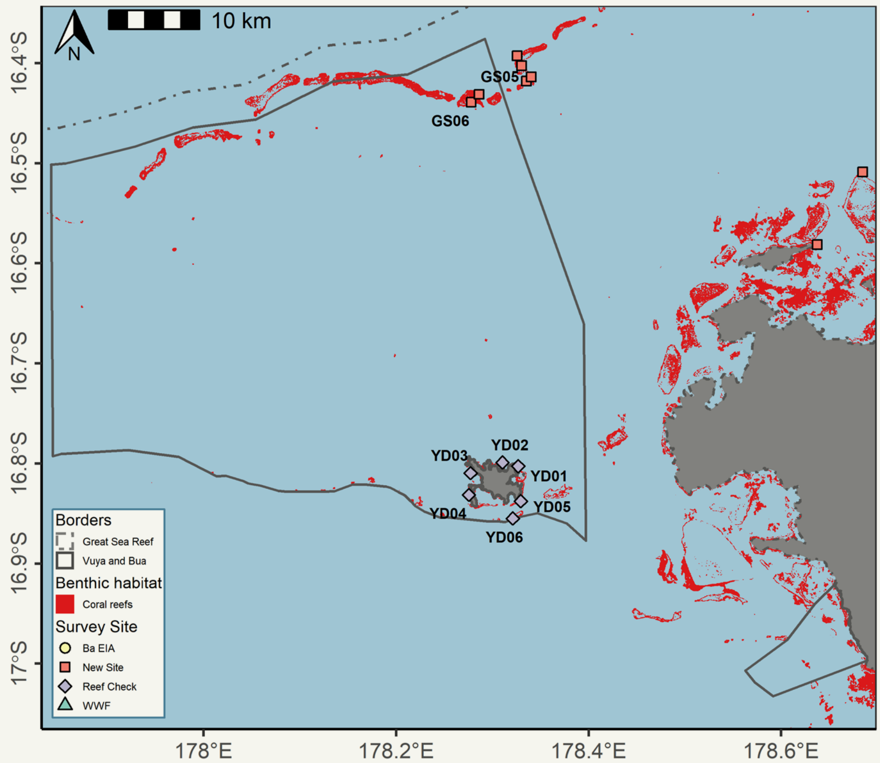


Figure 7.2.8. Survey sites in Vuya and Bua *qoliqoli*.

7.2.3 Benthic cover

Hard coral cover was 42 ± 4% across reefs in Vuya and Bua in 2019 (Figure 7.1.9). This is amongst the highest cover of any district surveyed. The second highest benthic cover on reefs was soft coral, at 15 ± 4%. Macroalgae, while low, was amongst the highest seen for any *qoliqoli* in the GSR at 5 ± 2%.

Sites surveyed in Vuya and Bua split into two group based on reef type and geographic location – (i) Yadua Island and (ii) the Cakaulevu offshore barrier reef. While hard coral cover was high in both locations, macroalgae cover was very different (Figure 7.2.10). Yadua Island had low macroalgae cover at 2 ± 1%, while the outer barrier reef sites at macroalgae cover of 12 ± 2%.

Historic survey data for Vuya and Bua *qoliqoli* was limited to the six sites around Yadu Island. For Yadua Island, it was *very likely* (W=7, p=0.09) that hard coral cover increased, from 31 ± 6% in baseline surveys in 2001 and 2003 to 45 ± 3% in 2019 (Figure 7.2.11). It was *likely* (W=8, p=0.10) that algal cover also increased, from 1 ± 1% to 2 ± 1 %. Despite this slight increase, algal cover remains low. As coral cover and macroalgae cover have increased, it is *extremely likely* (W=34, p=0.01) that the amount of bare rock has halved on the reef from 24 ± 3% to 12 ± 2%. There have been limited changes in other benthic groups (Figure 7.2.11).

Figure 7.2.9. Benthic cover in 2019 for Vuya and Bua *qoliqoli*. Figure 7.2.9. Benthic cover in 2019 for Vuya and Bua *qoliqoli*.

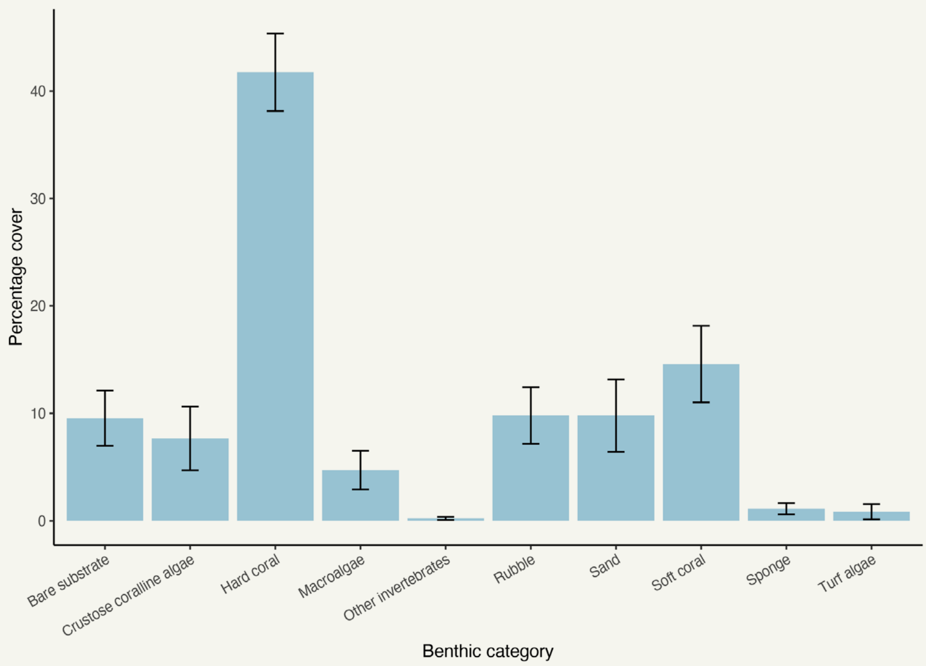


Figure 7.2.10. (A) Hard coral cover and (B) macroalgae cover by subgroup for sites within Vuya and Bua *qoliqoli*.

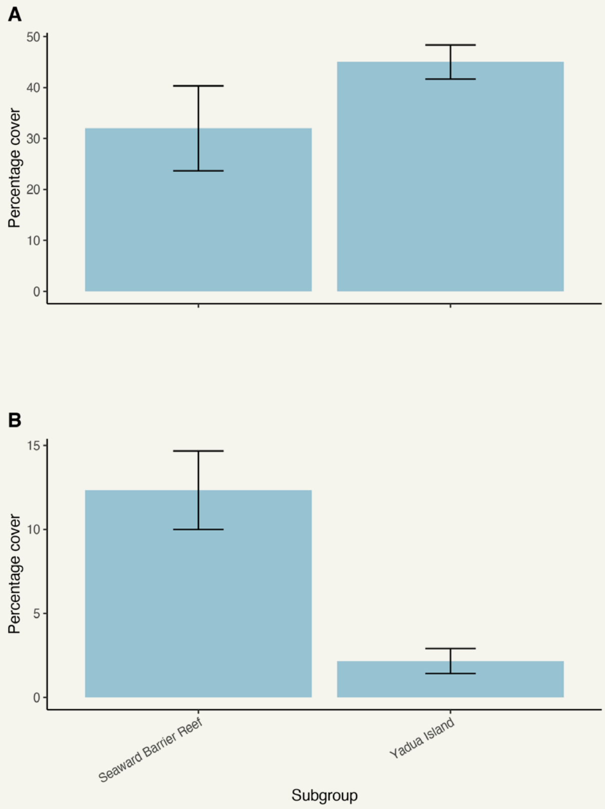
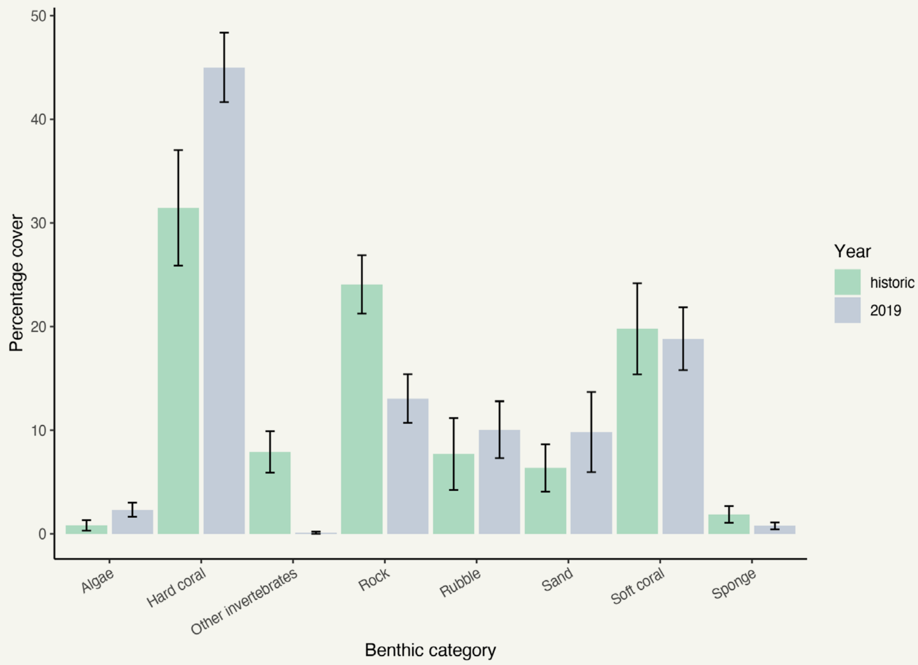


Figure 7.2.11. Change in benthic communities for Yadua Island in Vuya and Bua *qoliqoli*.



7.2.4 Fish communities

A mean fish abundance for the target family/species list of 2,498 ± 208 ind/ha was recorded across all Vuya and Bua sites, while mean fish biomass was 283 ± 49 kg/ha. Fish communities were dominated by herbivores (Figure 7.2.12). The most abundant fish family was Scaridae (932 ± 245 ind/ha) followed by Acanthuridae (700 ± 133 ind/ha). Scaridae was the largest fish family by biomass (121 ± 28 kg/ha), with acanthids the third largest (35 ± 6 kg/ ha). The greatest carnivorous family by both abundance and biomass was Lutjanidae (218 ± 72 ind/ha; 52 ± 14 kg/ha). Fish abundance and biomass was similar between the two sites on the Cakaulevu offshore barrier reef and Yadua Island (Figure 7.2.13).

It was *very likely* (V=1, p=0.06) that key fisheries family abundance increased for the six sites around Yadua Island from historic surveys in 2001 and 2003 to the present survey in 2019 (Figure 7.2.14). Key fisheries family abundance was 667 ± 190 ind/ha historically, increasing to 1,403 ± 243 ind/ha in 2019. No data is available for biomass or fish length change for Vuya and Bua *qoliqoli*, as the only historic data available is limited to fish abundance.

Figure 7.2.12. Fish community structure by (A) abundance and (B) biomass for Vuya and Bua *qoliqoli*.

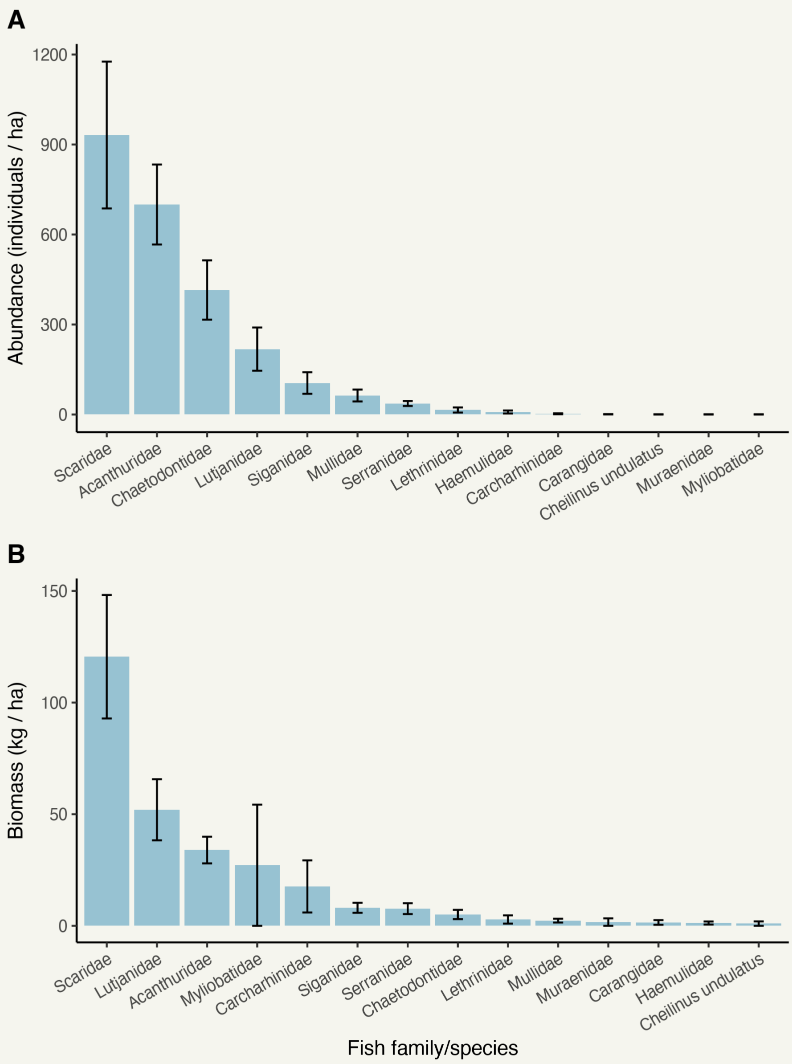


Figure 7.2.13. Overall fish (A) abundance and (B) biomass for sites surveyed in 2019 in Vuya and Bua *qoliqoli*. Results divided by subgroups representing broad reef types.

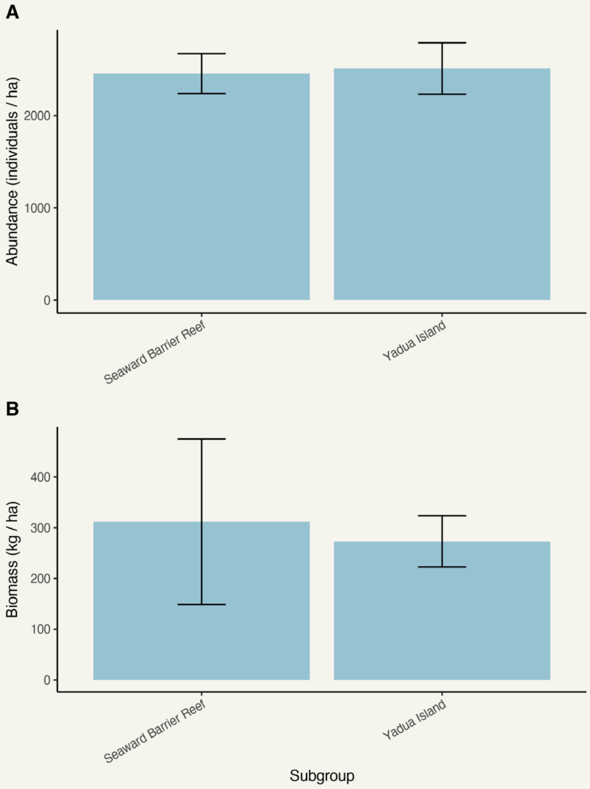
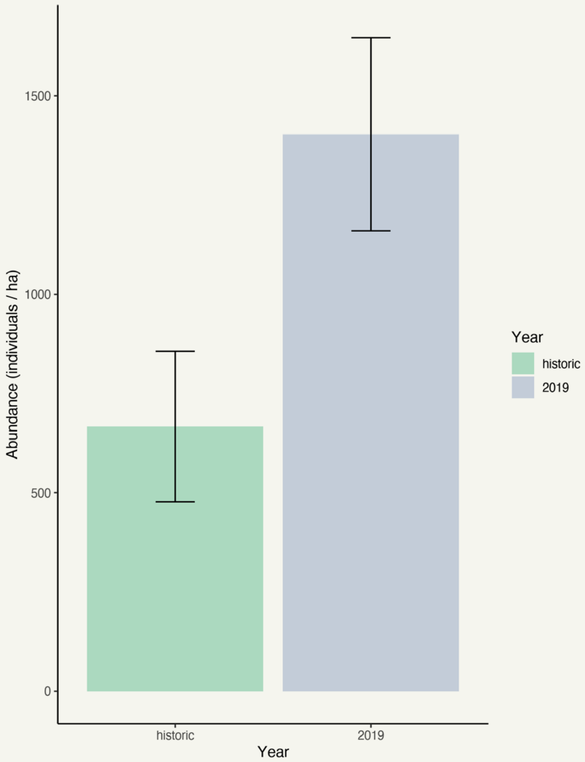


Figure 7.2.14. Change in key fisheries family abundance (Haemulidae, Lutjanidae, Scaridae, and Serranidae) for Yadua Island in Vuya and Bua *qoliqoli* for six sites with historic data.



7.2.5 Rare Species

Humphead wrasse were recorded at a density of 0.42 ± 0.42 ind/ha with a biomass of 1.00 ± 1.00 kg/ha across all sites surveyed in 2019 in Vuya and Bua (Figure 7.2.15). The historic surveys at six sites around Yadua Island did not record any humphead wrasse, while the 2019 survey recorded their abundance at 0.56 ± 0.56 ind/ha. No bumphead parrotfish were recorded in Vuya and Bua during the historic or 2019 GSR surveys.

Serranidae abundance and biomass was 37 ± 8 ind/ha and 7.71 ± 2.43 kg/ha, respectively, across all surveyed Vuya and Bua sites in 2019. For the six Yadua island sites with historic data, it was *very likely* (V=2, p=0.09) that Serranidae abundance increased, from 17 ± 6 ind/ha in 2001 and 2003 to 40 ± 10 ind/ha in 2019 (Figure 7.2.16).

Sharks in the family Carcharhinidae were recorded at an abundance of 2.50 ± 1.64 ind/ha and biomass of 18 ± 12 kg/ha across all Vuya and Bua sites in 2019. Historic surveys around Yadua Island did not recorded any sharks, while at these sites in 2019 we recorded shark density as 1.67 ± 1.67 ind/ha (Figure 7.2.17).

Figure 7.2.15. Humphead wrasse (*Cheilinus undulatus*) abundance for Vuya and Bua *qoliqoli* (eight sites-left) and for Yadua Island (six sites with historic data-right).

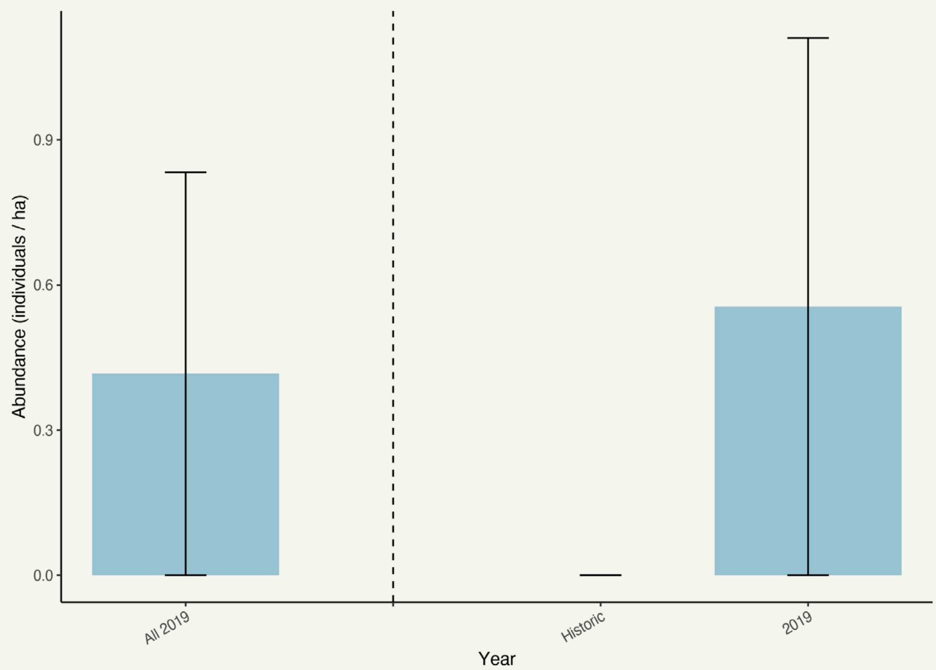


Figure 7.2.16. Serranidae (grouper) abundance for Vuya and Bua *qoliqoli*, (eight sites-left) and for Yadua Island (six sites with historic data-right).

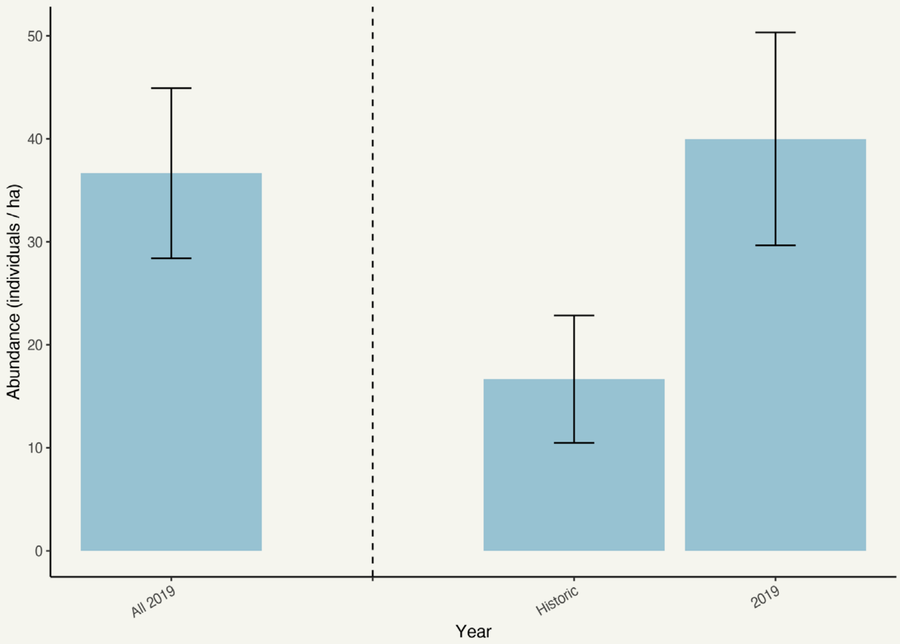
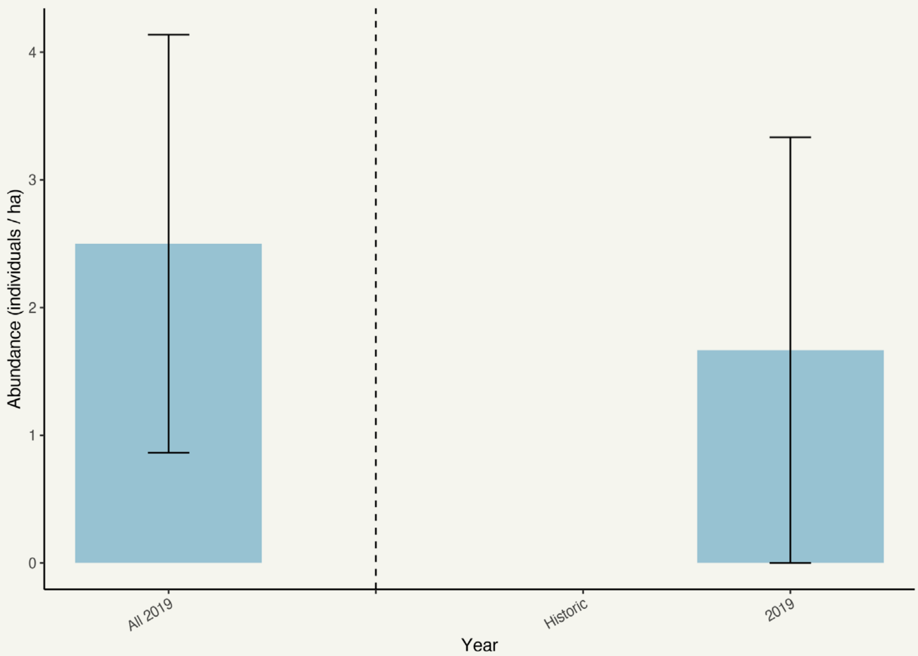


Figure 7.2.17. Carcharhinidae (shark) abundance for Vuya and Bua *qoliqoli* (eight sites-left) and for Yadua Island (six sites with historic data-right).



7.3 Lekutu and Navakasiga

7.3.1 Introduction and critical habitat coverage

Lekutu and Navakasiga *qoliqoli* is comprised of a single area located in Bua province on the north western coast of Vanua Levu and spanning 1,821 km^2 (Figure 7.3.1). The *qoliqoli* contains a mix of shallow water and deeper water areas, with extensive fringing reef systems and mangrove islands. As the *qoliqoli* sits adjacent to Vanua Levu, there is substantial sedimentation impact in coastal areas of Lekutu and Navakasiga *qoliqoli*. The Lekutu River flows out into the *qoliqoli* as well as several other smaller rivers (Figure 7.3.2)

Reefs take multiple forms within Lekutu and Navakasiga *qoliqoli*, with shallow fringing reefs along the northen coastline of Vanua Levu and extensive fringing reefs and reef flats around coastal mangrove islands. Part of the main Cakaulevu barrier reef, as well as several small reefs contained behind Cakaulevu exist in the *qoliqoli* (Figure 7.3.3). In total, coral covers approximately 81 km^2 within the *qoliqoli*, though summing all Allen Coral Atlas benthic categories that likely contribute to broader coral reef ecosystem composition (i.e. coral/algae, microalgal mats, rock, and rubble) suggests a coverage of 121 km^2 of shallow reef-related ecosystems. The majority of these reefs are comprised of terrestrially adjacent reef flats (32 km^2), followed by significant areas of shallow lagoonal reefs (30 km^2) and inner reef flats (25 km^2), with other reef types also present (Figure 7.3.4).

Figure 7.3.1. Bathymetry of Lekutu and Navakasiga *qoliqoli*.

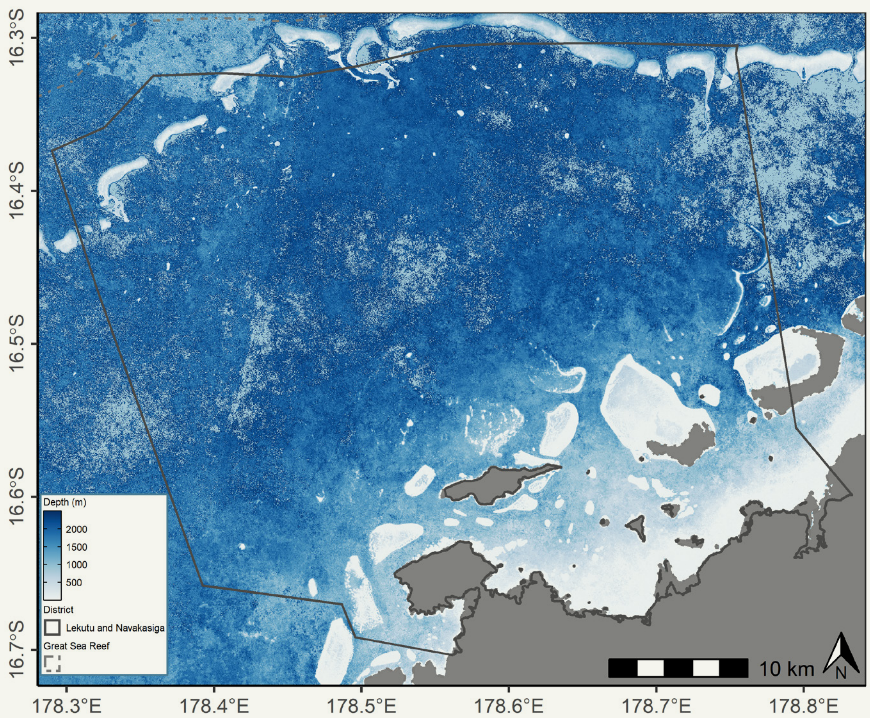


Figure 7.3.2. Sedimentation rates inside and adjacent to Lekutu and Navakasiga *qoliqoli*.

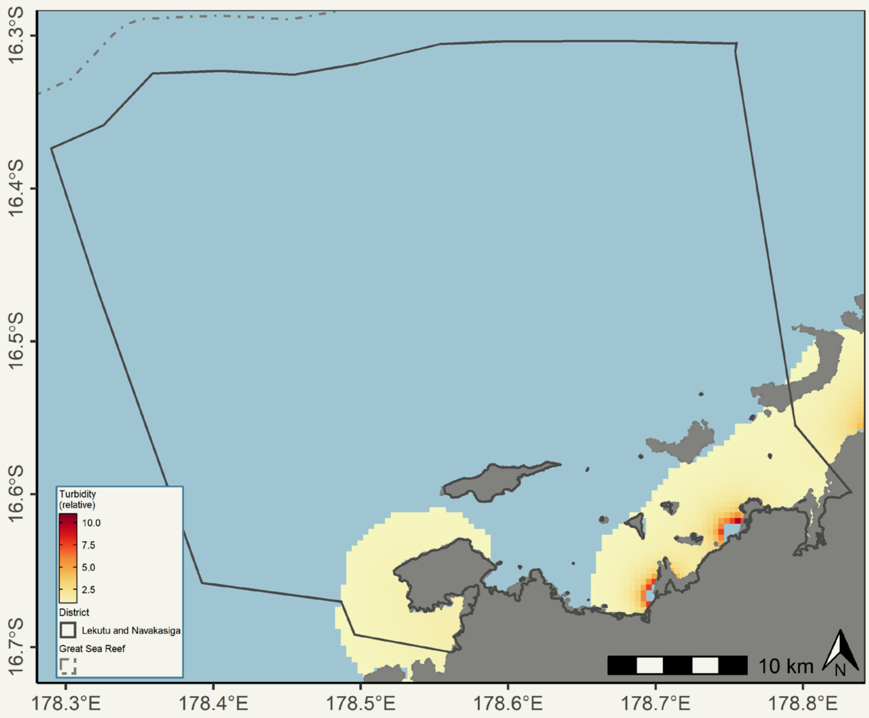
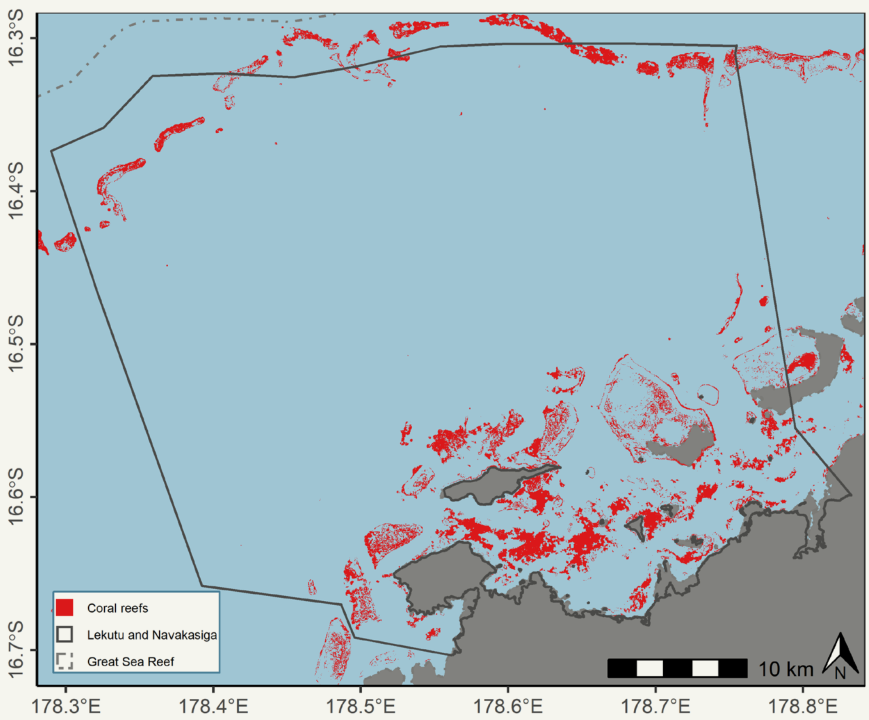


Figure 7.3.3. Coral reef extent in Lekutu and Navakasiga *qoliqoli*.



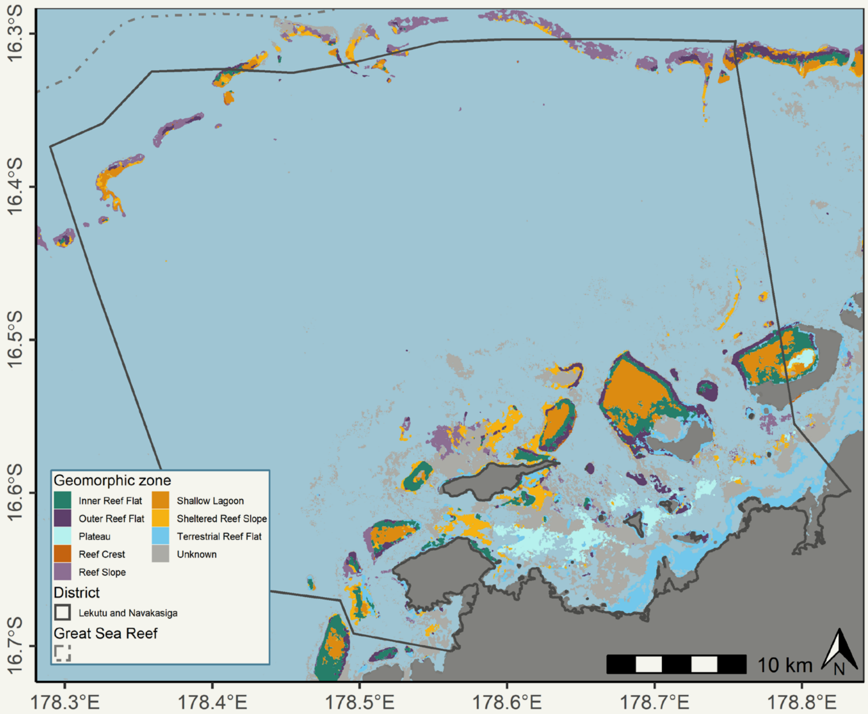


Figure 7.3.4. Coral reef geomorphic types in Lekutu and Navakasiga *qoliqoli*.

Mangrove extent is high and stable in the *qoliqoli* at 28 km², with no change between 1996 and 2016 (Figures 7.2.5; 7.2.6). This high mangrove cover reflects the extensive coastline with rivers providing sediment input for mangroves. The shallow coastal waters with many small islands also provide suitable substrate for extensive mangrove forests to form. Seagrass covers approximately 21 km² within the *qoliqoli*, with much of this split in the coastal areas of Vanua Levu and the small islands adjacent to the shoreline (Figure 7.3.7). However, some narrow bands of seagrass are found associated with the Cakaulevu offshore reef.

7.3.2 Survey sites

Surveys were completed at nine sites within Lekutu and Navakasiga *qoliqoli* (Figure 7.3.8). Four of these sites were located in the Vanua Levu coastal area – sites associated with the reefs of three of the costal island reefs and a small ribbon reef adjacent to the islands. The remaining five sites within the *qoliqoli* were on the Cakaulevu offshore barrier reef. Four of these were at the western end of the barrier reef within Lekutu and Navakasiga *qoliqoli*, while one was on a channel at the eastern end of the barrier reef within Lekutu and Navakasiga *qoliqoli*. Two sites (CH1, IB1) were surveyed by the WWF 2004 GSR survey, and so have historic benthic and fish data available (Figure 7.3.8).

Figure 7.3.5. Mangrove extent in Lekutu and Navakasiga *qoliqoli*.

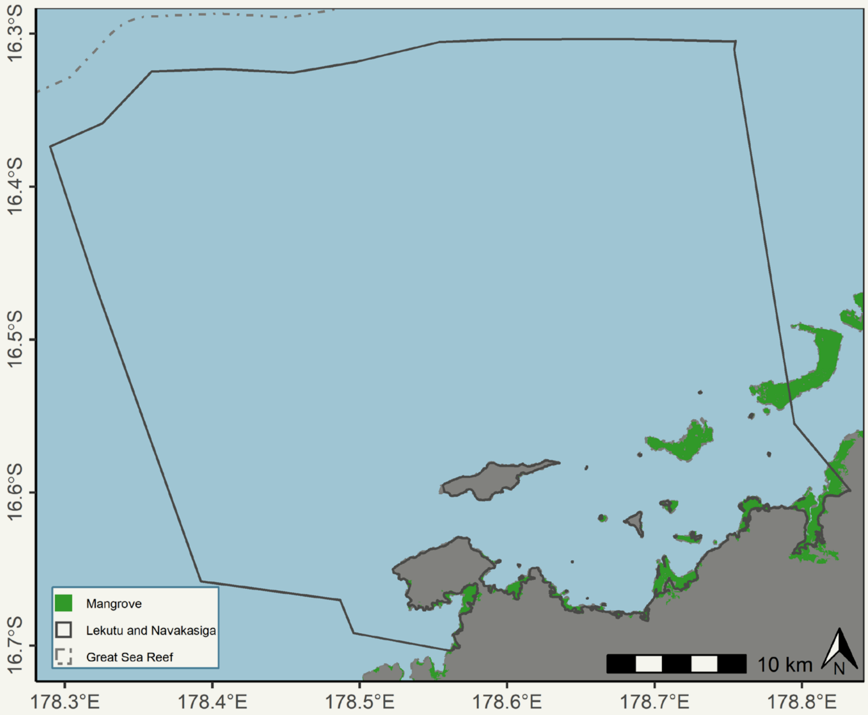


Figure 7.3.6. Mangrove change between 1996-2016 in Lekutu and Navakasiga *qoliqoli*.

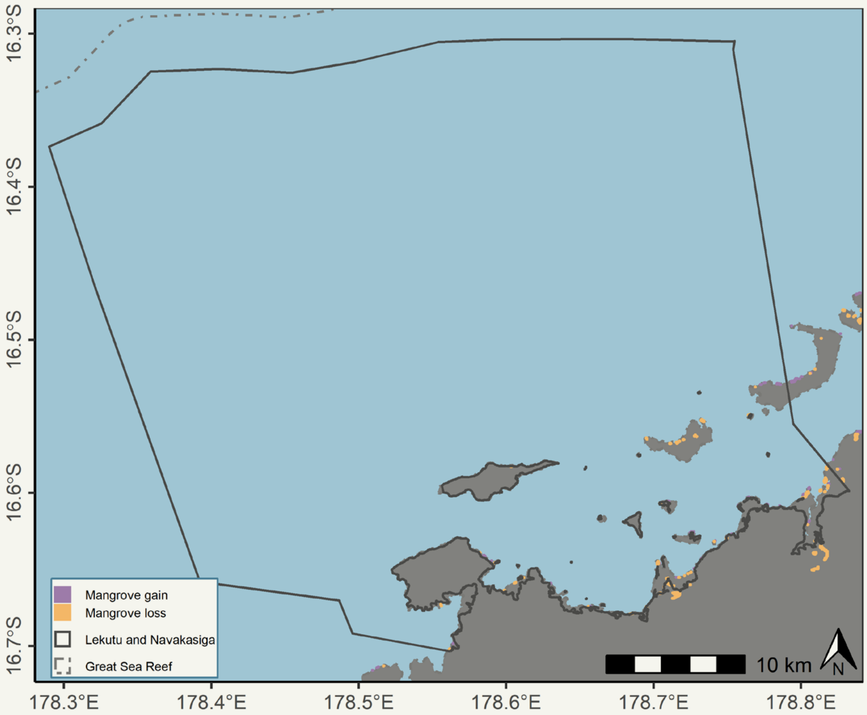


Figure 7.3.7. Seagrass cover in Lekutu and Navakasiga *qoliqoli*.

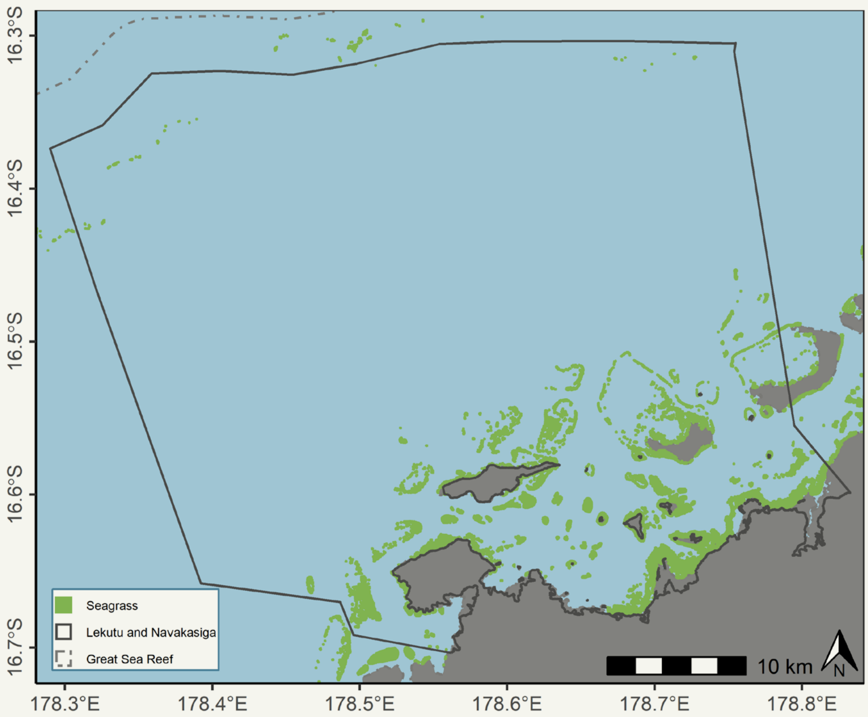
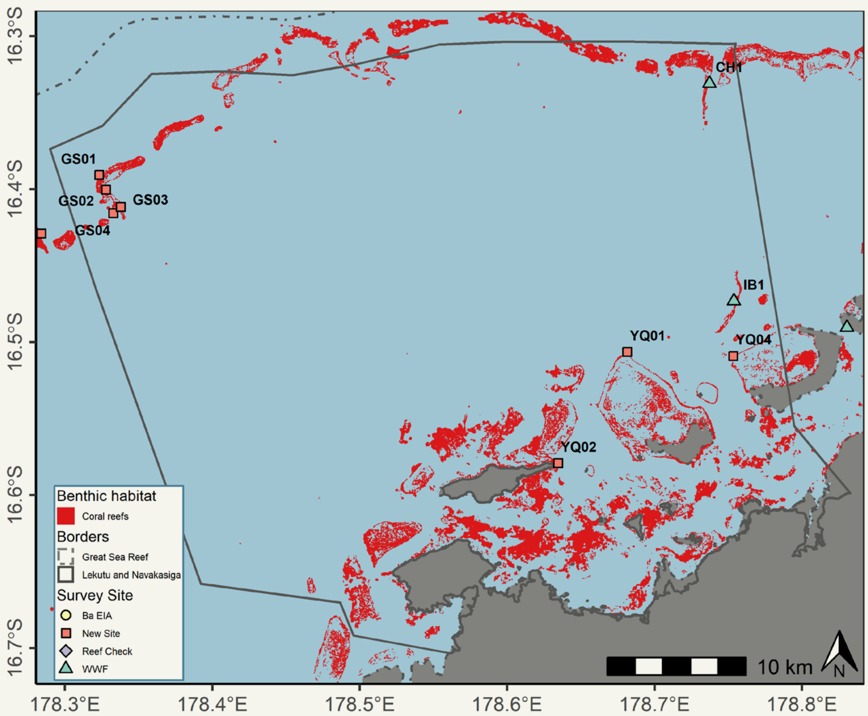


Figure 7.3.8. Survey sites in Lekutu and Navakasiga *qoliqoli*.



7.3.3 Benthic cover

Hard coral cover was 49 ± 6% across reefs in Lekutu and Navakasiga in 2019 (Figure 7.2.9). This is amongst the highest cover of any district surveyed. The second highest live benthic cover on reefs was macroalgae, at 5 ± 2%. Nonliving benthic cover was high in the *qoliqoli*, with sand at 15 ± 3%, rubble at 11 ± 3%, and bare substrate at 11 ± 2% cover.

Sites surveyed in Lekutu and Navakasiga split into two group based on reef type and geographic location – (i) inner reefs along the coastline, and (ii) the Cakaulevu offshore barrier reef. While hard coral cover was high in both locations, the outer barrier reef was exceptionally high at 56 ± 8% (Figure 7.3.10A). Macroalgae cover was similar between inner reefs and the outer barrier reef (Figure 7.3.10B).

Historic survey data for Lekutu and Navakasiga *qoliqoli* was limited to the two sites, one inner reef site and one outer reef site. It was *about as likely as not* (W=0, p=0.33) that hard coral cover increased at the two sites with historic data, from 13 ± 3% in baseline surveys in 2004 to 29 ± 10% in 2019 (Figure 7.3.11). It was *likely* (W=0, p=0.22) that sponge cover also increased, from 0 ± 0% to 1 ± 1%. It was *unlikely* (W=1, p=0.67) that algae changed, though there is weak power to detect trends with only two sites with available historical data. There have been limited changes in other benthic groups (Figure 7.3.11). Breaking apart the data between the site on the barrier reef and the inner reef shows that the inner reef site went from no recorded algae in 2004 to 12% cover in 2019 (Figure 7.3.12).

Figure 7.3.9. Benthic cover in 2019 for Lekutu and Navakasiga *qoliqoli*.

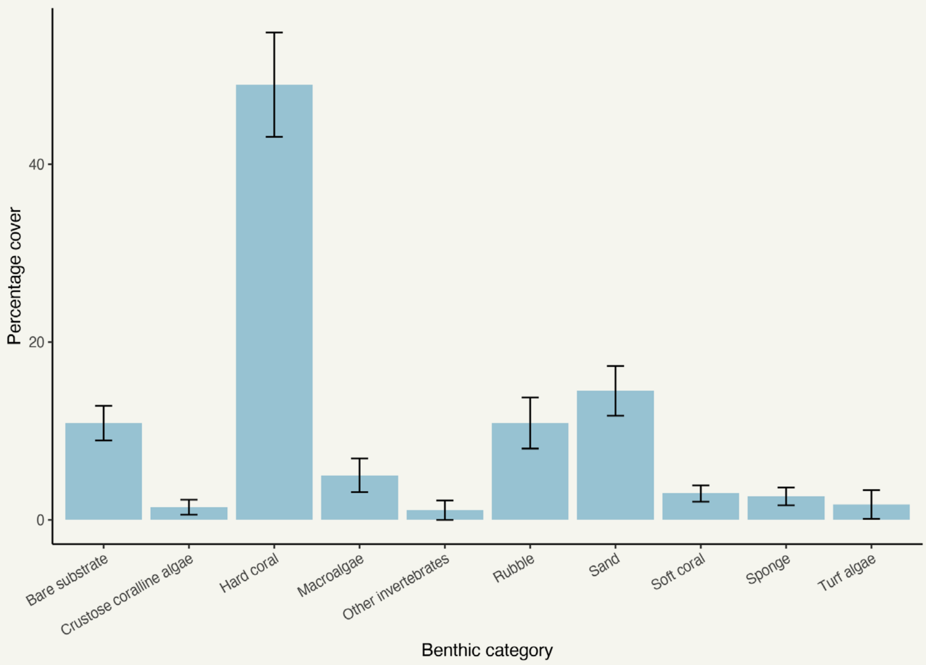


Figure 7.3.10. (A) Hard coral cover and (B) macroalgae cover by subgroup for sites within Lekutu and Navakasiga *qoliqoli*.

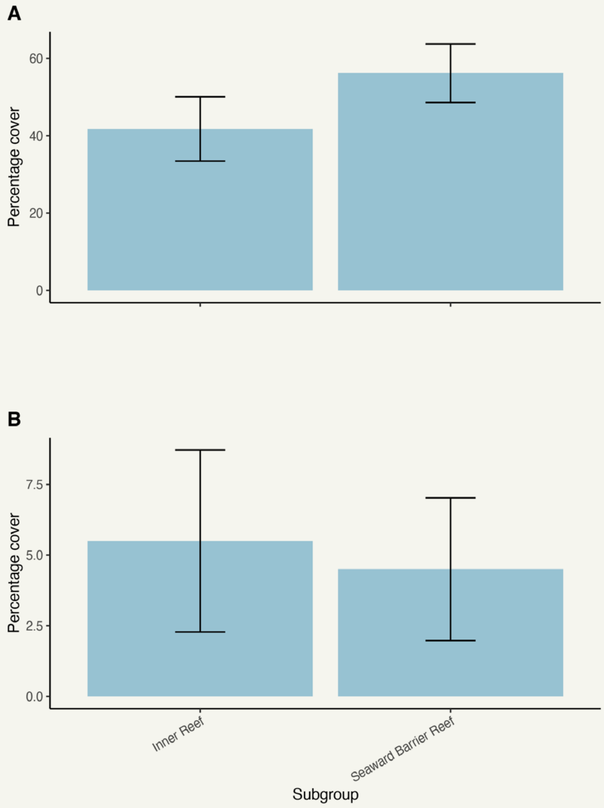
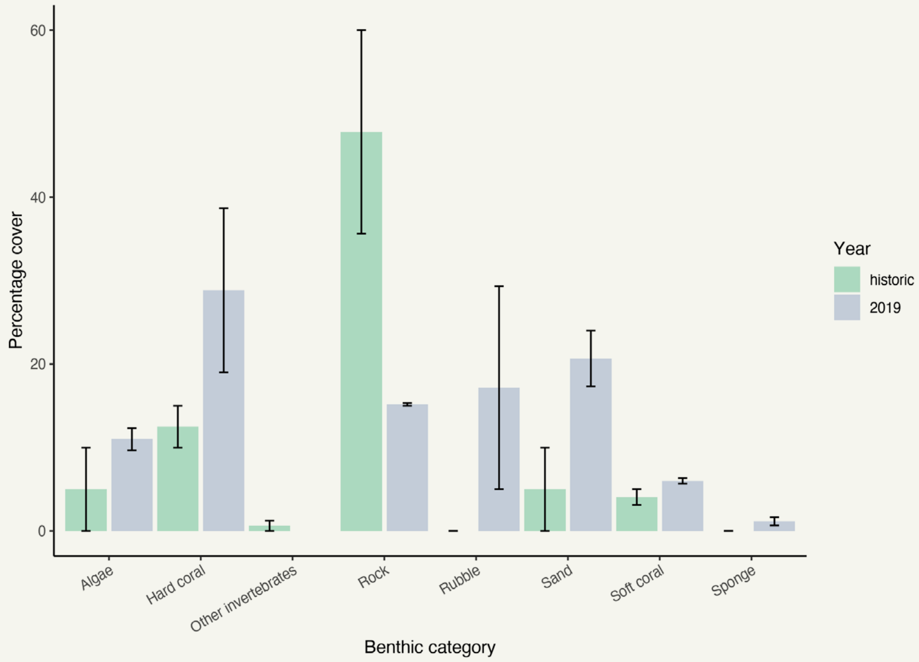


Figure 7.3.11. Change in benthic communities for Lekutu and Navakasiga *qoliqoli*.



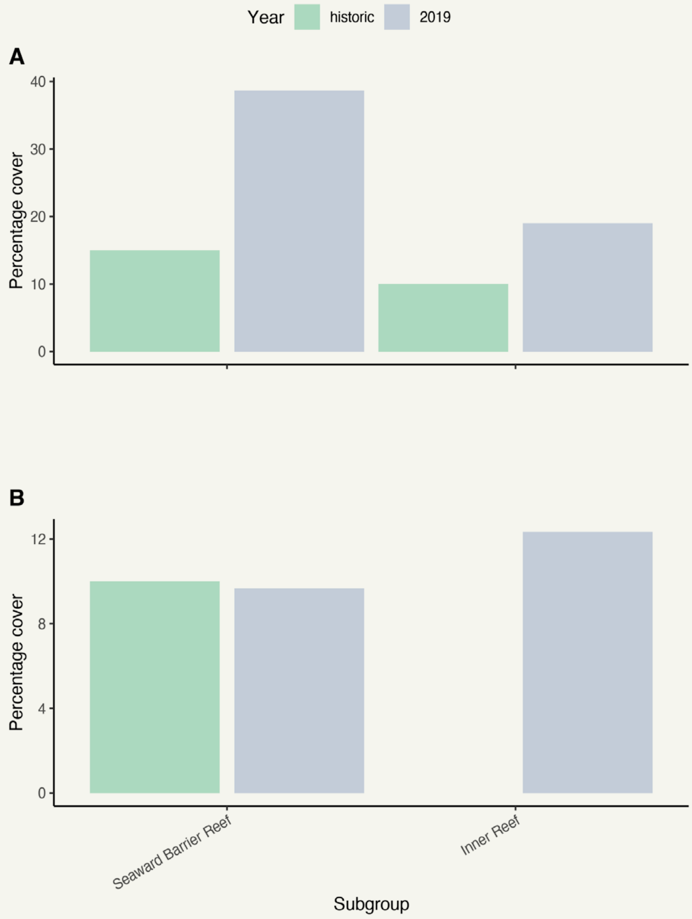


Figure 7.3.12. Change in (A) hard coral and (B) macroalgae cover for the site on the seaward outer reef and the inner reef within Lekutu and Navakasiga *qoliqoli*. Note data represents one site for each reef type, and no algae was recorded on the inner reef site in 2004.

7.3.4 Fish communities

A mean fish abundance for the target family/species list of 3,813 ± 572 ind/ha was recorded across all Lekutu and Navakasiga sites, while mean fish biomass was 586 ± 112 kg/ha. Fish communities were dominated by herbivores by abundance, but by carnivores by biomass (Figure 7.3.13). The most abundant fish family was Acanthuridae (1,379 ± 293 ind/ha) followed by Scaridae (768 ± 98 ind/ha). Lutjanidae was the largest fish family by biomass (171 ± 73 kg/ha), with sharks (Carcharhinidae) the fourth largest (82 ± 54 kg/ha), and Lethrinidae the fifth largest (75 ± 48 kg/ha). Herbivores made up a substantial proportion of the fish community by biomass with Scariae the second largest group (123 ± 15 kg/ha) and Acanthuridae the third largest group (82 ± 15 kg/ha). It was *extremely likely* (W=15, p=0.04) that fish abundance was greater on the outer barrier reef sites than the inner reef coastal sites in Lekutu and Navakasiga (Figure 7.3.14). It was also *likely* (W=13, p=0.14) that fish biomass showed the same pattern.

It was *about as likely as not* (V=3, p=0.50) that key fisheries family abundance declined at the two sites with historic surveys in 2004 (Figure 7.3.15A). Key fisheries family abundance was 4,250 ± 1,310 ind/ha historically, declining to 1,572 ± 788 ind/ha in 2019. Declines occurred for both sites with historic data (Figure 7.3.15B). It was *about as likely as not* (V=3, p=0.50) that key fisheries family fish biomass declines, though we recorded biomass at 1,242 ± 723 kg/ha in 2004 and 201 ± 44 kg/ha in 2019 Figure 7.3.16A).

Figure 7.3.13. Fish community structure by (A) abundance and (B) biomass for Lekutu and Navakasiga *qoliqoli*.

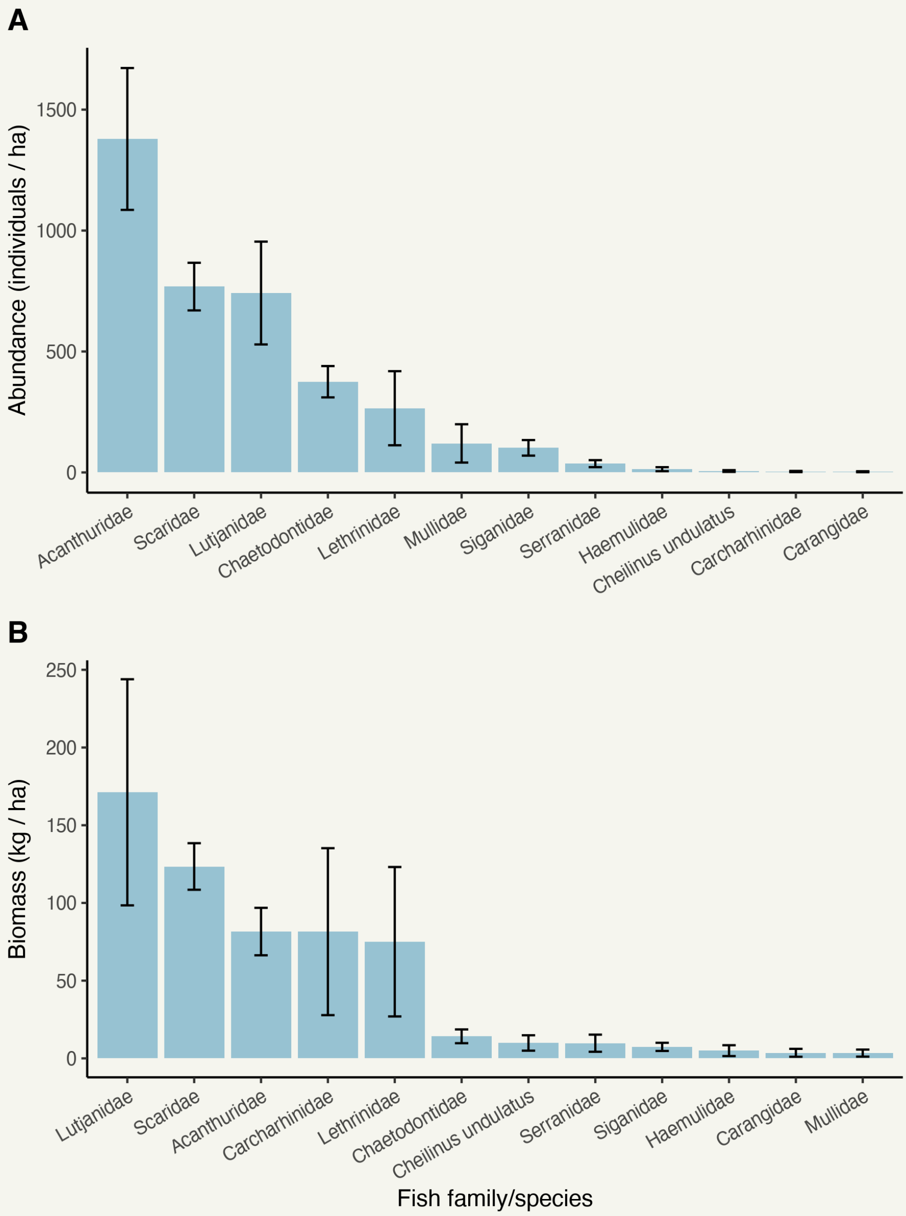


Figure 7.3.14. Overall fish (A) abundance and (B) biomass for sites surveyed in 2019 in Lekutu and Navakasiga *qoliqoli*. Results divided by subgroups representing broad reef types.

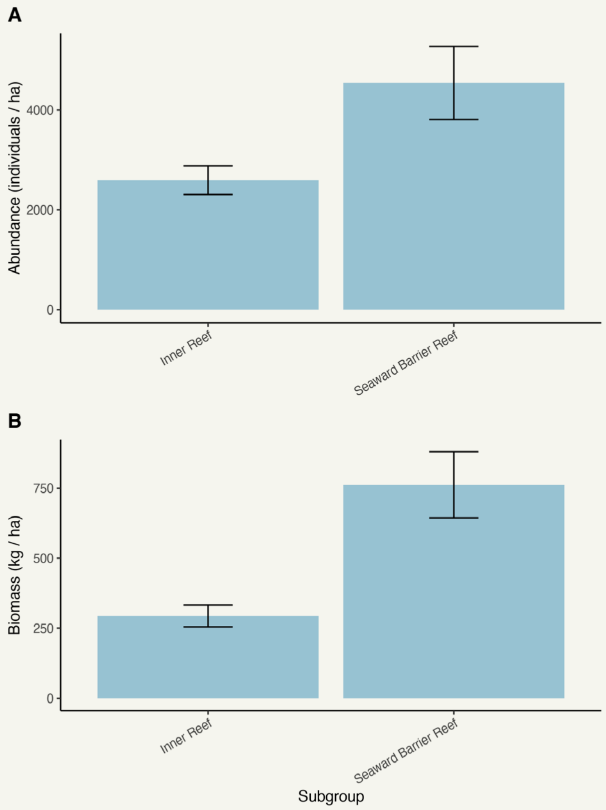


Figure 7.3.15. Change in key fisheries family abundance (Haemulidae, Lutjanidae, Scaridae, and Serranidae) for Lekutu and Navakasiga *qoliqoli* for (A) two sites with historic data and (B) separately based on reef type.

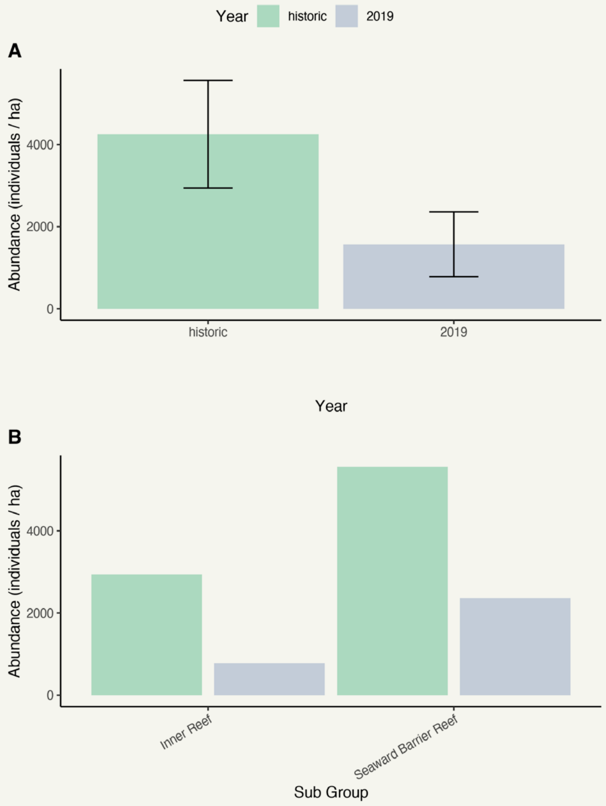
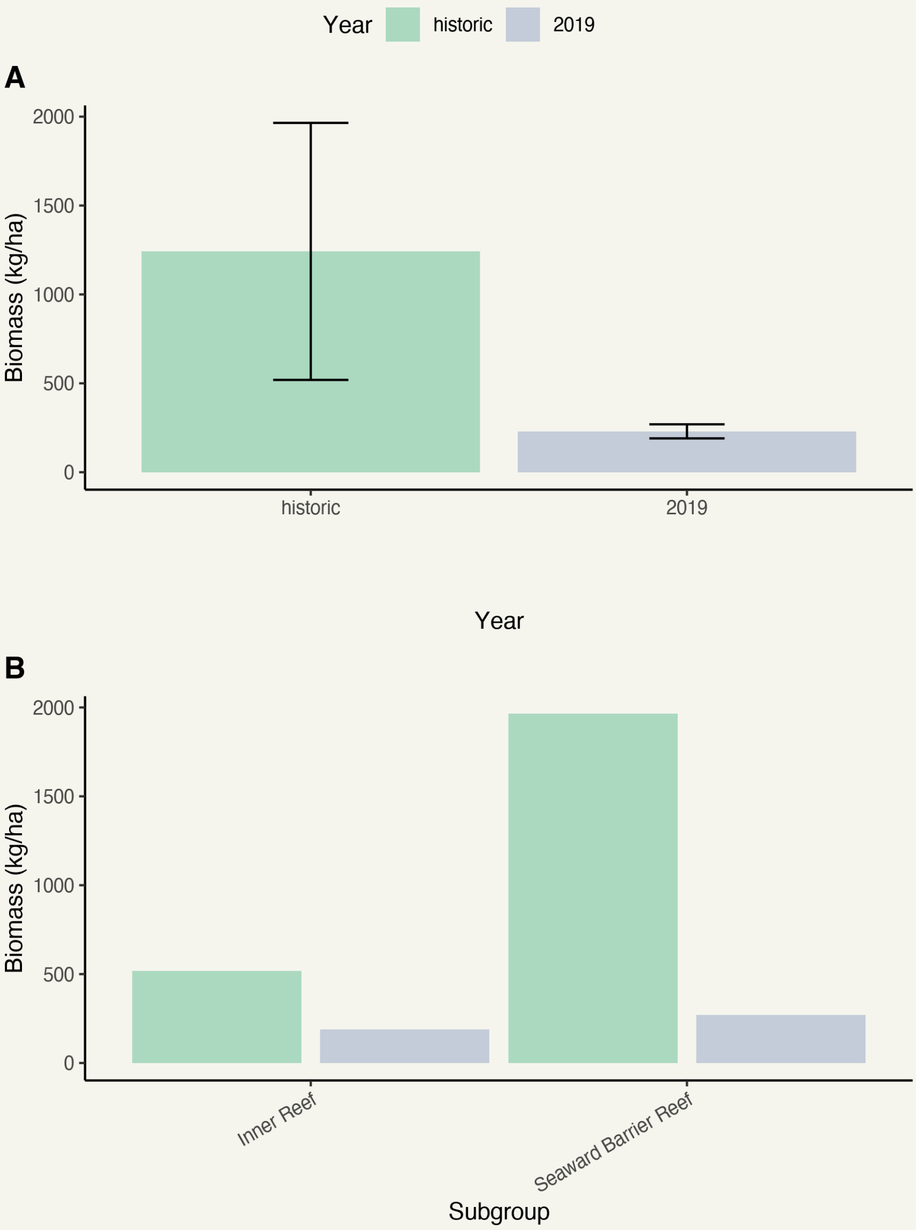


Figure 7.3.16. Change in key fisheries family biomass (Haemulidae, Lutjanidae, Scaridae, and Serranidae) for Lekutu and Navakasiga *qoliqoli* for (A) two sites with historic data and (B) separately based on reef type. Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.



7.3.5 Rare Species

Humphead wrasse were recorded at a density of 5.83 ± 3.61 ind/ha with a biomass of 9.91 ± 4.96 kg/ha across all sites surveyed in 2019 in Lekutu and Navakasiga *qoliqoli* (Figure 7.3.17). The two historic survey sites did not record any humphead wrasse, while the 2019 survey recorded their abundance at 8.33 ± 8.33 ind/ha. No bumphead parrotfish were recorded in Lekutu and Navakasiga *qoliqoli* during the historic or 2019 GSR survey.

Serranidae abundance and biomass was 36 ± 15 ind/ha and 45 ± 18 kg/ha, respectively, across all surveyed Lekutu and Navakasiga sites in 2019 (Figure 7.3.18). For the two sites with historic data, it was *about as likely as not* (V=3, p=0.50) that Serranidae abundance changed and *exceptionally unlikely* (V=2, p>0.99) that Serranidae biomass changed (Figure 7.3.18).

Sharks in the family Carcharhinidae were recorded at an abundance of 3.75 ± 2.48 ind/ha and biomass of 81 ± 54 kg/ha across all Lekutu and Navakasiga sites in 2019. Historic surveys did not recorded any sharks, while at these two sites in 2019 we recorded shark density as 3.94 ± 3.94 ind/ha (Figure 7.3.19).

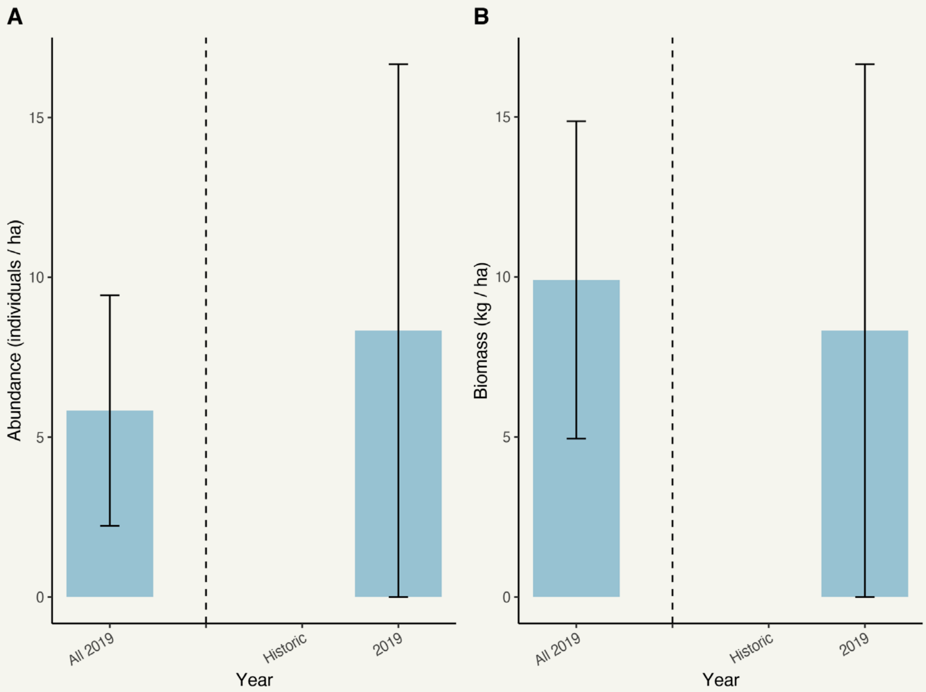


Figure 7.3.17. Humphead wrasse (*Cheilinus undulatus*) (A) abundance and (B) biomass for Lekutu and Navakasiga *qoliqoli*. Each panel shows data for all sites (left of dashed vertical line) and only the two sites with historic data available (right of dashed vertical line). Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.

Figure 7.3.18. Serranidae (grouper) (A) abundance and (B) biomass for Lekutu and Navakasiga *qoliqoli*. Each panel shows data for all sites (left of dashed vertical line) and only two sites with historic data available (right of dashed vertical line). Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.

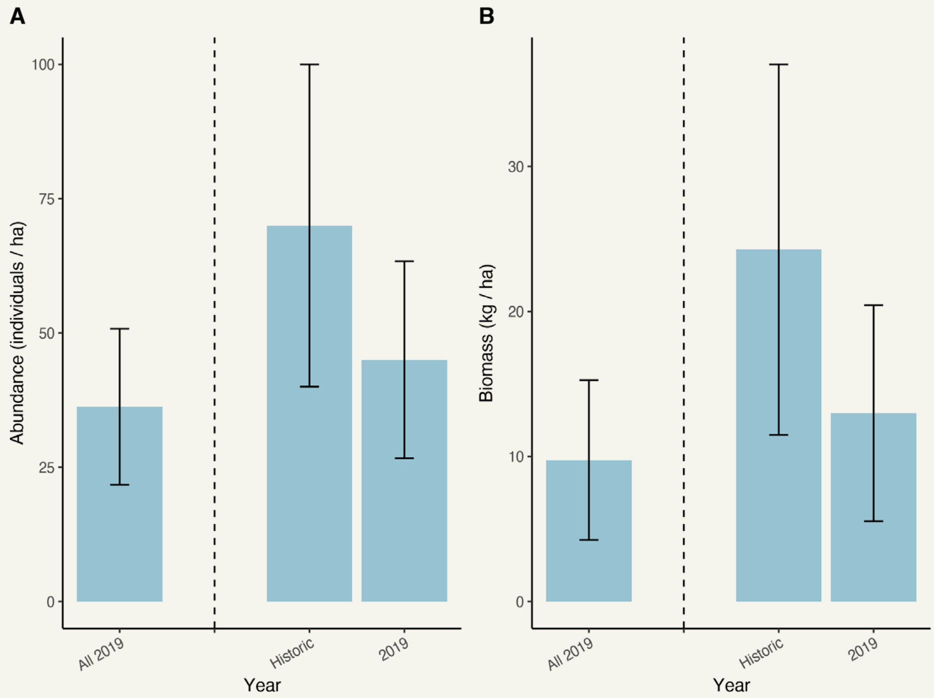
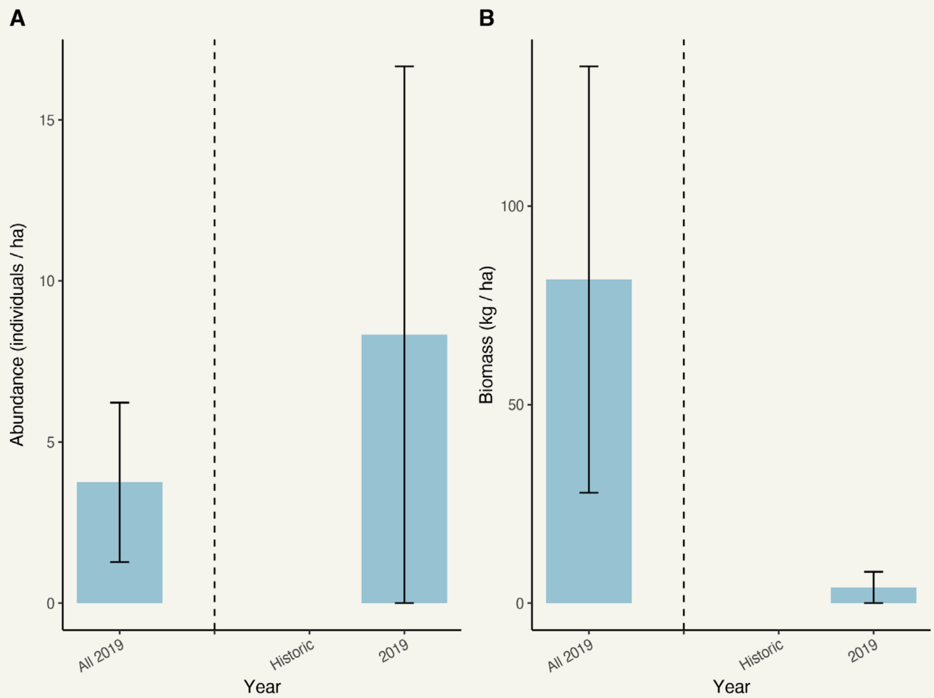


Figure 7.3.19. Carcharhinidae (shark) (A) abundance and (B) biomass for Lekutu and Navakasiga *qoliqoli*. Each panel shows data for all sites (left of dashed vertical line) and only two sites with historic data available (right of dashed vertical line). Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.



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One of the alternative livelihood projects of the Nakawaga village: beekeeping. The honey is then sold and generates income for the people outside of fishing. Mali Island, Macuata province, Vanua Levu, Fiji.


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8 MACUATA

8.1 Macuata province

8.1.1 Introduction and critical habitat coverage

Macuata province lies on the northern and north eastern coast of Vanua Levu. It has a land area of approximately 2,004 km^2 – approximately 40% of Vanua Levu area. The 2017 census indicated a population of approximately 66,000 people – making it one of the larger provinces in the GSR region and in Fiji. The waters of Macuata province are divided into seven *qoliqoli*, and span 2,038 km^2 (Figure 8.1.1). The province is bounded to the north by the main Cakaulevu barrier reef, which drops off into deep ocean to the north. Within this large area enclosed by the barrier reef there are many small patch reefs rising up from the seabed. Nearer to the Vanua Levu coastline are many mangrove fringed reef islands. Some of these islands enclose lagoons that are accessible by boats at high tide, and local communities fish within. There are also several larger uplifted islands along the coastline. Several major rivers flow into Macuata coastal waters, including the Dreketi and Labasa Rivers (Figure 8.1.2). These rivers carry substantial sediment to coastal inner reefs, increasing the turbidity.

Allen Coral Atlas mapping currently only exists for Vanua Levu for the eastern hemisphere. The antemeridian passes through Udu point, and so the coastal ecosystems of the eastern tip of Udu point are excluded from all presented ecosystem extent data.

Reefs take multiple forms within Macuata province, with shallow fringing reefs along the coastline of Vanua Levu, and extensive fringing reefs and reef flats around coastal islands. The main Cakaulevu barrier reef runs along the northern edge of the province marine area, including a 25 km double barrier reef to the northeast of Labasa (Figure 8.1.3). In total, coral covers approximately 154 km² within Bua province, though summing all Allen Coral Atlas benthic categories that likely contribute to broader coral reef ecosystem composition (i.e. coral/algae, microalgal mats, rock, and rubble) suggests a coverage of 349 km² of shallow reef-related ecosystems. The majority of these reefs are comprised of inner reef flats (111 km²), closely followed by outer reef flats (105 km²) and shallow lagoons (101 km²), with many other reef types also present (Figure 8.1.4).

Mangrove extent is high and reasonably stable in Bua province at 123 km², though 1 km of mangrove extent was lost within the province between 1996 and 2016 (Figures 8.1.5; 8.1.6). This high mangrove cover reflects the extensive coastline with rivers providing sediment input for mangroves, with especially dense mangrove stands adjacent to Labasa. The shallow coastal waters with many small islands also provide suitable substrate for extensive mangrove forests to form. Seagrass covers approximately 51 km² within Macuata province, with much of this split offshore within the lagoon formed by the outer barrier reefs (Figure 8.1.7). However, some narrow bands of seagrass are found close into shore on the north coast of Vanua Levu.

Figure 8.1.1. Bathymetry of Macuata province.

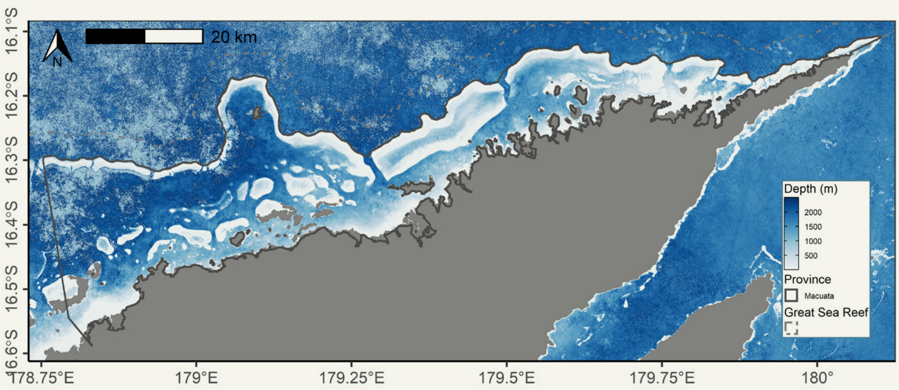


Figure 8.1.2. Sedimentation rates inside and adjacent to Macuata province.

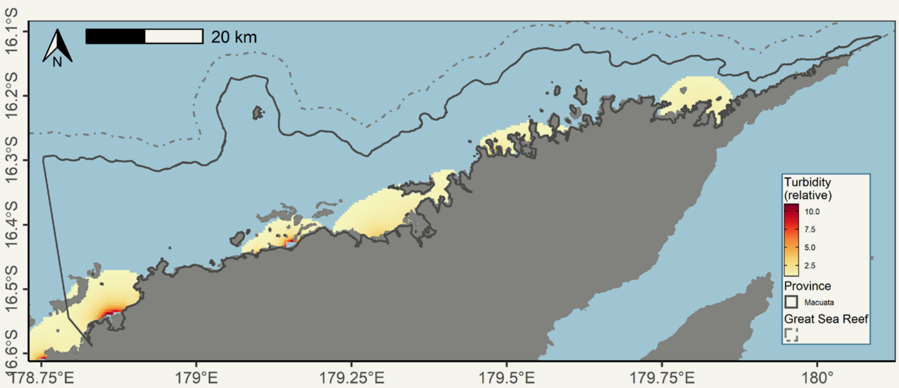


Figure 8.1.3. Coral reef extent in Macuata province.

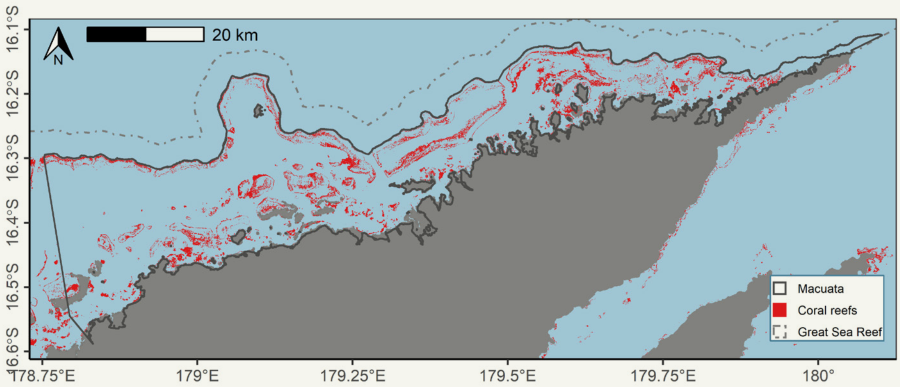


Figure 8.1.4. Coral reef geomorphic types in Macuata province.

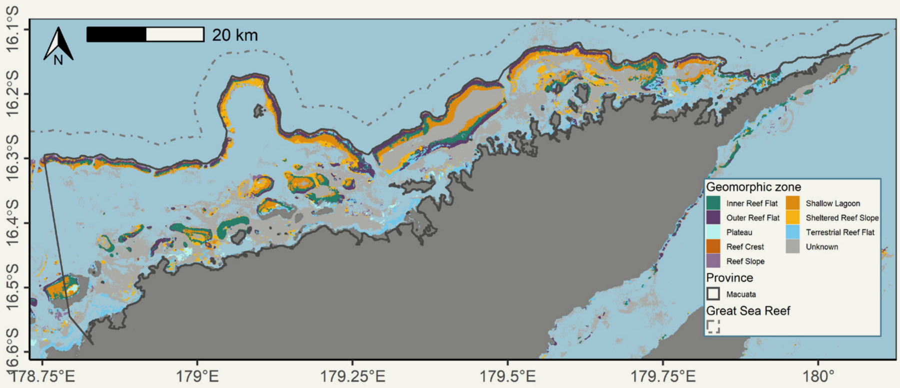


Figure 8.1.5. Mangrove extent in Macuata province.

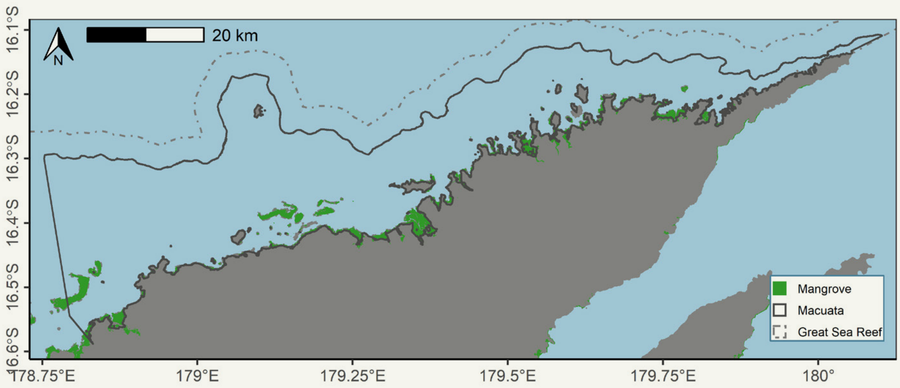


Figure 8.1.6. Mangrove change between 1996-2016 in Macuata province.

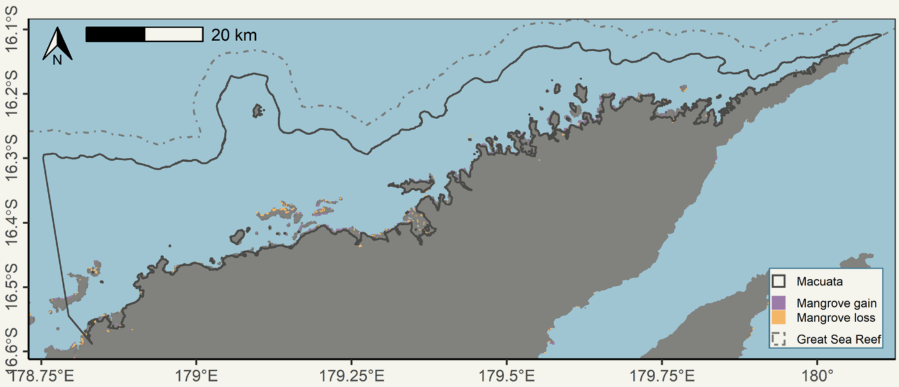
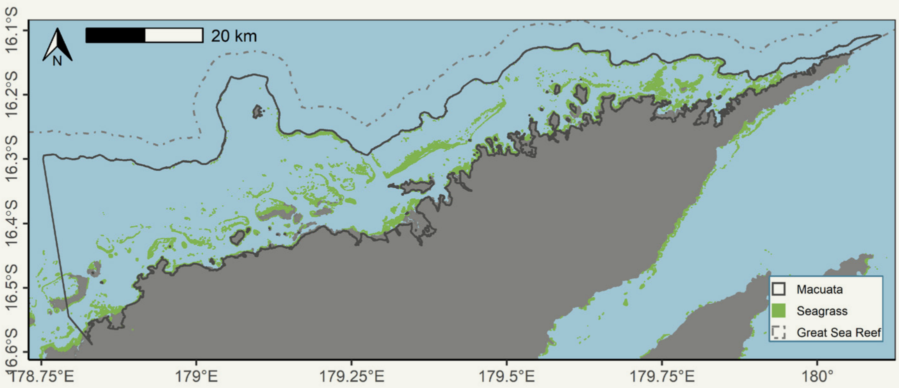


Figure 8.1.7. Seagrass cover in Macuata province.



8.1.2 Survey sites

Surveys were completed at 28 sites within Macuata province (Figure 8.1.8). Sites spanned the different reef types, with 16 sites on the outer barrier reef and channels through the reef, and 12 on islands within the lagoon. Most sites had some historic data available, with 18 sites surveyed by the WWF 2004 GSR survey and four sites were surveyed by Reef Check benthic bleaching assessments in 2000 (Lovell 2000) (Figure 8.1.8). This meant historic benthic data was available for 22 sites and historic fish abundance and biomass data was available for 18 sites within the province.

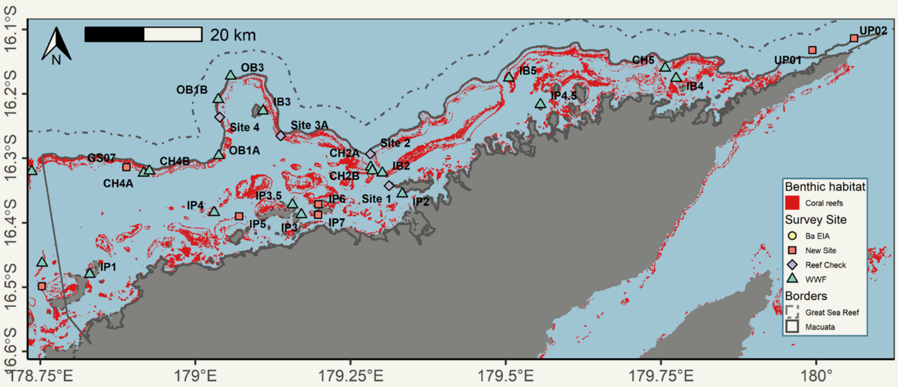


Figure 8.1.8. Survey sites in Macuata province.

8.1.3 Benthic cover

Hard coral cover was 36 ± 3% across reefs in Macuata province in 2019 (Figure 8.1.9). This value represents reasonably high coral cover, suggesting the benthic cover on these reefs is currently generally healthy. The second highest live benthic cover on reefs was soft coral, at 6 ± 1%. Non-living benthic cover was high in the province, with sand at 17 ± 2%, rubble at 14 ± 2%, and bare substrate at 11 ± 2% cover.

Sites surveyed in Macuata province split into three subgroups based on reef type and geographic location – (i) inner reef islands, (ii) seaward sites on the barrier reef (also including channels through the barrier reef), and (iii) leeward sites on the barrier reef. Both seaward and leeward reefs had the highest hard coral cover, at 38 ± 6% and 38 ± 9%, respectively (Figure 8.1.10), though inner reef islands also had similarly high coral cover. Macroalgae cover was similar between all three types of reefs – varying between 1-3% (Figure 8.1.10).

Historic benthic comparisons for Macuata province were based on 22 sites. Based on these sites, it was *unlikely* (W=203, p=0.67) that hard coral cover changed between baseline surveys in 2000 and 2004 and the 2019 survey (Figure 8.1.11). It was *extremely likely* (W=130, p=0.02) that algae cover increased, from 3 ± 1% to 6 ± 1%. There were also changes in non-living benthic cover. For example, it was *virtually certain* (W=368, p<0.01) that bare rock declined from 35 ± 3% in historic surveys to 17 ± 2%, and it was *virtually certain* (W=12, p<0.01) that rubble increased from 0.1 ± 0.1% in historic surveys to 16 ± 2% in 2019. There have been limited changes in other benthic groups (Figure 8.1.11). Breaking apart the data between the different subgroups (Figure 8.1.12), it was *likely* (W=24, p=0.16) that hard coral cover increased on inner reef sites (from 29 ± 4% to 37 ± 3%), while it was *likely* (W=53, p=0.30) that hard coral cover declined on seaward barrier reef sites (from 38 ± 5% to 30 ± 4%). It was *unlikely* (W=3, p=0.70) that there was any change in hard coral cover for leeward barrier reef sites. For algal change, it was *very likely* (W=19, p=0.06) that algae cover increased on the seaward barrier reef sites – from 2 ± 1% in historic surveys to 7 ± 2% in 2019. It was also *likely* (W=0, p=0.1) that algae cover increased on seaward sites on the barrier reef, from 2 ± 1% to 7 ± 2%.

Figure 8.1.9. Benthic cover in 2019 for Macuata province.

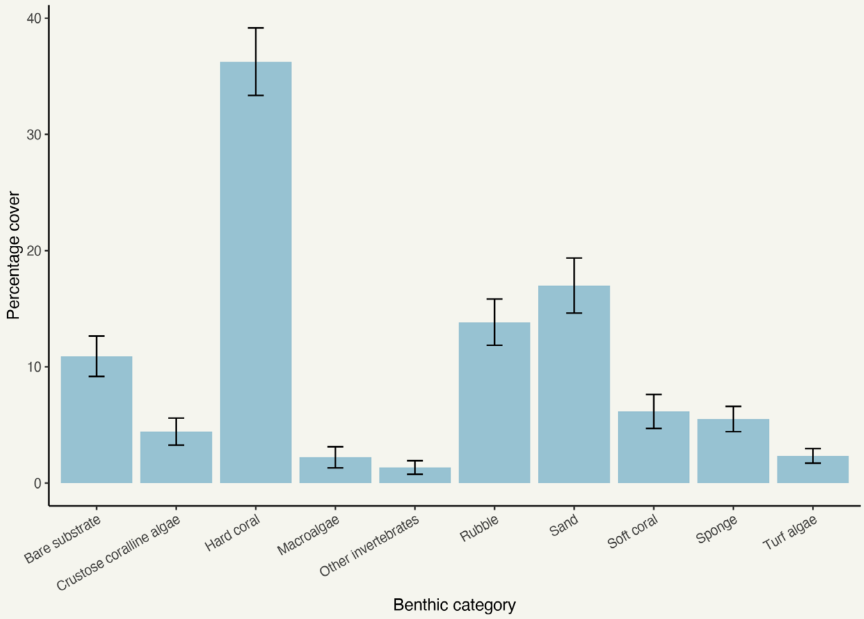


Figure 8.1.10. (A) Hard coral cover and (B) macroalgae cover by subgroup for sites within Macuata province.

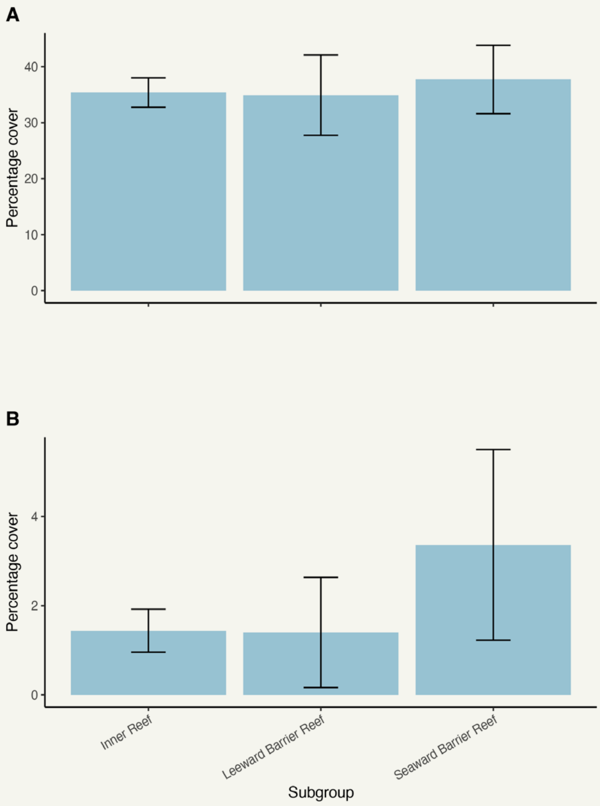


Figure 8.1.11. Change in benthic communities for Macuata province.

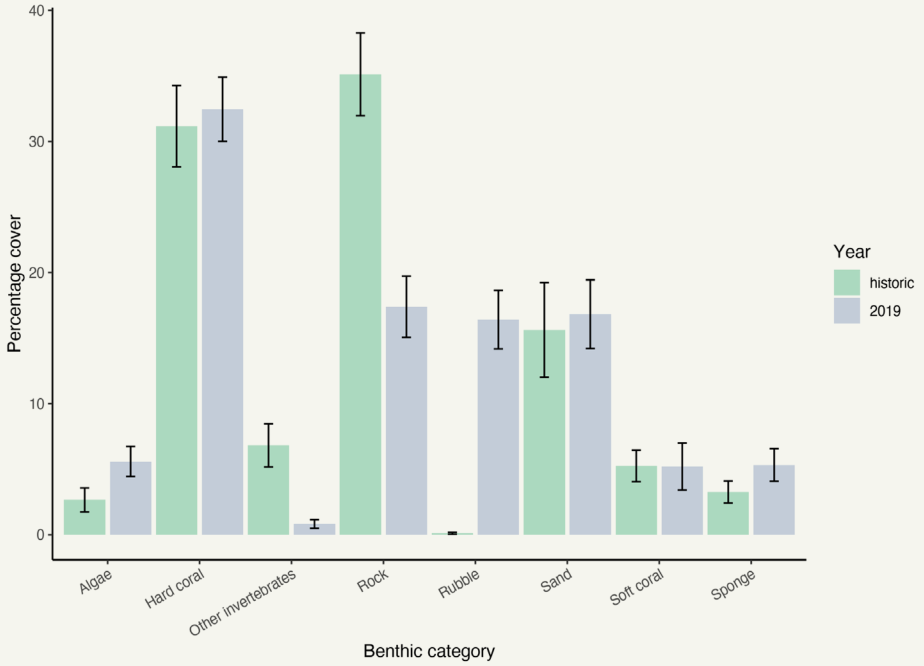
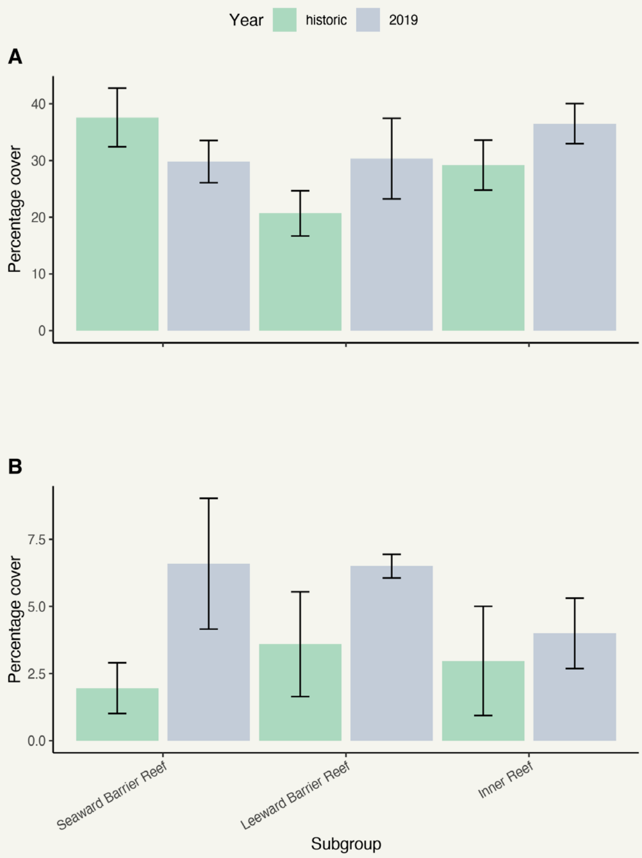


Figure 8.1.12. Change in (A) hard coral and (B) macroalgae cover for sites with historic data in Macuata province.



8.1.4 Fish communities

A mean fish abundance for the target family/species list of 3,072 ± 364 ind/ha was recorded across all Macuata province sites, while mean fish biomass was 462 ± 140 kg/ha. Fish communities were dominated by herbivores by abundance, but with a more even split between herbivores and carnivores by biomass (Figure 8.1.13). The most abundant fish family was Acanthuridae (1020 ± 165 ind/ha) followed by Scaridae (757 ± 151 ind/ha). Scaridae was the largest fish family by biomass (143 ± 42 kg/ha), with Acanthuridae the fourth largest (74 ± 13 kg/ha). Carnivores made up the largest proportion of the fish community by biomass with Carcharhinidae the second largest family by biomass (141 ± 72 kg/ha) and Lutjanidae the third largest group (131 ± 33 kg/ha). The seaward barrier reef (including sites within channels in the barrier reef) had the greatest fish biomass—at 924 ± 279 kg/ha—of the different subgroups based on reef type (Figure 8.1.14).

It was *likely* (V=118, p=0.16) that key fisheries family abundance declined from 2,269 ± 545 ind/ha in the historic 2004 surveys to 1,446 ± 294 ind/ha in 2019 in Macuata province (Figure 8.2.15). However, this lack of change marked differing trends based on different reef areas within the province (Figure 8.1.15). It was *likely* (V=28, p=0.20) that fish abundance declined at sites on the seaward barrier reef, and *likely* (V=22, p=0.21) that fish abundance declined on inner reef sites. It was *unlikely* (V=2, p=0.75) that fish abundance changed on the leeward side of the barrier reef. It was *virtually certain* (V=151, p<0.01) that key fisheries family fish biomass declined across the province. We recorded biomass at 1,409 ± 539 kg/ha in 2004 and 341 ± 101 kg/ha in 2019 (Figure 8.1.16). The greatest magnitude of biomass loss was on the seaward barrier reef, where it was *very likely* (V=31, p=0.08) that biomass declined, with 2004 surveys recording 2,141 ± 1,142 kg/ha compared to 490 ± 206 kg/ha in 2019. It was *extremely likely* (V=26, p=0.05) that fish biomass also declined in inner reefs, from 1,065 ± 401 kg/ha in 2004 to 268 ± 89 kg/ha in 2019. It was *likely* (V=6, p=0.25) that leeward barrier reef sites also declined in biomass.

Figure 8.1.13. Fish community structure by (A) abundance and (B) biomass for Macuata province.

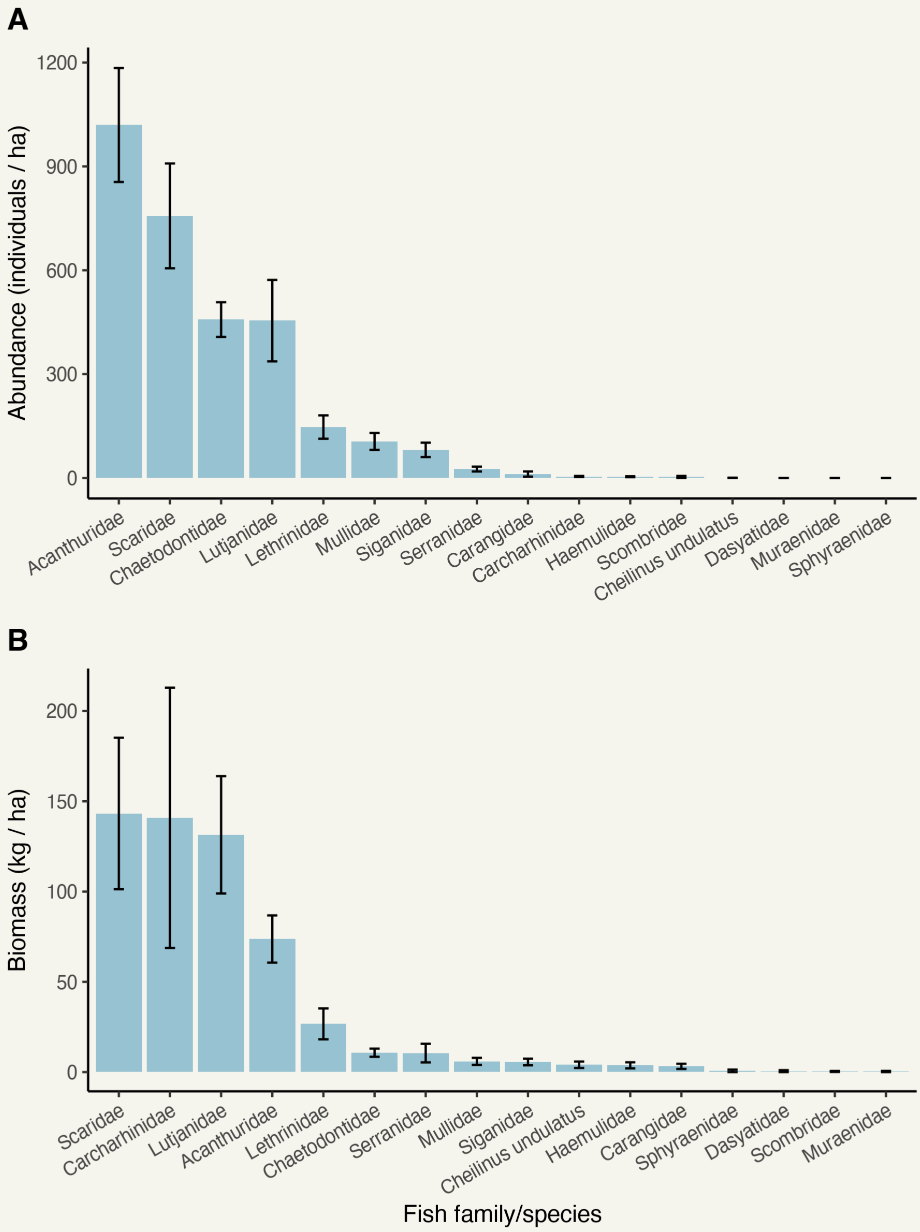


Figure 8.1.14. Overall fish (A) abundance and (B) biomass for sites surveyed in 2019 in Macuata province. Results divided by subgroups representing broad reef types.

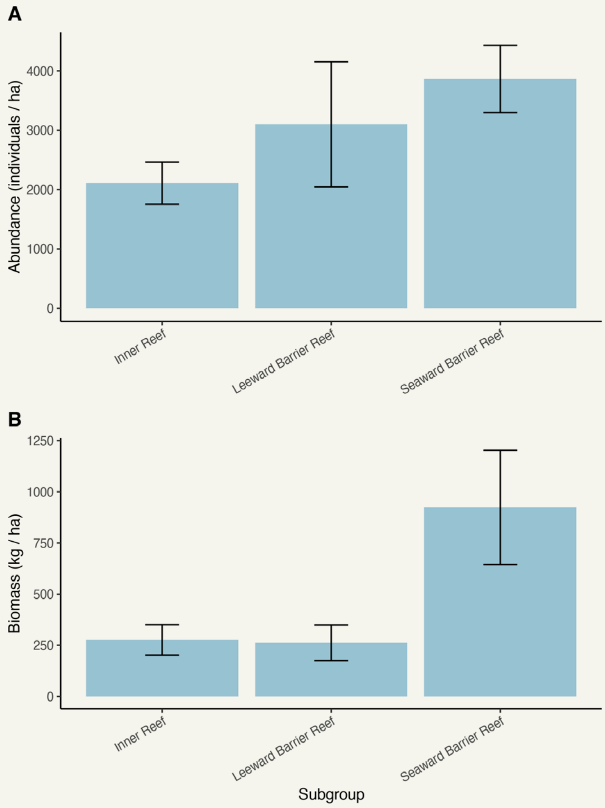


Figure 8.1.15. Change in key fisheries family abundance (Haemulidae, Lutjanidae, Scaridae, and Serranidae) for Macuata province for (A) all sites with historic data and (B) sites with historic data by subgroup.

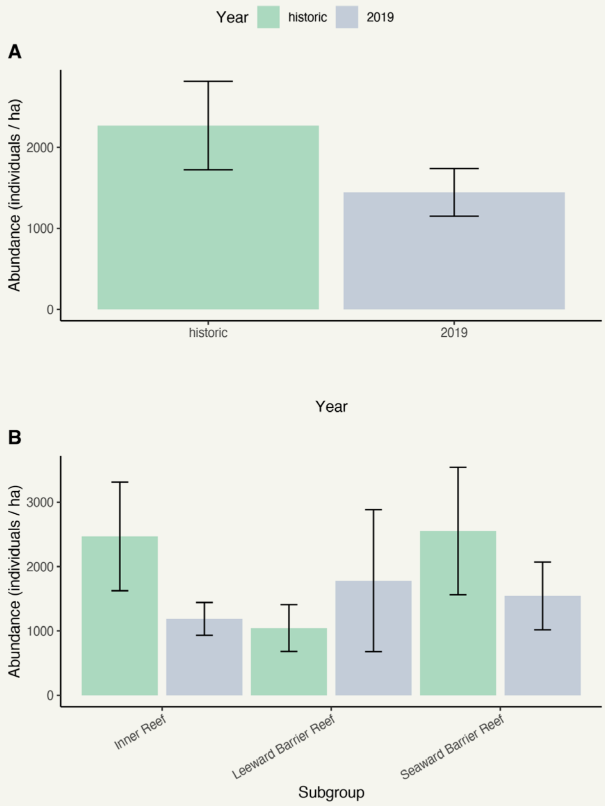
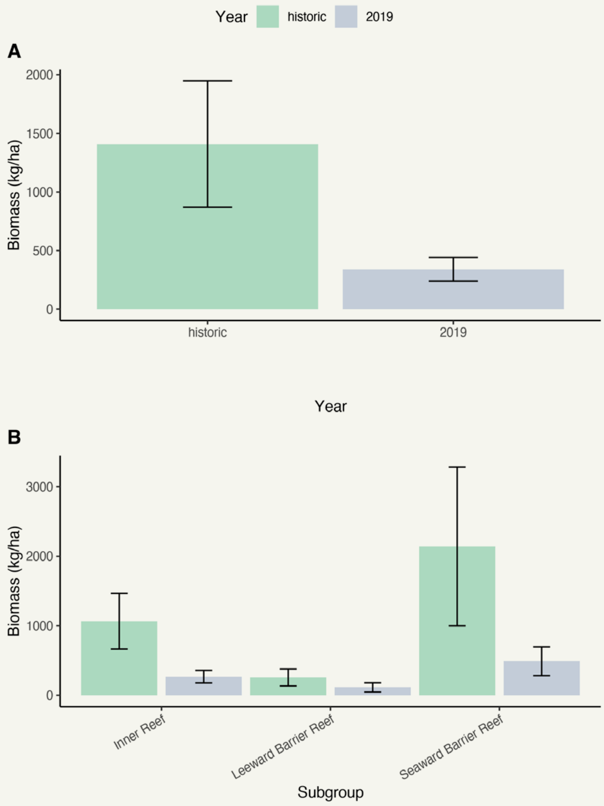


Figure 8.1.16. Change in key fisheries family biomass (Haemulidae, Lutjanidae, Scaridae, and Serranidae) for Macuata province for (A) all sites with historic data and (B) sites with historic data by subgroup. Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.



8.1.5 Rare Species

Humphead wrasse were recorded at a density of 0.62 ± 0.25 ind/ha with a biomass of 4.06 ± 1.78 kg/ha across all sites surveyed in 2019 in Macuata province (Figure 8.1.17). From the 18 surveys with historic fish data available, it was *likely* (V=14, p=0.10) that humphead wrasse abundance declined (from 7.77 ± 4.00 ind/ha to 0.56 ± 0.30 ind/ha), and it was *likely* (V=14, p=0.10) that biomass also declined (from 12.02 ± 5.94 kg/ha to 0.97 ± 0.52 kg/ha).

Bumphead parrotfish were recorded at a density of 0.49 ± 0.49 ind/ha with a biomass of 0.12 ± 0.12 kg/ha across all sites surveyed in 2019 in Macuata province (Figure 8.1.18). From the 18 surveys with historic fish data available, it was *about as likely as not* (V=5, p=0.42) that bumphead parrotfish abundance and biomass declined between 2004 historic surveys and the 2019 survey (Figure 8.1.18). These results are unsurprising for a rare schooling fish such as bumphead parrotfish, as the 2004 survey encountered a single large school compared to the individual juvenile observed during the 2019 survey.

Serranidae abundance and biomass was 26 ± 7 ind/ha and 11 ± 5 kg/ha, respectively, across all surveyed Macuata sites in 2019 (Figure 8.1.19). For the 18 sites with historic data, it was *virtually certain* (V=163, p<0.01) that Serranidae abundance declined, with historic surveys recording 222 ± 77 ind/ha and 2019 surveys recording 34 ± 10 ind/ha (Figure 8.1.19). It was very likely (V=130, p=0.05) that Serranidae biomass also declined, from 19 ± 5 kg/ha in 2004 to 8 ± 4 kg/ha in 2019.

Sharks in the family Carcharhinidae were recorded at an abundance of 4.32 ± 1.73 ind/ha and biomass of 141 ± 72 kg/ha across all Macuata sites in 2019. Historic surveys recorded shark abundance at 12 ± 6 ind/ha, and it was *likely* (V=26, p=0.32) that abundance declined as at these sites in 2019 we recorded shark abundance at 5 ± 2 ind/ha (Figure 8.1.20). It was *unlikely* (V=21, p=0.73) that shark biomass changed, though caution is needed in comparing these data as all individuals recorded >45 cm length were recorded as 45 cm, making biomass comparisons unreliable.

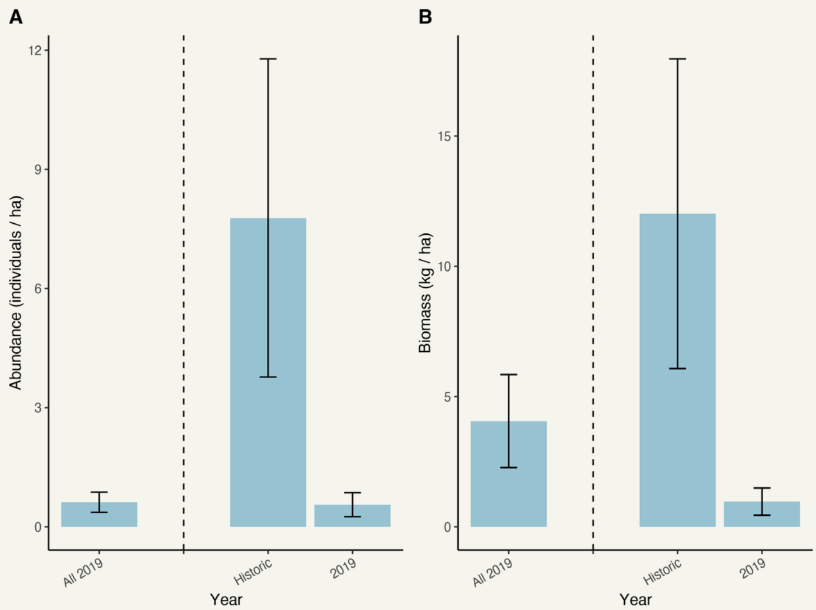


Figure 8.1.17. Humphead wrasse (*Cheilinus undulatus*) (A) abundance and (B) biomass for Macuata province. Both panels show data for all 2019 sites to the left of dashed vertical line, and only the sites with historic data available to the right of dashed vertical line. Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.

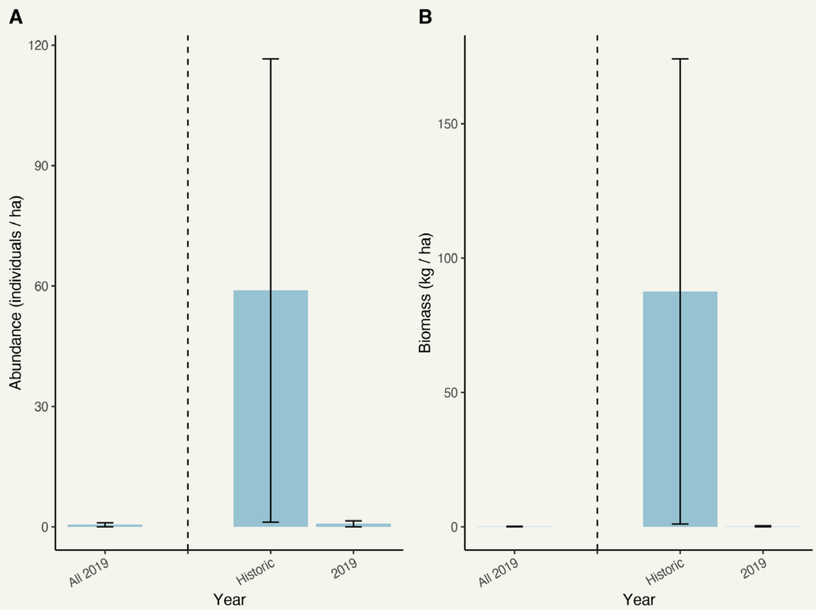


Figure 8.1.18. Bumphead parrotfish (Bolbometopon muricatum) (A) abundance and (B) biomass for Macuata province. Both panels show data for all 2019 sites to the left of dashed vertical line, and only the sites with historic data available to the right of dashed vertical line. Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.

Figure 8.1.19. Serranidae (grouper) (A) abundance and (B) biomass for Macuata province. Each panel shows data for all sites (left of dashed vertical line) and only the sites with historic data available (right of dashed vertical line). Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.

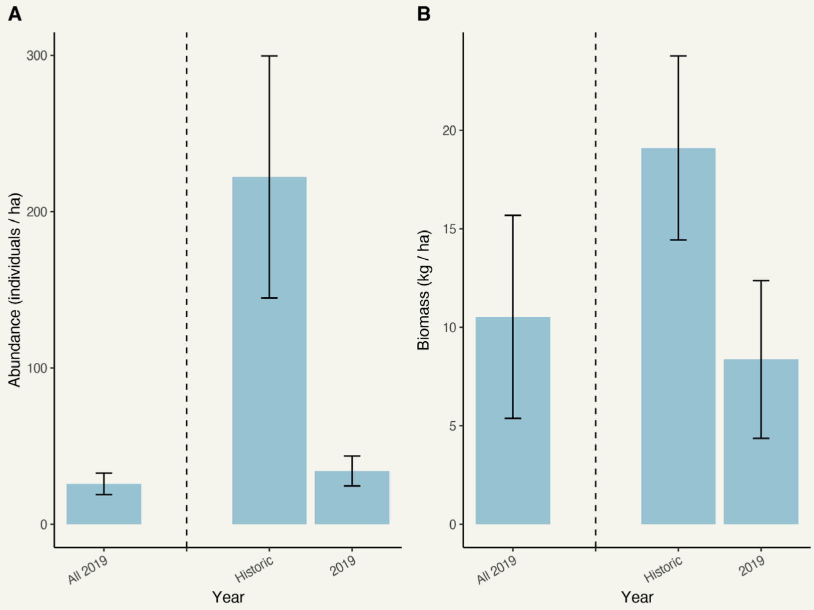
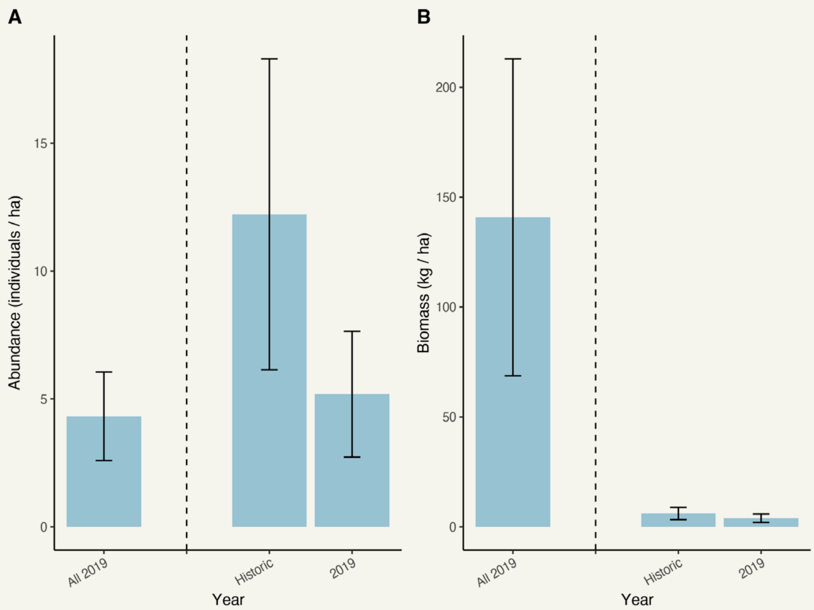


Figure 8.1.20. Carcharhinidae (shark) (A) abundance and (B) biomass for Macuata province. Each panel shows data for all sites (left of dashed vertical line) and only the sites with historic data available (right of dashed vertical line). Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.



8.2 Qoliqoli Cokovata (Macuata, Seaqaqa, Dreketi, Sasa, and Mali)

8.2.1 Introduction and critical habitat coverage

Qoliqoli Cokovata is the combined area from the Macuata, Seaqaqa, Dreketi, Sasa, and Mali *qoliqoli*; together they comprise a single marine area of 1,345 km^2 located along the north coast of Macuata province on the north coast of Vanua Levu (Figure 8.2.1). The area contains a mix of shallow water and deeper water areas, with extensive fringing reef systems and mangrove islands. The northern edge of Qoliqoli Cokovata is bounded by the offshore barrier reef. As the *qoliqoli* is located adjacent to Vanua Levu, there is substantial sedimentation impact in coastal areas, with several important rivers flowing into the area (Figure 8.2.2). Qoliqoli Cokovata was declared Fiji's second Ramsar site in 2018.

Reefs take multiple forms within Qoliqoli Cokovata, with shallow fringing reefs along the northern coastline of Vanua Levu and extensive fringing reefs and reef flats around coastal mangrove islands. Part of the main Cakaulevu barrier reef, as well as several small reefs contained behind Cakaulevu, exist in the area (Figure 8.2.3). In total, coral covers approximately 92 km^2 within the *qoliqoli*, though summing all Allen Coral Atlas benthic categories that likely contribute to broader coral reef ecosystem composition (i.e. coral/algae, microalgal mats, rock, and rubble) suggests a coverage of 209 km^2 of shallow reef-related ecosystems. The majority of these reefs are comprised of inner reef flats (72 km^2), followed by significant areas of outer reef flats (64 km^2), shallow lagoonal reefs (58 km^2), and sheltered reef slopes (55 km^2), with other reef types also present (Figure 8.2.4).

Mangrove extent is 46 km^2, with no change between 1996 and 2016 (Figures 8.2.5; 8.2.6). This mangrove cover reflects the extensive coastline with rivers providing sediment input for mangroves. The shallow coastal waters with many small islands also provide suitable substrate for extensive mangrove forests to form. Seagrass covers approximately 23 km^2 within Qoliqoli Cokovata, with much of this split in the coastal areas of Vanua Levu and the small islands adjacent to the shoreline (Figure 8.2.7). However, some narrow bands of seagrass are found associated with the Cakaulevu offshore reef.

8.2.2 Survey sites

Surveys were completed at 22 sites within Qoliqoli Cokovata (Figure 8.2.8). Of these sites, 12 were located on the offshore barrier reef or in the channels passing through the barrier reef, while 10 sites were on islands in lagoons between the Vanua Levu coast and the offshore barrier reef. Across the 22 sites, 14 were previously surveyed by WWF in 2004, four were surveyed for benthic data by Reef Check in 2000 (Lovell 2000), and four were new sites (Figure 8.2.8).

Figure 8.2.1. Bathymetry of Qoliqoli Cokovata.

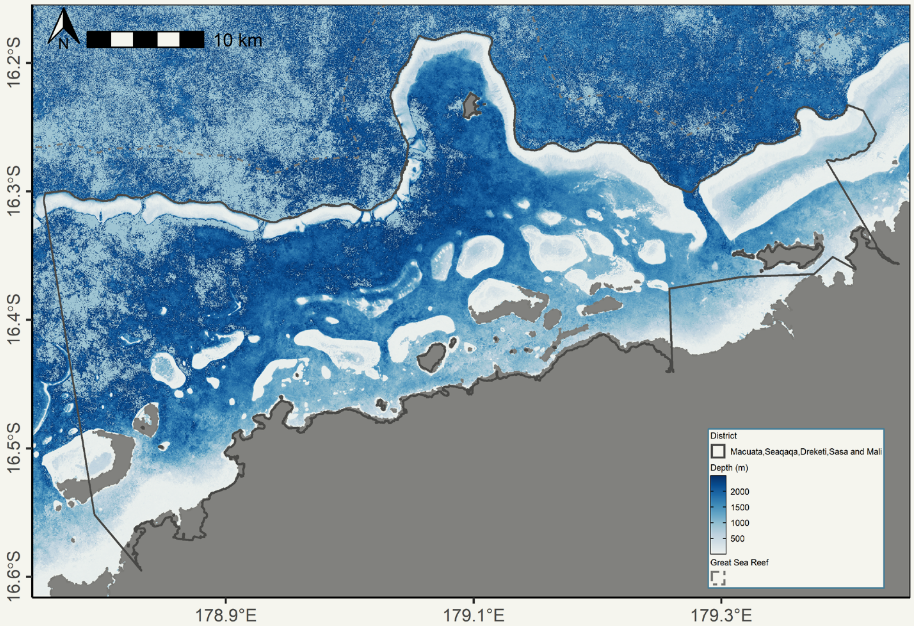


Figure 8.2.2. Sedimentation rates inside and adjacent to Qoliqoli Cokovata.

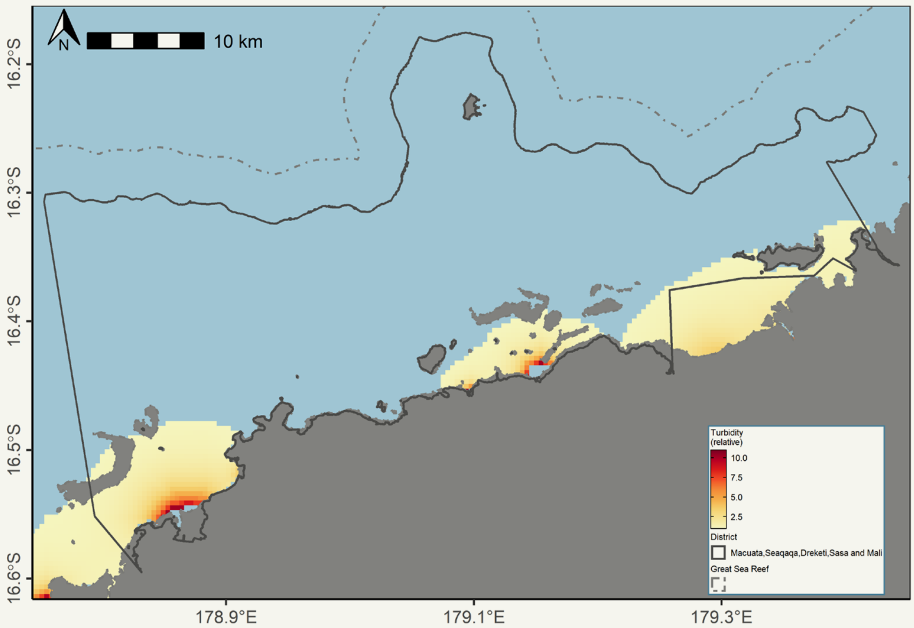


Figure 8.2.3. Coral reef extent in Qoliqoli Cokovata.

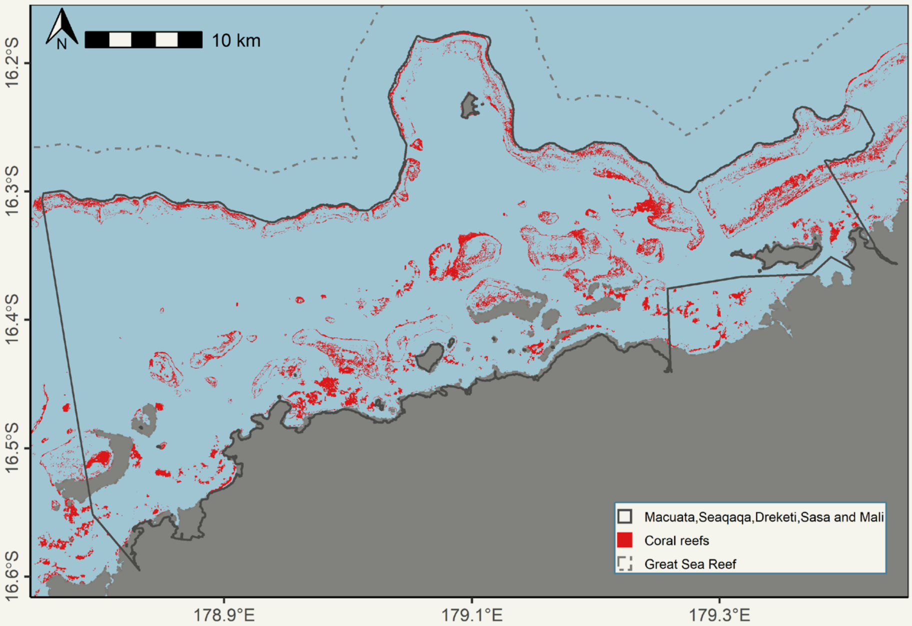


Figure 8.2.4. Coral reef geomorphic types in Qoliqoli Cokovata.

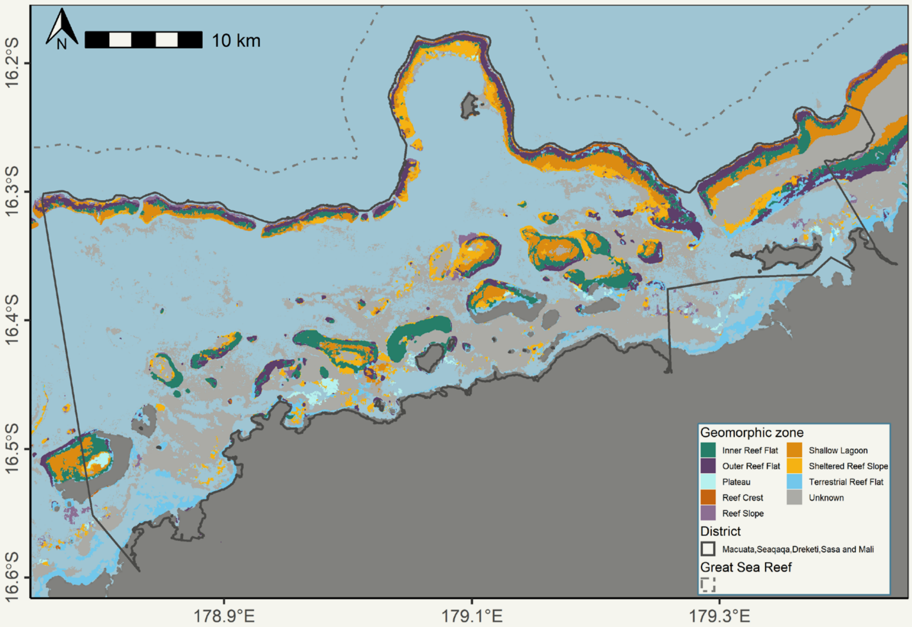


Figure 8.2.5. Mangrove extent in Qoliqoli Cokovata.

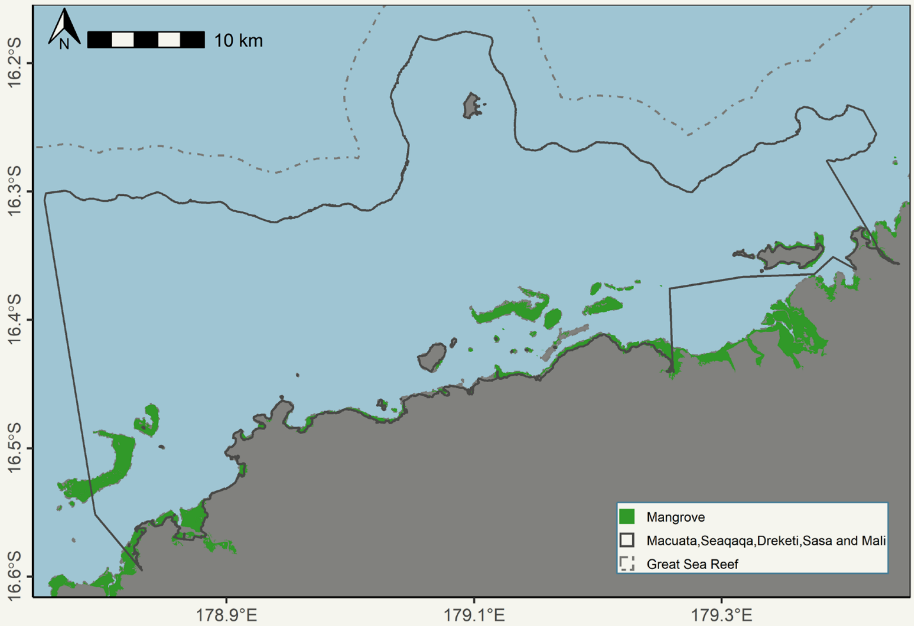


Figure 8.2.6. Mangrove change between 1996-2016 in Qoliqoli Cokovata.

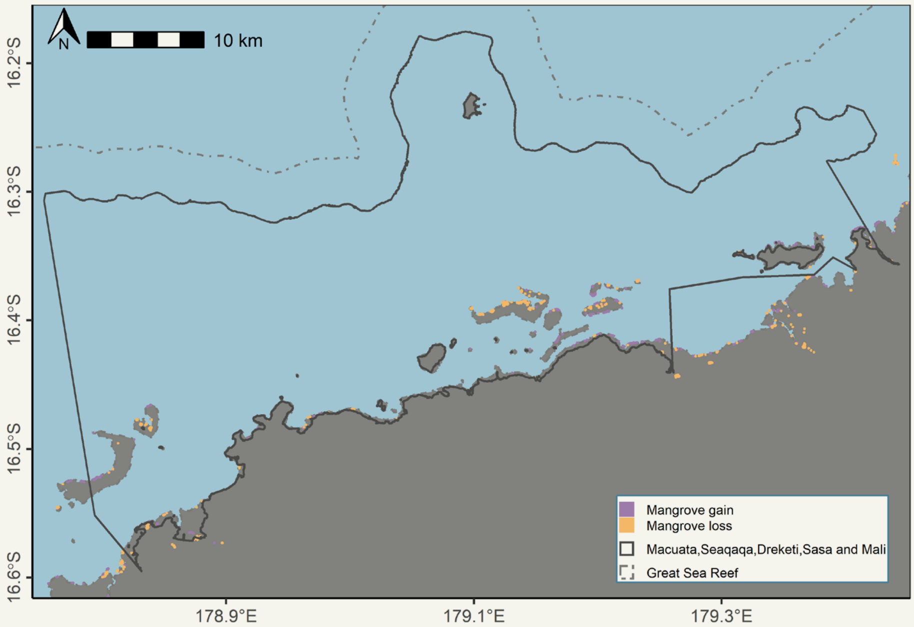


Figure 8.2.7. Seagrass cover in Qoliqoli Cokovata.

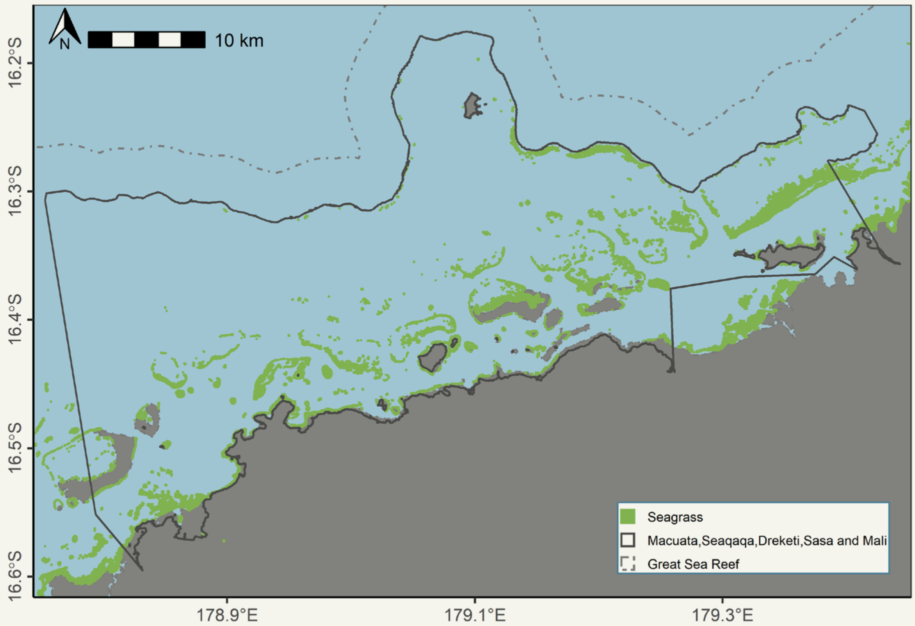
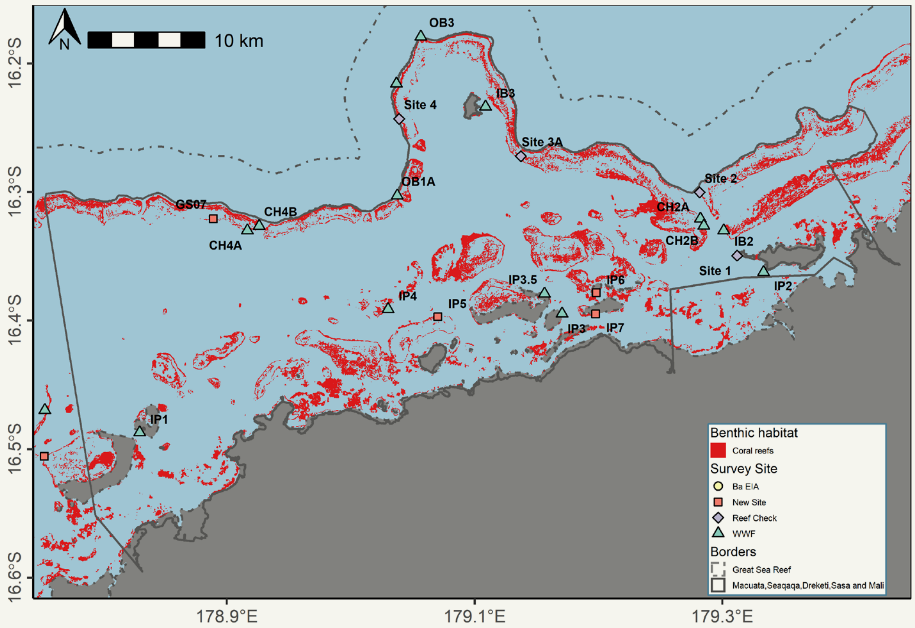


Figure 8.2.8. Survey sites in Qoliqoli Cokovata.



8.2.3 Benthic cover

Hard coral cover was 35 ± 2% across reefs in Qoliqoli Cokovata in 2019 (Figure 8.2.9). The second highest live benthic cover on reefs was soft coral, at 7 ± 2%. Non-living benthic cover was high in Qoliqoli Cokovata, with sand at 20 ± 3%, rubble at 12 ± 2%, and bare substrate at 11 ± 2% cover.

Sites surveyed in Qoliqoli Cokovata split into three subgroups based on reef type and geographic location– (i) inner reef islands, (ii) seaward sites on the barrier reef (also including channels through the barrier reef), and (iii) leeward sites on the barrier reef. All three types of reef had similar hard coral cover (Figure 8.2.10). Macroalgae cover, however, was similar between inner reefs and the leeward side of the barrier reef, but higher on the seaward side of the barrier reef (Figure 8.2.10).

From comparisons with historic survey data for Qoliqoli Cokovata, it was about as *likely as not* (W=127, p=0.56) that hard coral cover changed between baseline surveys in 2000 and 2004 and the 2019 survey (Figure 8.2.11). It was *extremely likely* (W=83, p=0.03) that algae cover increased, from 2 ± 1% to 5 ± 1 %. It was also *likely* (W=107, p=0.20) that sponge cover increased, from 3 ± 1% to 5 ± 1%. There have been limited changes in other living benthic groups (Figure 8.2.11), though it is *virtually certain* (W=10, p<0.01) that rubble cover has increased – from <1% historically to 14 ± 2% in 2019. It is also *virtually certain* (W=231, p<0.01) that rock has declined from 33 ± 4% to 14 ± 2%. Breaking apart the data between the sites on the seaward and leeward barrier reefs and the inner reef shows that hard coral cover has generally been consistent through time across all reef types (Figure 8.2.12). However, it is *very likely* (W=14, p=0.06) that algae increased on the seaward barrier reef (2 ± 1% increasing to 6 ± 3%) and it is *likely* (W=0, p=0.10) that algae also increased on the leeward barrier reef (2 ± 1% increasing to 7 ± 1%) (Figure 8.2.12).

Figure 8.2.9. Benthic cover in 2019 for Qoliqoli Cokovata.

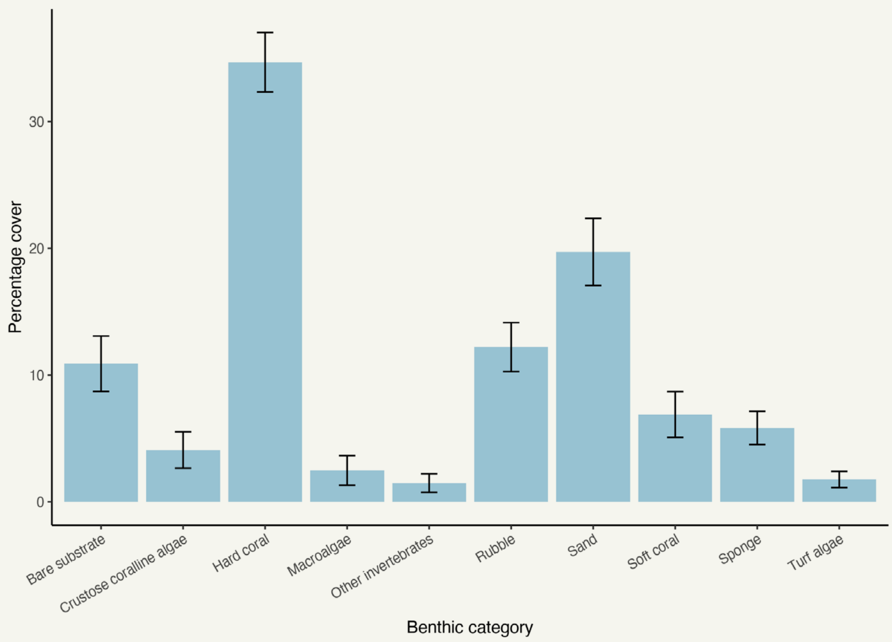


Figure 8.2.10. (A) Hard coral cover and (B) macroalgae cover by subgroup for sites within Qoliqoli Cokovata.

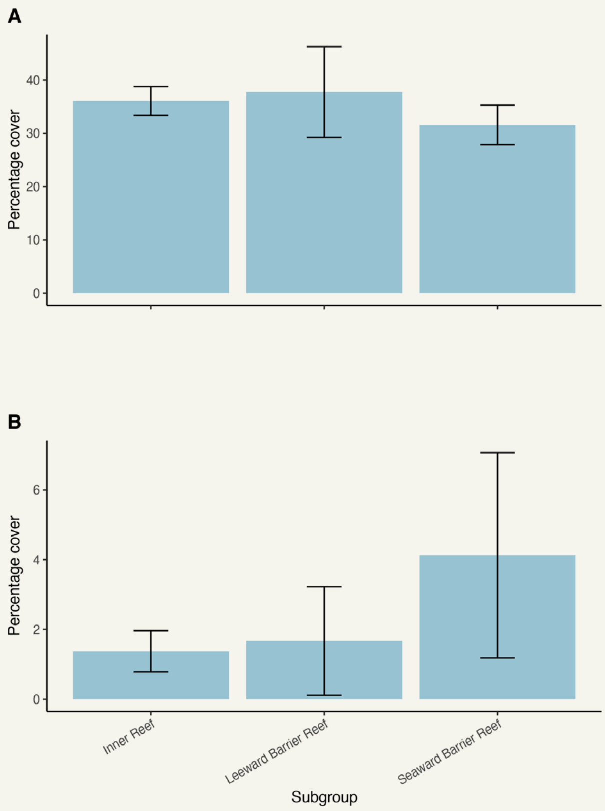


Figure 8.2.11. Change in benthic communities for Qoliqoli Cokovata.

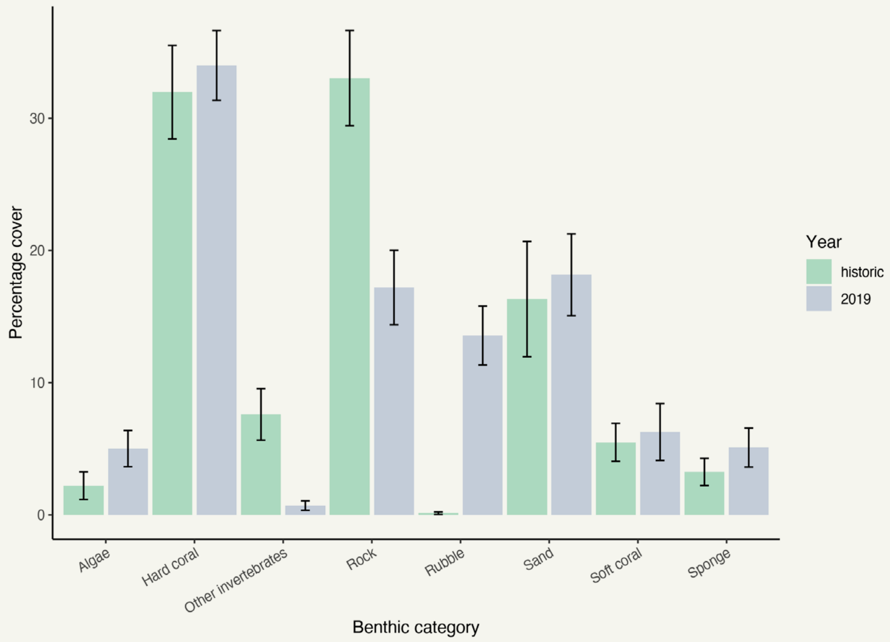
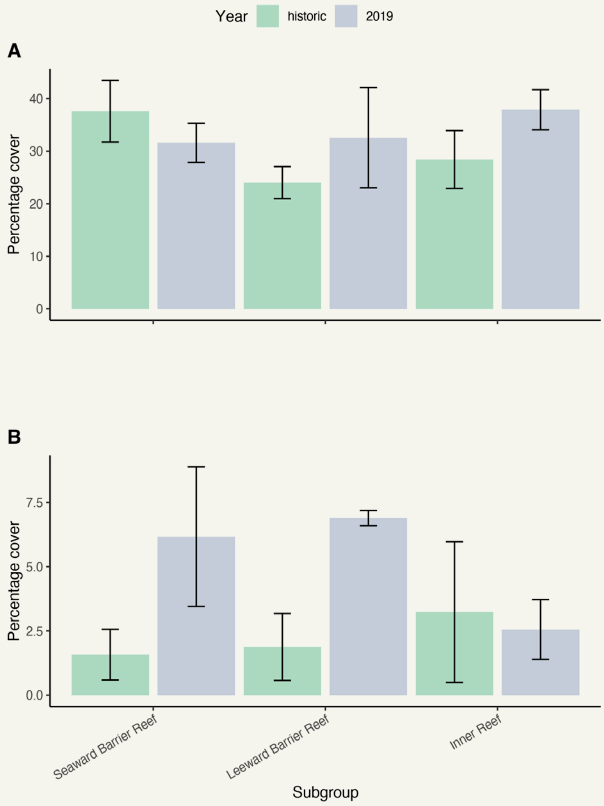


Figure 8.2.12. Change in (A) hard coral and (B) macroalgae cover for the seaward outer barrier reef, the leeward side of the outer barrier reef, and the inner reef lagoonal island sites within Qoliqoli Cokovata.



8.2.4 Fish communities

A mean fish abundance for the target family/species list of 3,102 ± 462 ind/ha was recorded across all Qoliqoli Cokovata sites, while mean fish biomass was 662 ± 174 kg/ha. Fish communities were dominated by herbivores by abundance, but by carnivores by biomass (Figure 8.2.13). The most abundant fish family was Acanthuridae (1,030 ± 209 ind/ha), followed by Scaridae (820 ± 188 ind/ha). Carcharhinidae was the largest fish family by biomass (181 ± 91 kg/ha), with Lutjanidae the third largest (146 ± 40 kg/ha). Herbivores still made up a substantial proportion of the fish community by biomass, with Scaridae the second largest group (174 ± 52 kg/ha) and Acanthuridae the fourth largest group (80 ± 16 kg/ha). Fish abundance and biomass varied by reef type, with the greatest biomass recorded on the seaward outer barrier reef (Figure 8.2.14).

It was *likely* (V=73, p=0.22) that key fisheries family abundance declined from 2,457 ± 686 ind/ha to 1,551 ± 372 ind/ha (Figure 8.2.15A). Declines occurred for both sites with historic data (Figure 8.2.15B). It was also *likely* (V=22, p=0.22) that key fisheries family fish abundance declined at the seaward barrier reef (Figure 8.2.15B). It was *extremely likely* (V=92, p=0.01) that fish biomass declined across Qoliqoli Cokovata sites for the key fisheries families. Historic surveys recorded biomass at 1,668 ± 681 kg/ha in 2004 compared to 416 ± 123 kg/ha in 2019 (Figure 8.2.16A). Biomass declines were particularly severe on the seaward side of the barrier reef, where it was *likely* (V=24, p=0.11) that fish biomass declined from 2,343 ± 1,298 kg/ha to 535 ± 233 kg/ha (Figure 8.2.16B).

Figure 8.2.13. Fish community structure by (A) abundance and (B) biomass for Qoliqoli Cokovata.

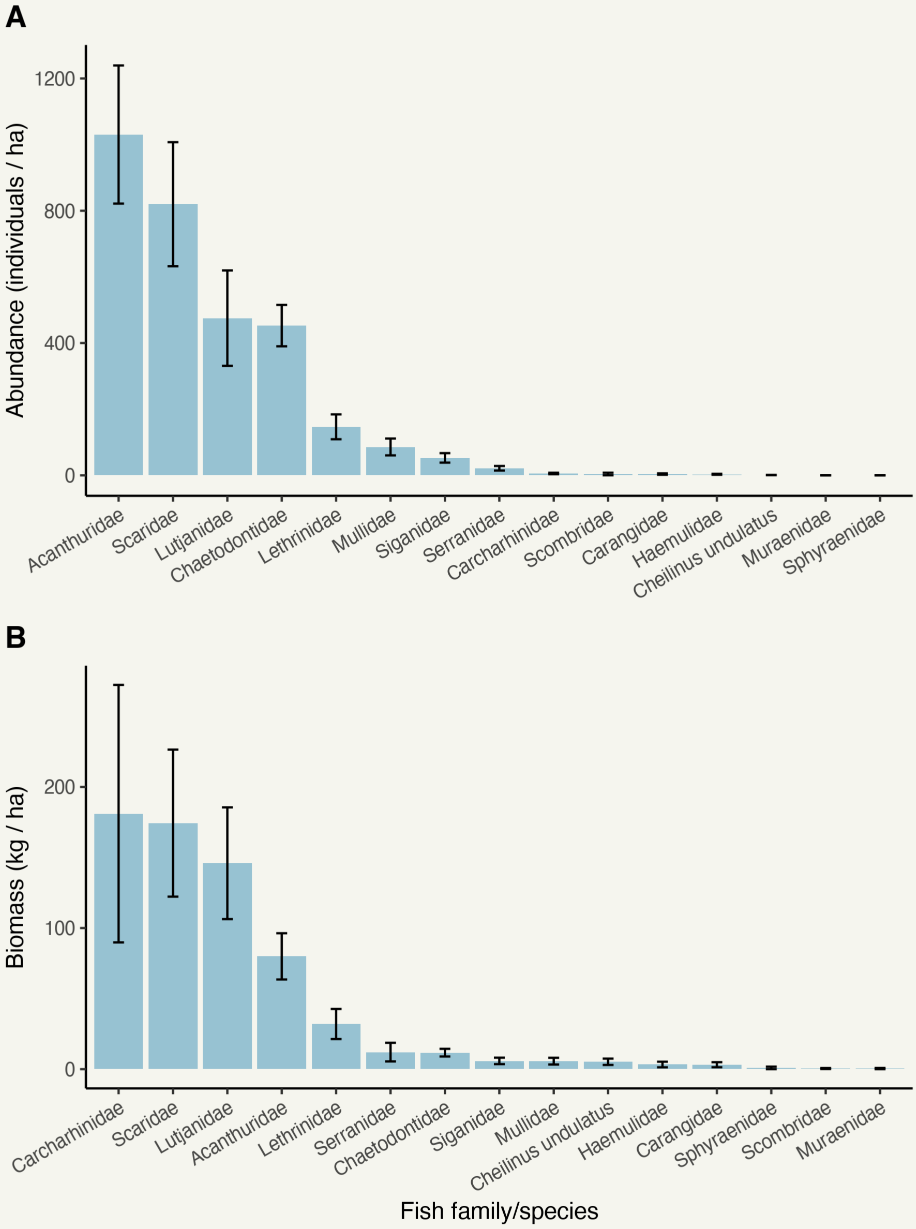


Figure 8.2.14. Overall fish (A) abundance and (B) biomass for sites surveyed in 2019 in Qoliqoli Cokovata. Results divided by subgroup representing broad reef types.

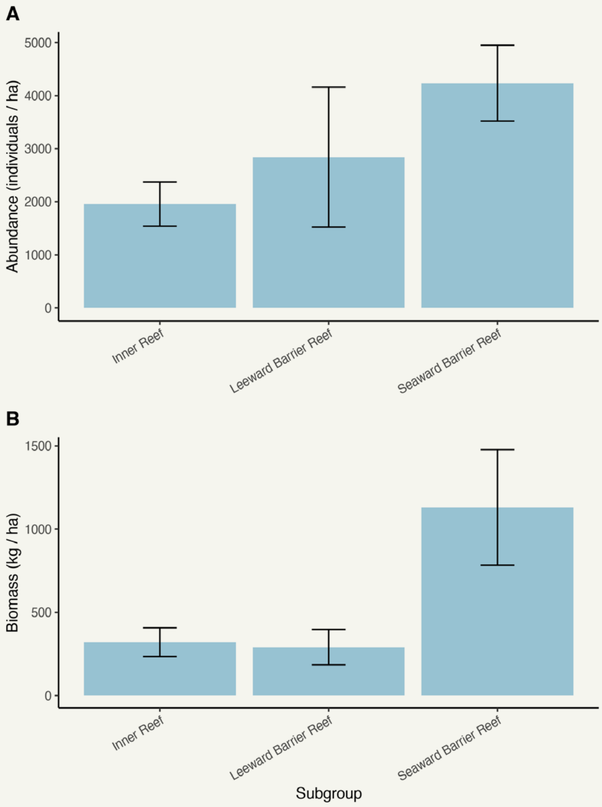


Figure 8.2.15. Change in key fisheries family abundance (Haemulidae, Lutjanidae, Scaridae, and Serranidae) for Qoliqoli Cokovata for (A) all sites with historic data and (B) separately based on reef type.

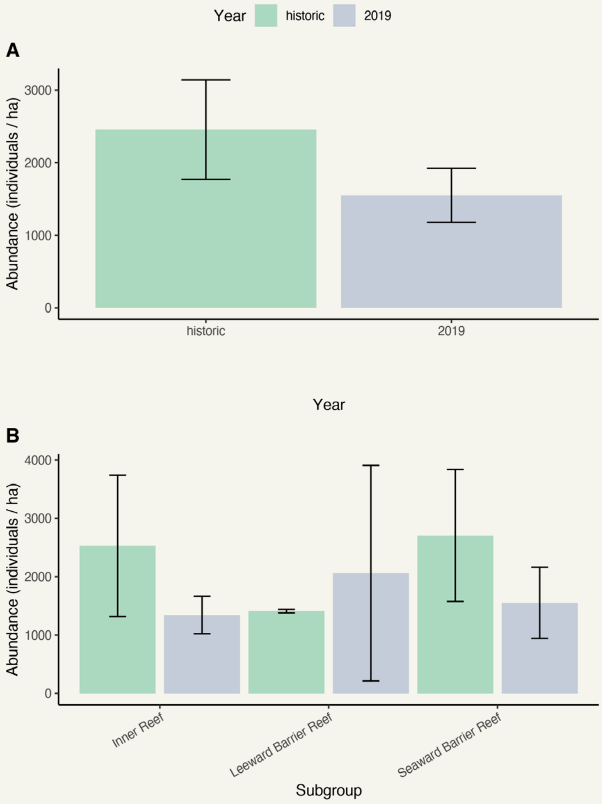
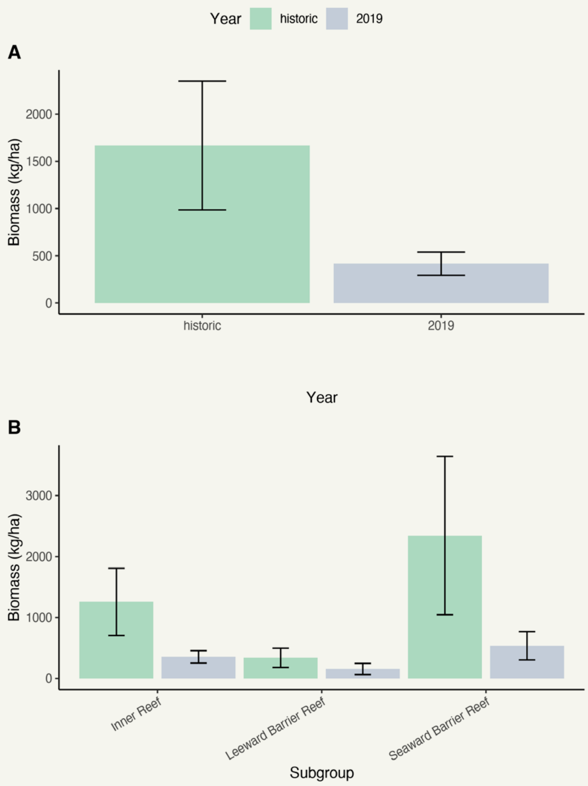


Figure 8.2.16. Change in key fisheries family biomass (Haemulidae, Lutjanidae, Scaridae, and Serranidae) for Qoliqoli Cokovata for (A) all sites with historic data and (B) separately based on reef type. Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.



8.2.5 Rare Species

Humphead wrasse were recorded at a density of 0.79 ± 0.31 ind/ha with a biomass of 5.22 ± 2.24 kg/ha across all sites surveyed in 2019 in Qoliqoli Cokovata (Figure 8.2.17). It was *likely* (V=9, p=0.20) that humphead wrasse abundance has declined. The 2004 survey sites recorded humphead wrasse at 7.14 ± 4.50 ind/ha, while the 2019 surveys at these same sites recorded their abundance at 0.71 ± 0.38 ind/ha. Biomass of humphead wrasse also showed similar *likely* (V=9, p=0.20) declines – from 10.61 ± 6.30 kg/ha in 2004 to 1.24 ± 0.66 kg/ha in 2019.

Bumphead parrotfish were recorded at a density of 0.63 ± 0.63 ind/ha with a biomass of 0.16 ± 0.16 kg/ha across all sites surveyed in 2019 in Qoliqoli Cokovata (Figure 8.2.18). It was *about as likely as not* (V=5, p=0.42) that bumphead parrotfish abundance and biomass has changed within Qoliqoli Cokovata (Figure 8.2.18).

Serranidae abundance and biomass was 21 ± 7 ind/ha and 12 ± 7 kg/ha, respectively, across all surveyed Qoliqoli Cokovata sites in 2019 (Figure 8.2.19). It was *virtually certain* (V=97, p<0.01) that Serranidae abundance declined in Qoliqoli Cokovata, from 229 ± 99 ind/ha in 2004 to 27 ± 10 ind/ha in 2019. It was also *very likely* (V=81, p=0.08) that Serranidae biomass declined (Figure 8.2.19).

Sharks in the family Carcharhinidae were recorded at an abundance of 5.56 ± 2.16 ind/ha and biomass of 181 ± 91 kg/ha across all Qoliqoli Cokovata sites in 2019. Historic surveys recorded sharks at 8.57 ± 5.82 ind/ha in 2004, and it was *unlikely* (V=12, p=0.83) that shark abundance changed – with 6.67 ± 3.07 ind/ha recorded in 2019 at these sites (Figure 8.2.20).

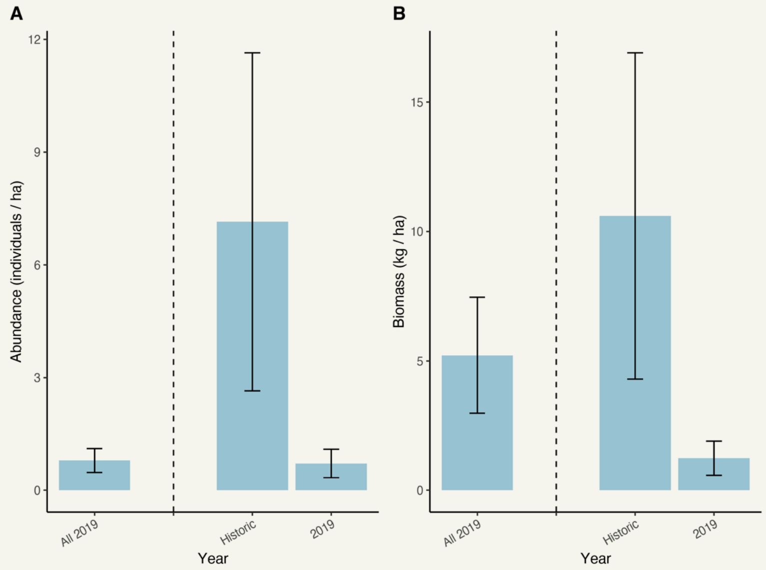


Figure 8.2.17. Humphead wrasse (*Cheilinus undulatus*) (A) abundance and (B) biomass for Qoliqoli Cokovata. Each panel shows data for all sites (left of dashed vertical line) and only the sites with historic data available (right of dashed vertical line). Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.

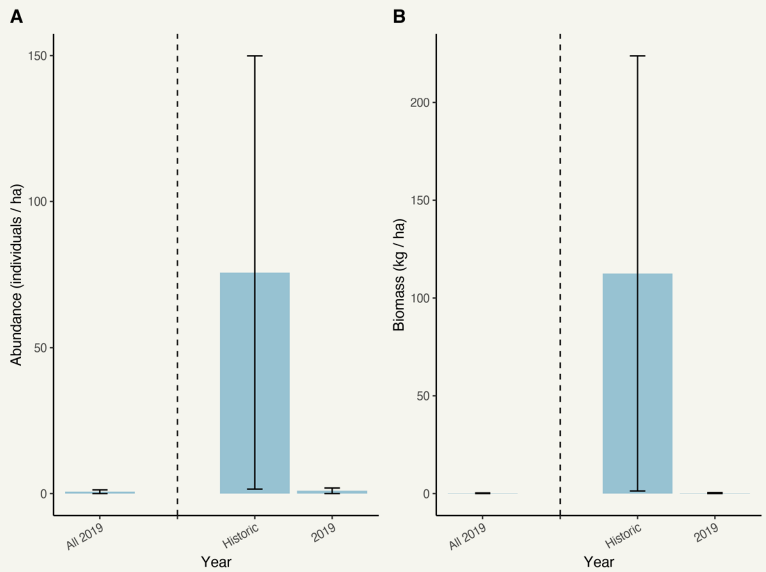


Figure 8.2.18. Bumphead parrotfish (*Bolbometopon muricatum*) (A) abundance and (B) biomass. Each panel shows data for all sites (left of dashed vertical line) and only the sites with historic data available (right of dashed vertical line). Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.

Figure 8.2.19. Serranidae (grouper) (A) abundance and (B) biomass for Qoliqoli Cokovata. Each panel shows data for all sites (left of dashed vertical line) and only the sites with historic data available (right of dashed vertical line). Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.

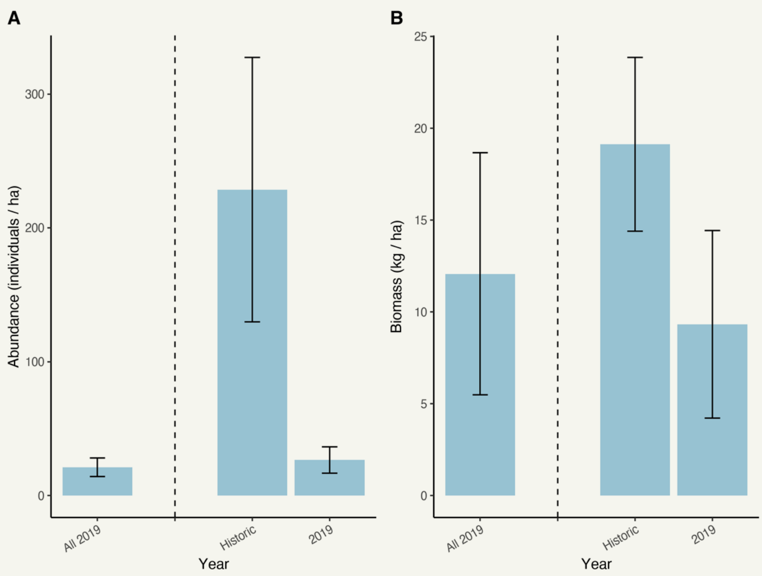
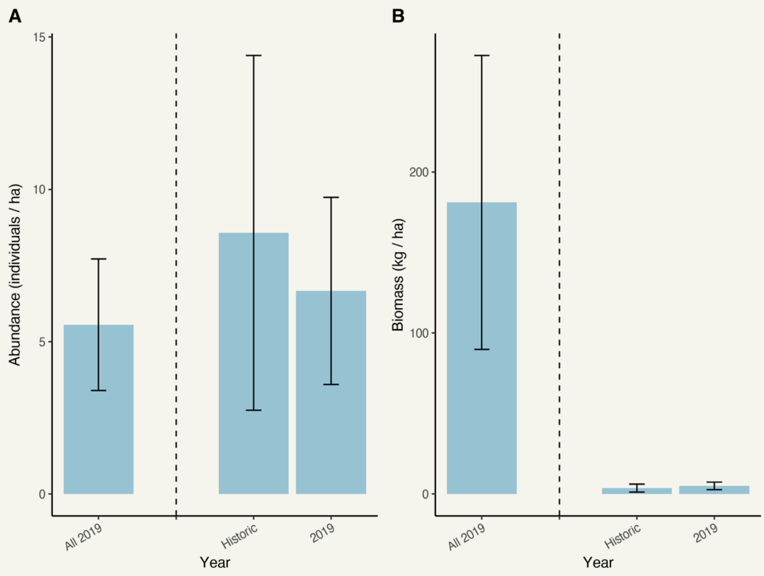


Figure 8.2.20. Carcharhinidae (shark) (A) abundance and (B) biomass for Qoliqoli Cokovata. Each panel shows data for all sites (left of dashed vertical line) and only the sites with historic data available (right of dashed vertical line). Note, low shark biomass for historic comparisons is a result of all fish lengths > 45 cm being analyzed as 45 cm. Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.



8.3 Nadogo

8.3.1 Introduction and critical habitat coverage

Nadogo *qoliqoli* covers a single marine area of 264 km^2 located along the north coast of Macuata province on the north coast of Vanua Levu (Figure 8.3.1). The area contains a mix of shallow reef areas, mangrove islands, and mud flats. The northern edge of the *qoliqoli* is bounded by the offshore barrier reef. As the *qoliqoli* sits adjacent to Vanua Levu, there is sedimentation impact in coastal areas, with several rivers and creeks flowing into the area (Figure 8.3.2).

Reefs take multiple forms within Nadogo, with shallow fringing reefs along the northern coastline of Vanua Levu and extensive fringing reefs and reef flats around coastal islands. Part of the main Cakaulevu barrier reef borders the *qoliqoli* to the north, including a section of the double barrier reef in the west of the *qoliqoli* (Figure 8.3.3). In total, coral covers approximately 23 km^2 within the *qoliqoli*, though summing all Allen Coral Atlas benthic categories that likely contribute to broader coral reef ecosystem composition (i.e. coral/ algae, microalgal mats, rock, and rubble) suggests a coverage of 59 km^2 of shallow reef-related ecosystems. The majority of these reefs are comprised of shallow lagoonal reefs (22 km^2), followed by significant areas of outer reef flats (20 km^2), and sheltered reef slopes (16 km^2), with other reef types also present (Figure 8.3.4).

Mangrove extent is 13 km^2, with no change between 1996 and 2016 (Figure 8.3.5; 8.3.6). Despite a relatively short coastline, there is extensive mangrove area in the bays along the Vanua Levu coastline. Several coastal islands also provide suitable substrate for extensive mangrove forests to form. Seagrass covers approximately 5 km^2 within Nadogo *qoliqoli*, with much of this split in the coastal areas of Vanua Levu and the small islands adjacent to the shoreline (Figure 8.3.7). However, some narrow bands of seagrass are found associated with the Cakaulevu offshore reef, and between the double barrier reefs.

8.3.2 Survey sites

Surveys were completed at two sites within Nadogo *qoliqoli* (Figure 8.3.8). One of these sites was located on a reef flat on the offshore barrier reef, and the other site was on a fringing reef around one of the coastal islands. Both of these sites were previously surveyed by WWF in 2004 and so have historic benthic and fish data available (Figure 8.3.8).

Figure 8.3.1. Bathymetry of Nadogo *qoliqoli*.

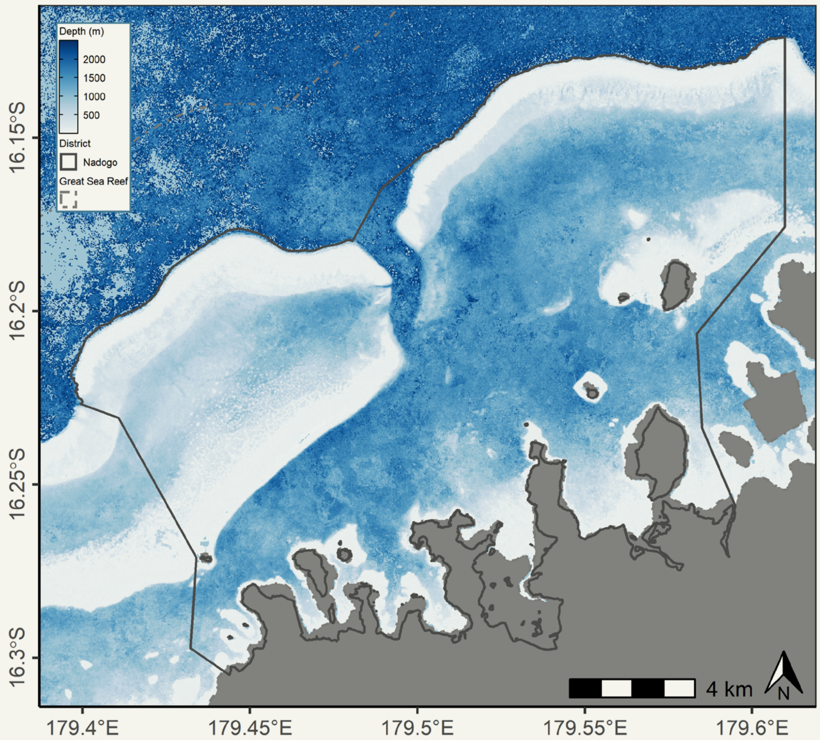


Figure 8.3.2. Sedimentation rates inside and adjacent to Nadogo *qoliqoli*.

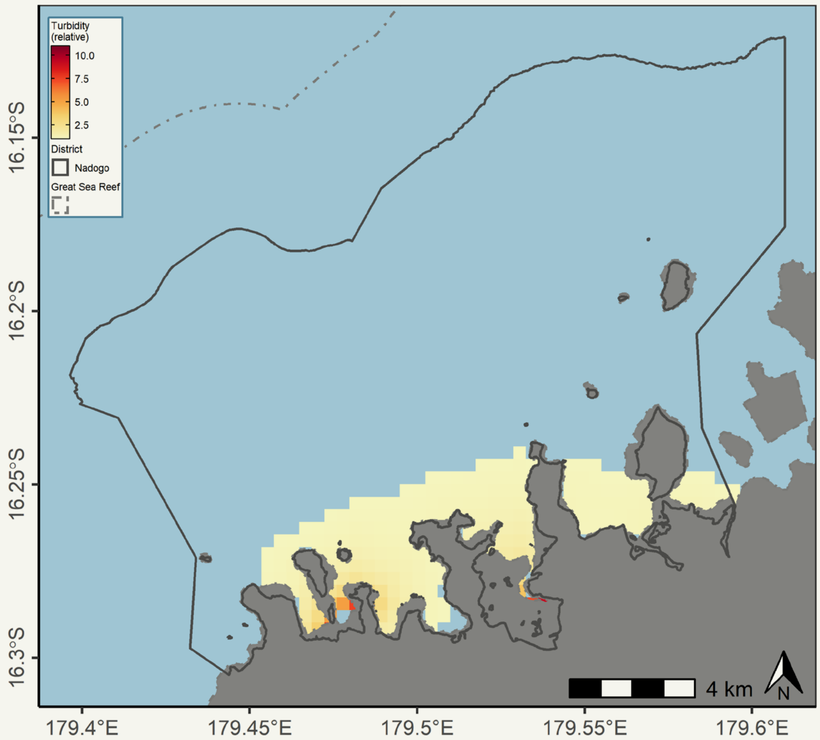


Figure 8.3.3. Coral reef extent in Nadogo *qoliqoli*.

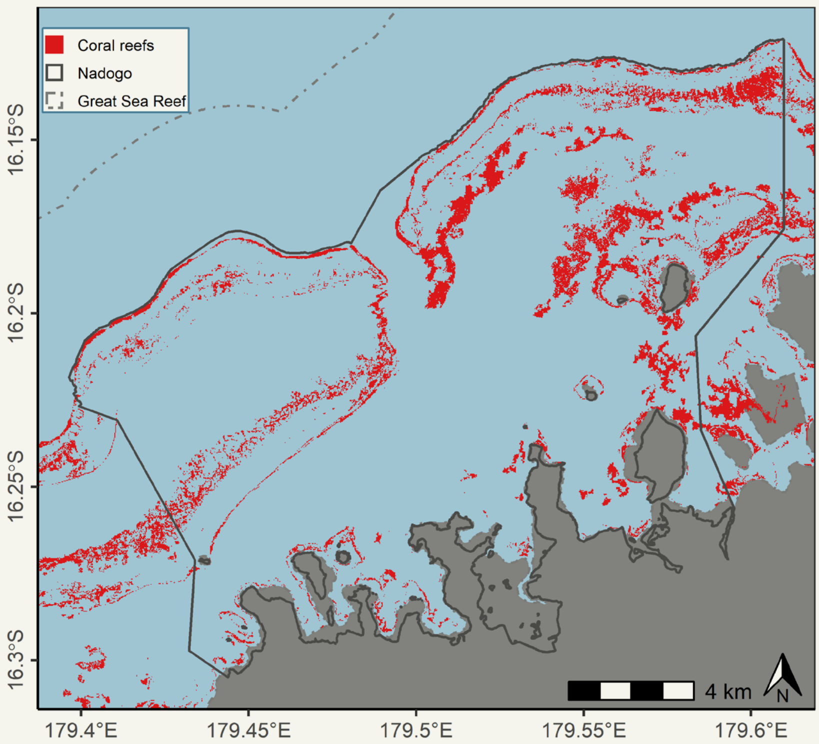


Figure 8.3.4. Coral reef geomorphic types in Nadogo *qoliqoli*.

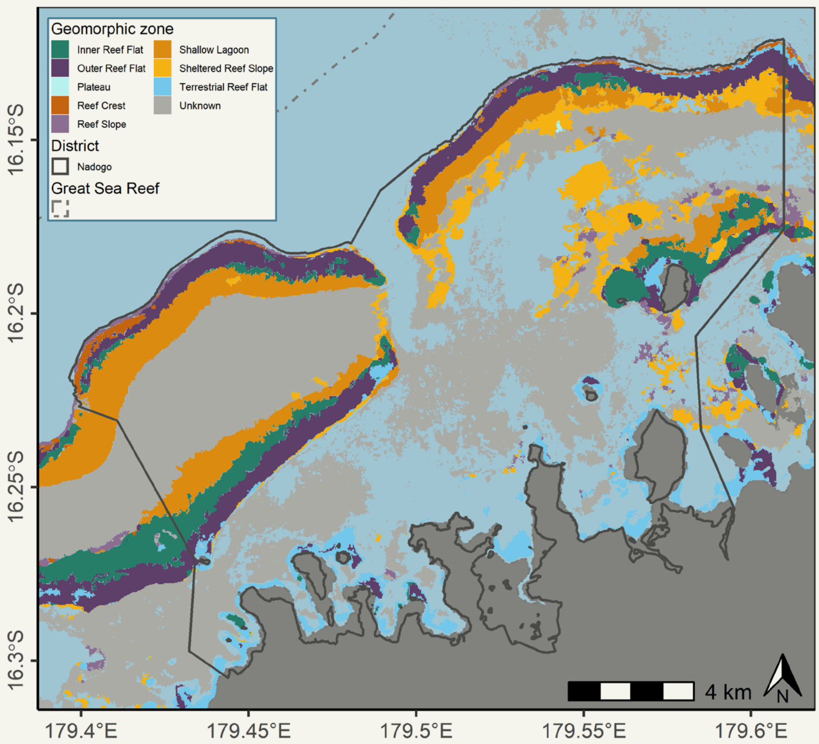


Figure 8.3.5. Mangrove extent in Nadogo *qoliqoli*.

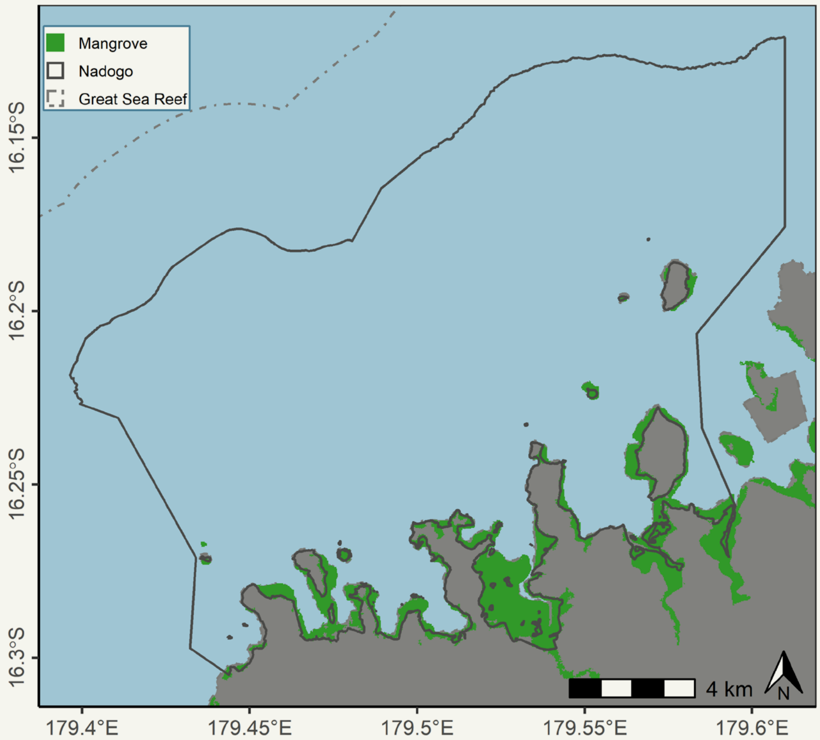


Figure 8.3.6. Mangrove change between 1996-2016 in Nadogo *qoliqoli*.

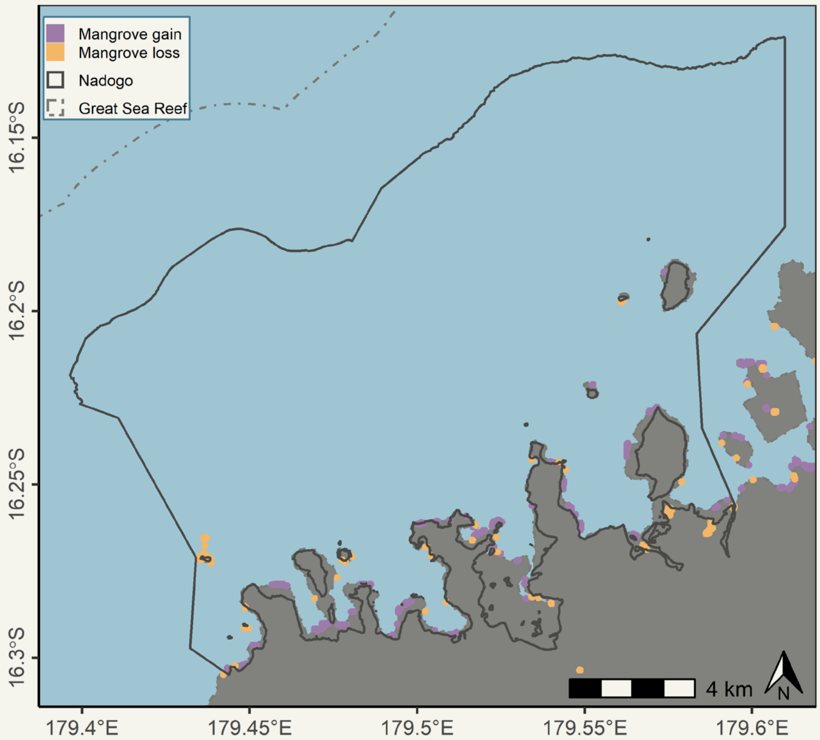


Figure 8.3.7. Seagrass cover in Nadogo *qoliqoli*.

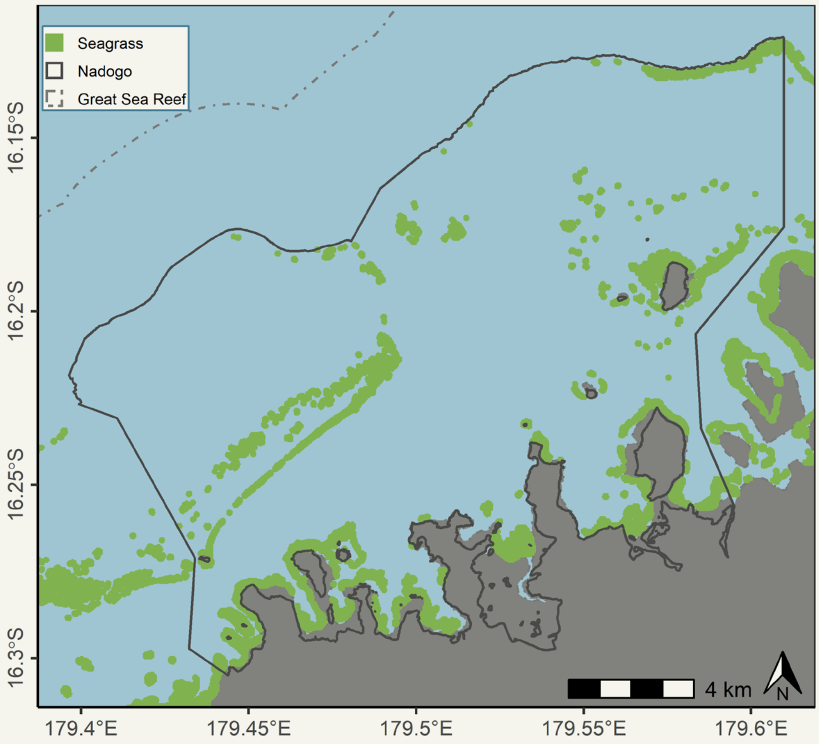
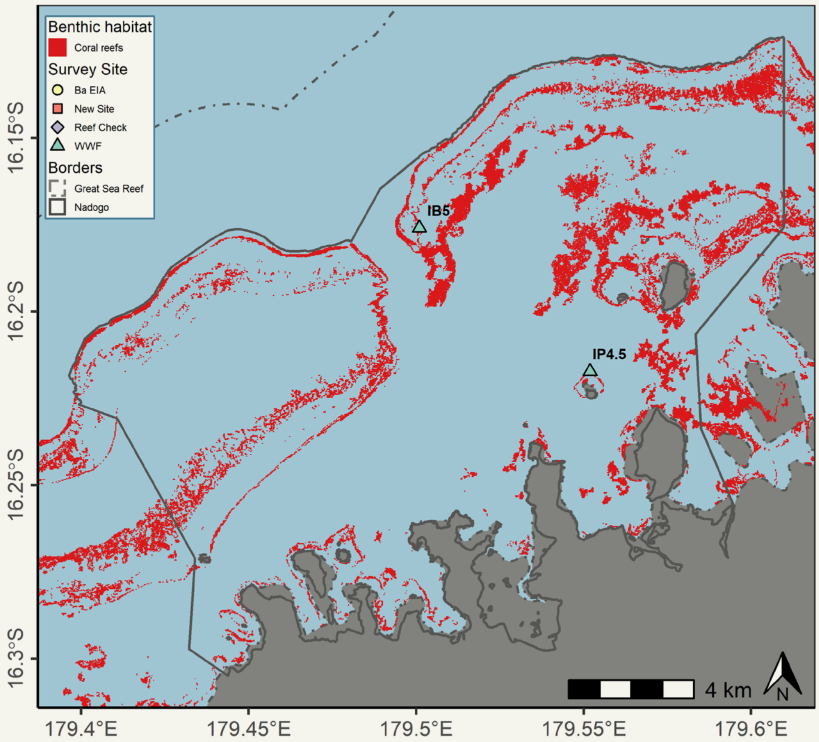


Figure 8.3.8. Survey sites in Nadogo *qoliqoli*.



8.3.3 Benthic cover

Hard coral cover was 23 ± 1% across reefs in Nadogo *qoliqoli* in 2019 (Figure 8.3.9). The second highest live benthic cover on reefs was crustose coralline algae, at 8 ± 3%. Non-living benthic cover was high in Nadogo, with rubble at 30 ± 3% and sand at 14 ± 5%.

The two sites surveyed in Nadogo were on different reef types and geographic location– (i) IP4.5 was on a fringing reef on one of the inner reef islands and (ii) IB5 was on a reef flat on the leeward side of the barrier reef. Both sites had similar hard coral cover (Figure 8.3.10A). Macroalgae cover, however, was higher on the inner reef island site (Figure 8.3.10B).

From comparisons with historic survey data for Nadogo, it was unlikely (W=1, p=0.67) that hard coral cover or algae cover changed between baseline surveys in 2004 and the 2019 survey (Figure 8.3.11). It was *about as likely as not* (W=4, p=0.33) that soft coral cover decreased, from 4 ± 3% to 1 ± 1 %. There have been limited changes in other living benthic groups (Figure 8.3.11), though it is *likely* (W=0, p<0.22) that rubble cover has increased – from <1% historically to 30 ± 3% in 2019. It is also *about as likely as not* (W=4, p=0.33) that rock has declined from 53 ± 1% to 16 ± 3%. Breaking apart the data between the site on the leeward barrier reef and the inner reef site suggests that hard coral cover may have increased on the leeward reef (Figure 8.3.12A). However, results suggest that algae cover may have increased on the inner reef (Figure 8.3.12B). Trends in benthic communities should be treated with caution given that data is based on two sites.

Figure 8.3.9. Benthic cover in 2019 for Nadogo *qoliqoli*.

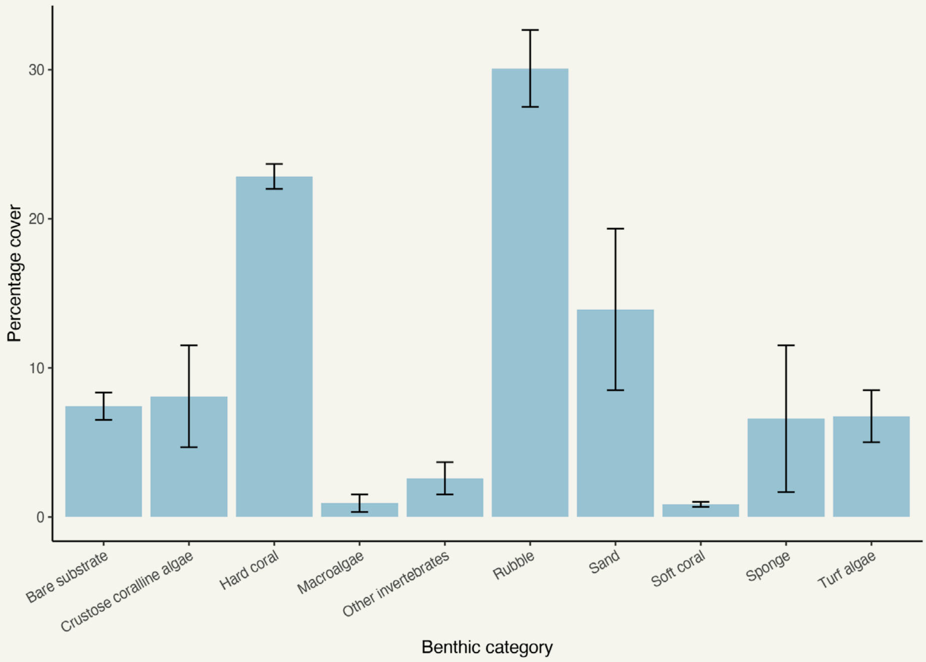


Figure 8.3.10. (A) Hard coral cover and (B) macroalgae cover by subgroup for sites within Nadogo *qoliqoli*.

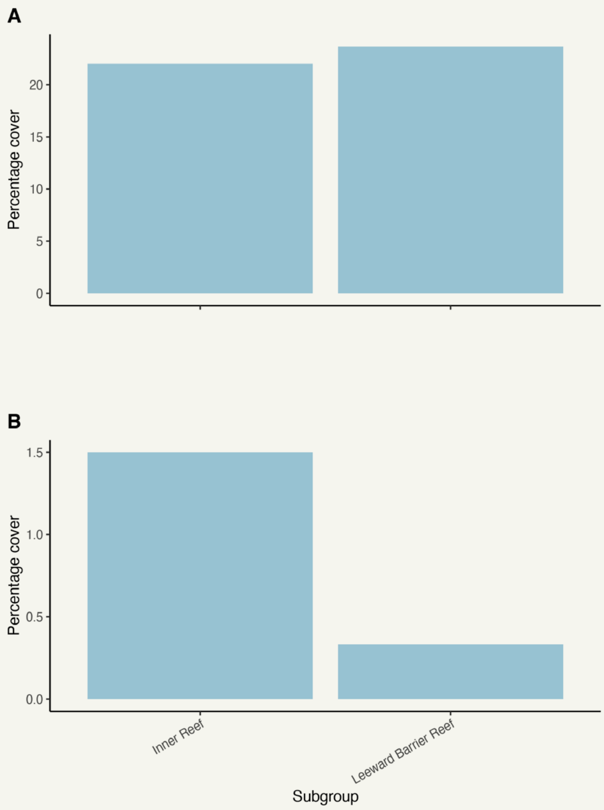


Figure 8.3.11. Change in benthic communities for Nadogo *qoliqoli*.

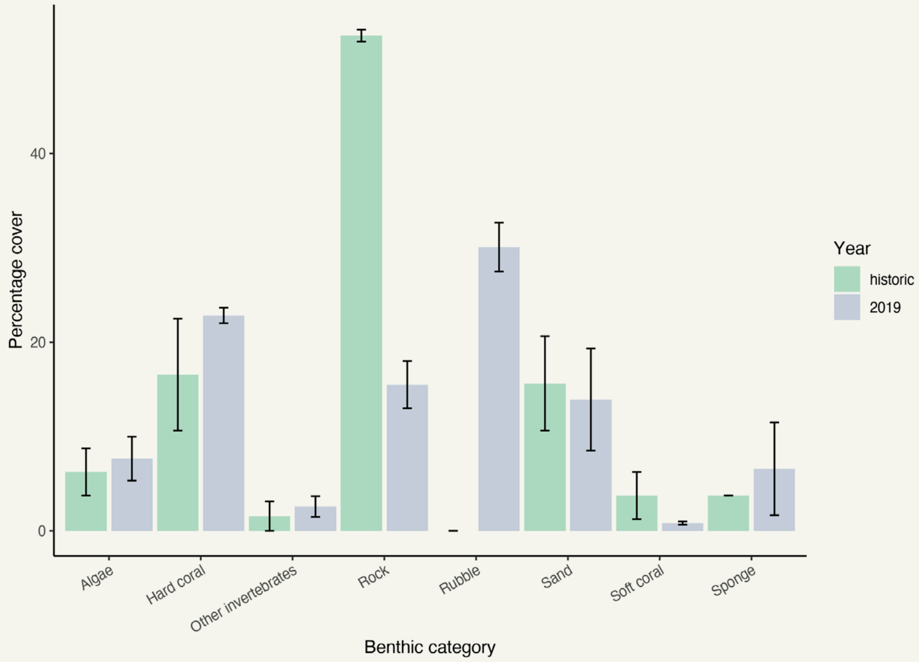
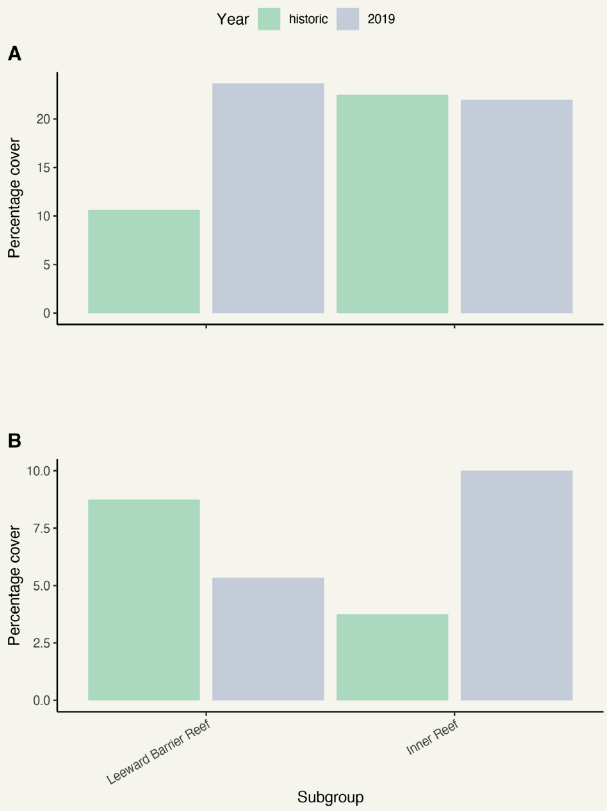


Figure 8.3.12. Change in (A) hard coral and (B) macroalgae cover for the seaward outer barrier reef, the leeward side of the outer barrier reef, and the inner reef lagoonal island sites within Nadogo *qoliqoli*.



8.3.4 Fish communities

A mean fish abundance for the target family/species list of 3,129 ± 1004 ind/ha was recorded across all Nadogo sites, while mean fish biomass was 111 ± 36 kg/ha. Fish communities were dominated by herbivores by abundance and biomass (Figure 8.3.13). The most abundant fish family was Acanthuridae (1,263 ± 443 ind/ha), followed by Scaridae (750 ± 330 ind/ha). This also reflected biomass as well, with Acanthuridae the larger family by biomass (53 ± 32 kg/ha) followed by Scaridae (20 ± 1 kg/ha). Abundance and biomass of carnivorous fish species was particularly low in Nadogo (Figure 8.3.13). Fish abundance and biomass varied by reef type, with the greatest biomass recorded on the leeward outer barrier reef (Figure 8.3.14).

It was *exceptionally unlikely* (V=2, p>0.99) that key fisheries family abundance changed between 2004 and 2019, with 2004 surveys recording 1,550 ± 1,230 ind/ha compared to 843 ± 383 ind/ha in 2019 (Figure 8.3.15A). With only one site it is hard to make statistical comparisons, but recorded key fisheries family fish abundance was lower in 2019 than 2004 at the inner reef site (Figure 8.3.15B). It was *about as likely as not* (V=3, p=0.50) that fish biomass declined across Nadogo sites for the key fisheries families. Historic surveys recorded biomass at 271 ± 177 kg/ha in 2004 compared to 36 ± 3 kg/ha in 2019 (Figure 8.3.16A). Declines in biomass were particularly severe on the inner reef site (Figure 8.3.16B).

Figure 8.3.13. Fish community structure by (A) abundance and (B) biomass for Nadogo *qoliqoli*.

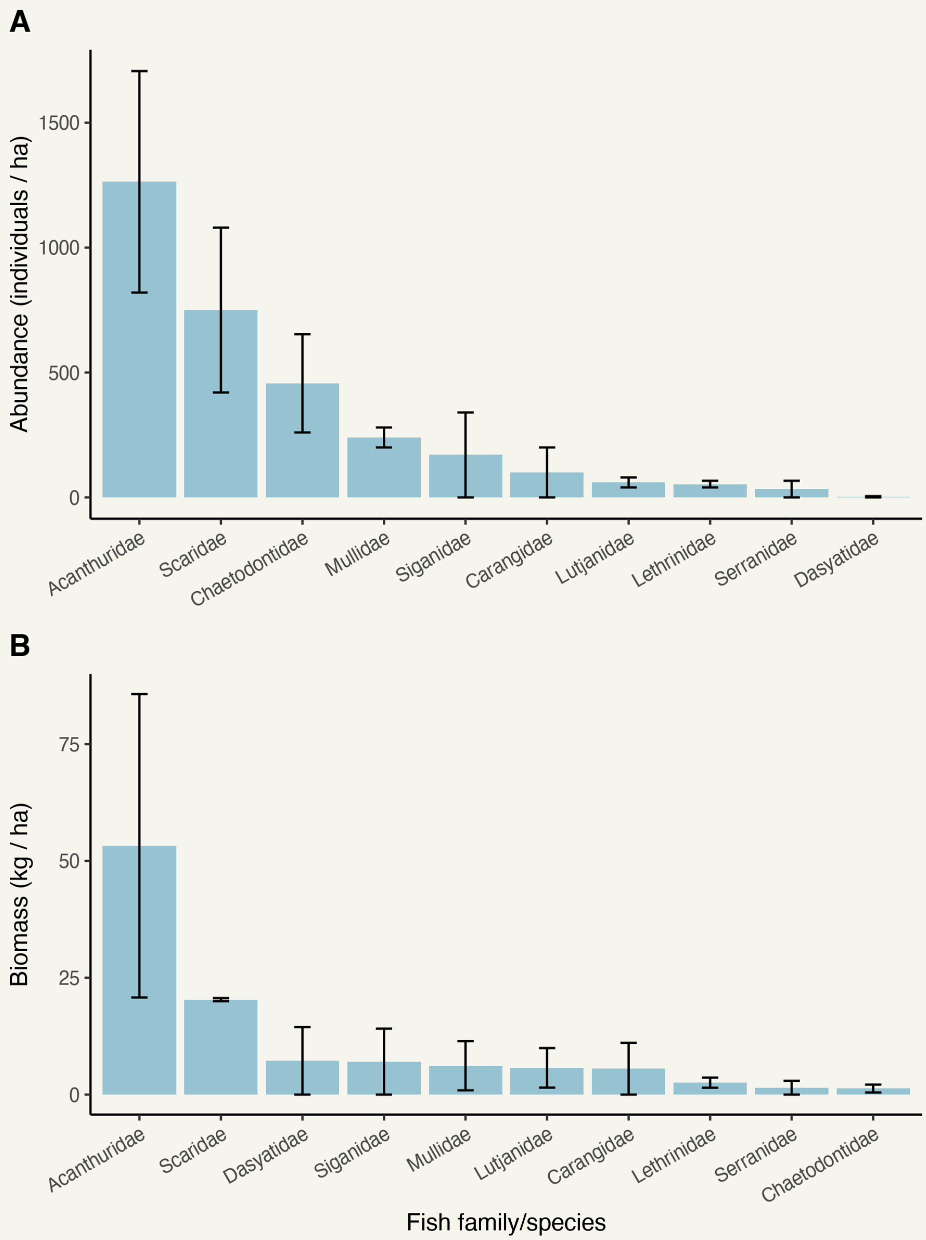


Figure 8.3.14. Overall fish (A) abundance and (B) biomass for sites surveyed in 2019 in Nadogo *qoliqoli*. Results divided by subgroup representing broad reef types.

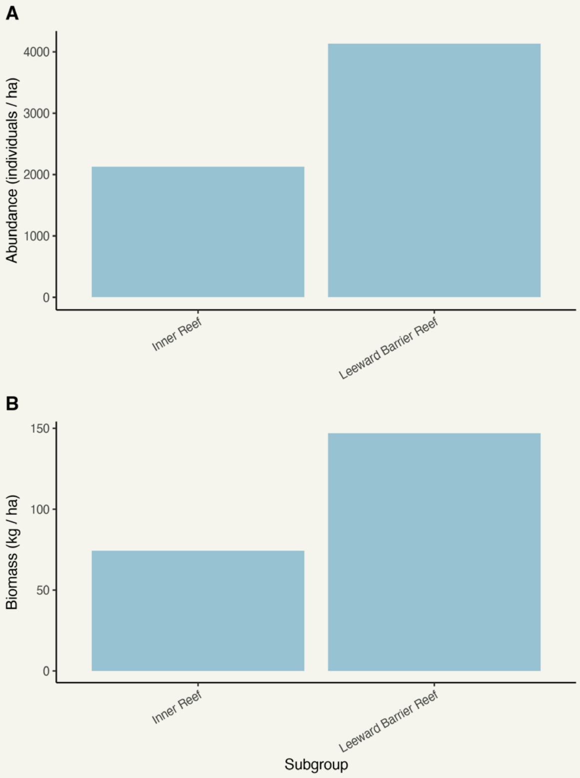


Figure 8.3.15. Change in key fisheries family abundance (Haemulidae, Lutjanidae, Scaridae, and Serranidae) for Nadogo *qoliqoli* for (A) all sites with historic data and (B) separately based on reef type.

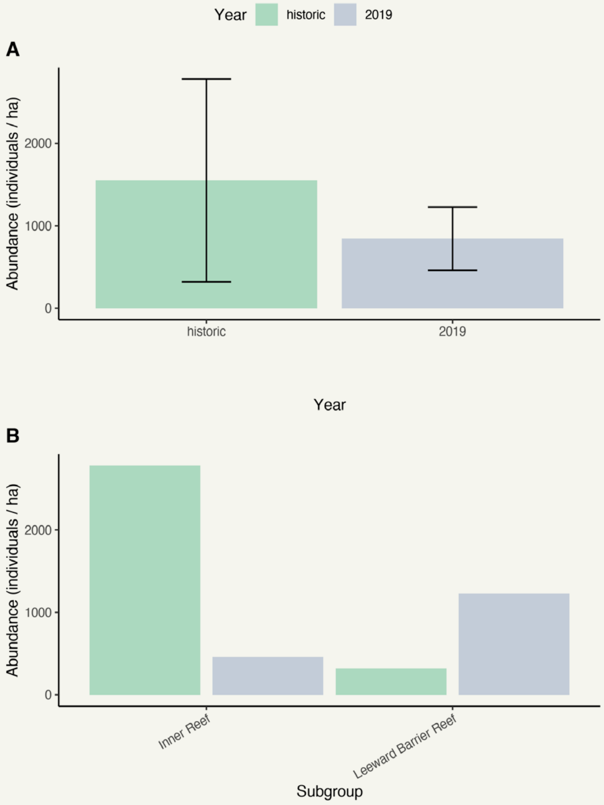
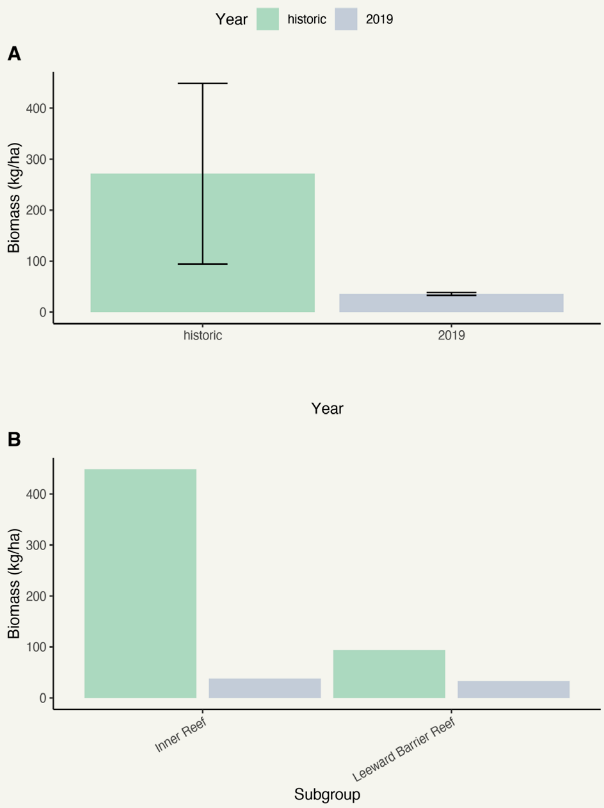


Figure 8.3.16. Change in key fisheries family biomass (Haemulidae, Lutjanidae, Scaridae, and Serranidae) for Nadogo *qoliqoli* for (A) all sites with historic data and (B) separately based on reef type. Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.



8.3.5 Rare Species

No humphead wrasse or bumphead parrotfish were recorded in Nadogo *qoliqoli* in the 2019 survey, or during the historic surveys in 2004.

Serranidae abundance and biomass were 33 ± 33 ind/ha and 1.47 ± 1.47 kg/ha, respectively, across both surveyed Nadogo sites in 2019 (Figure 8.3.17). It was *about as likely as not* (V=3, p=0.50) that Serranidae abundance and biomass declined in Nadogo, from 160 ± 100 ind/ha and 33 ± 30 kg/ha at both sites in 2004.

No sharks in the family Carcharhinidae were recorded during 2019 at Nadogo sites. Historic surveys recorded sharks at 10 ± 10 ind/ha in 2004 (Figure 8.3.18).

Figure 8.3.17. Serranidae (grouper) (A) abundance and (B) biomass for Nadogo *qoliqoli*. Each panel shows data for all sites (left of dashed vertical line) and only the sites with historic data available (right of dashed vertical line). Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.

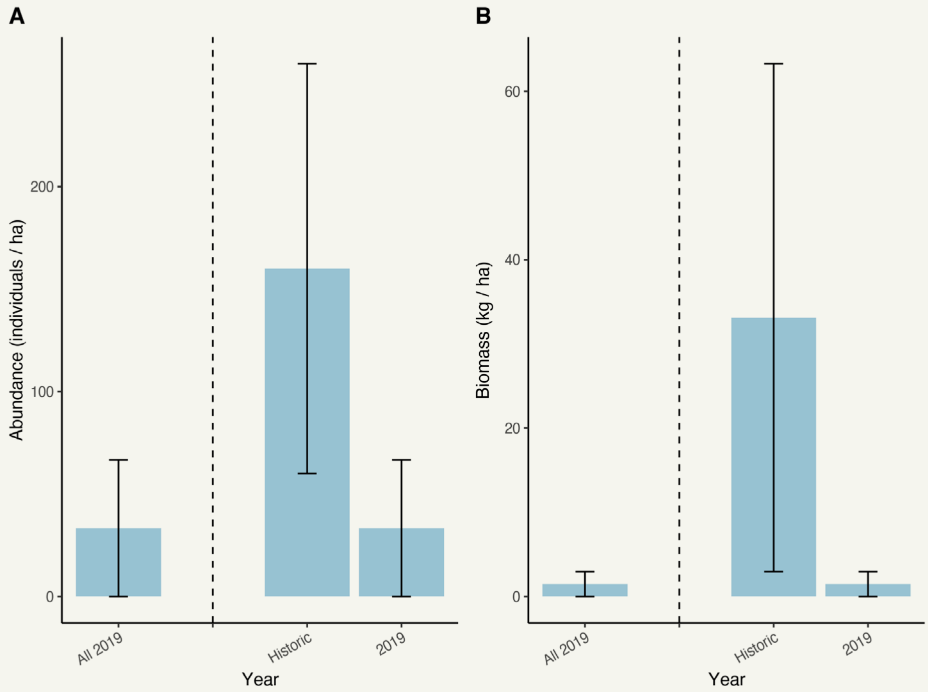
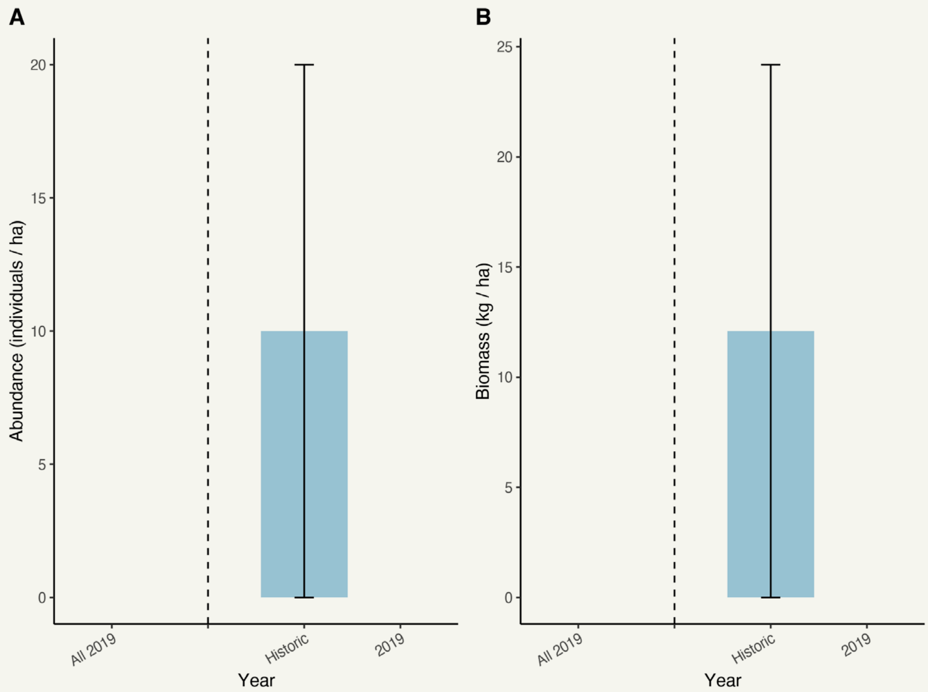


Figure 8.3.18. Carcharhinidae (shark) (A) abundance and (B) biomass for Nadogo *qoliqoli*. Each panel shows data for all sites (left of dashed vertical line) and only the sites with historic data available (right of dashed vertical line). Note, low shark biomass for historic comparisons is a result of all fish lengths > 45 cm being analyzed as 45 cm. Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.



8.4 Namuka and Dogotuki

8.4.1 Introduction and critical habitat coverage

Namuka and Dogotuki *qoliqoli* covers a single marine area of 231 km^2 located along the north coast of Macuata province on the north coast of Vanua Levu (Figure 8.4.1). The area contains a mix of shallow reef areas, shallow lagoonal seabed, mangrove-fringed islands, and mud flats. The northern edge of the *qoliqoli* is bounded by the offshore barrier reef. As the *qoliqoli* sits adjacent to Vanua Levu, there is some sedimentation impact in coastal areas from rivers and creeks flowing into the area – particularly in the eastern part of the *qoliqoli* (Figure 8.4.2).

Reefs take multiple forms within Namuka and Dogotuki, with shallow fringing reefs along the northern coastline of Vanua Levu and extensive fringing reefs and reef flats around coastal islands. Part of the main Cakaulevu barrier reef borders the *qoliqoli* to the north, and the barrier reef curves into the coastal fringing reefs of Vanua Levu in the east of *qoliqoli* (Figure 8.4.3). In total, coral covers approximately 25 km^2 within the *qoliqoli*, though summing all Allen Coral Atlas benthic categories that likely contribute to broader coral reef ecosystem composition (i.e. coral/algae, microalgal mats, rock, and rubble) suggests a coverage of 56 km^2 of shallow reef-related ecosystems. The majority of these reefs are comprised of shallow lagoonal reefs (19 km^2) and inner reef flats (19 km^2), followed by significant areas of terrestrial reef flats (16 km^2), sheltered reef slopes (14 km^2), and other reef flats (14 km^2), with other reef types also present (Figure 8.4.4).

Mangrove extent is 16 km^2, with no change between 1996 and 2016 (Figures 8.4.5; 8.4.6). There are extensive mangrove areas in the bays along the Vanua Levu coastline. Several coastal islands also provide suitable substrate for extensive mangrove forests to form. Seagrass covers approximately 13 km^2 within Namuka and Dogotuki *qoliqoli*, with much of this split in the coastal areas of Vanua Levu and on the lagoon bed between the barrier reef and the Vanua Levu coastline (Figure 8.4.7). However, some narrow bands of seagrass are found associated with the Cakaulevu offshore reef.

8.4.2 Survey sites

Surveys were completed at two sites within Namuka and Dogotuki *qoliqoli* (Figure 8.4.8). One of these sites was located on the channel edge of the offshore barrier reef (CH5), and the other site was on a fringing reef associated with one of the coastal islands (IB4). Both of these sites were previously surveyed by WWF in 2004 and so have historic benthic and fish data available (Figure 8.4.8).

Figure 8.4.1. Bathymetry of Namuka and Dogotuki *qoliqoli*.

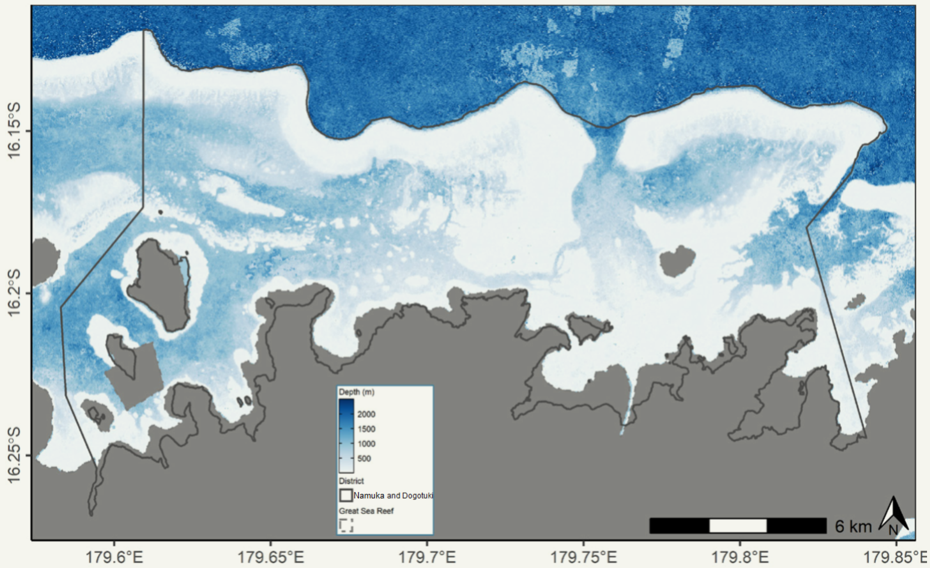


Figure 8.4.2. Sedimentation rates inside and adjacent to Namuka and Dogotuki *qoliqoli*.

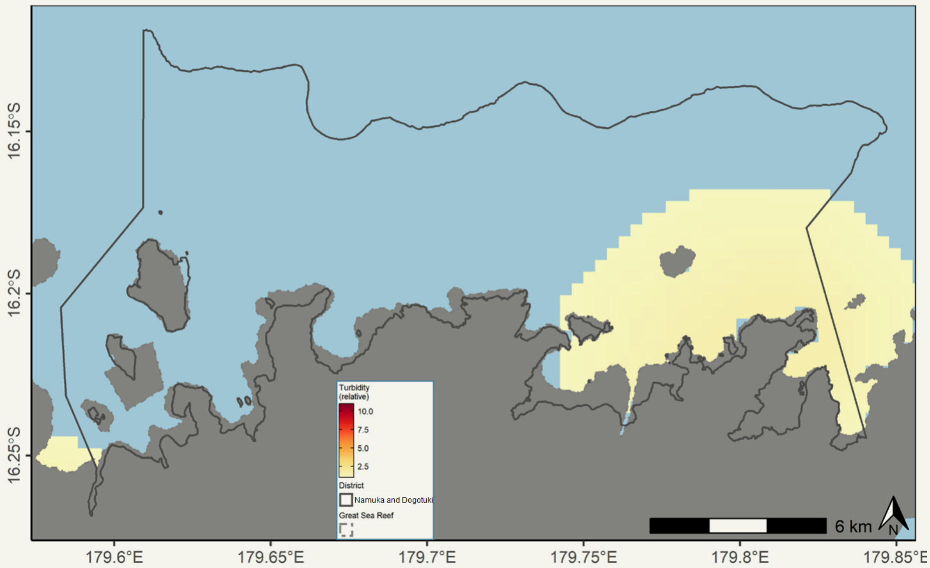


Figure 8.4.3. Coral reef extent in Namuka and Dogotuki *qoliqoli*.

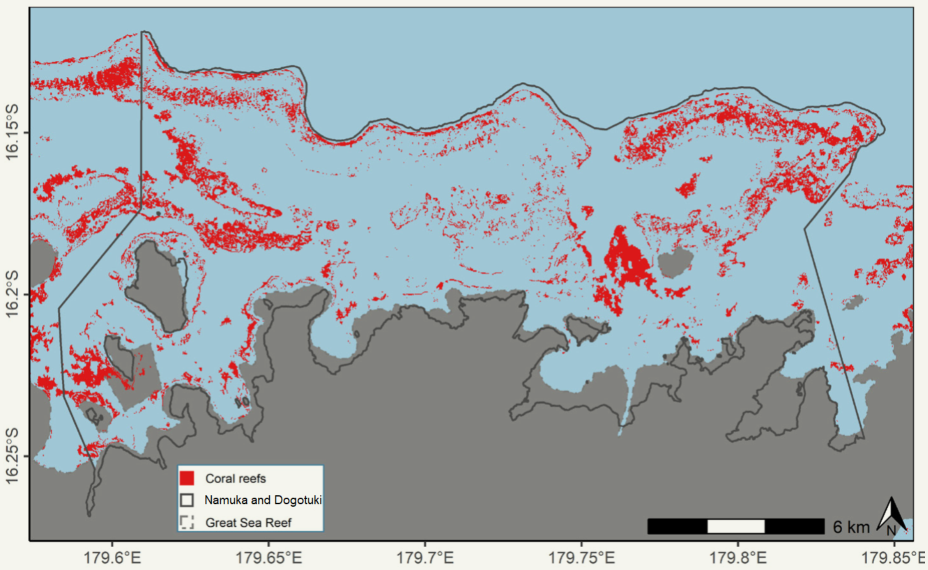


Figure 8.4.4. Coral reef geomorphic types in Namuka and Dogotuki *qoliqoli*.

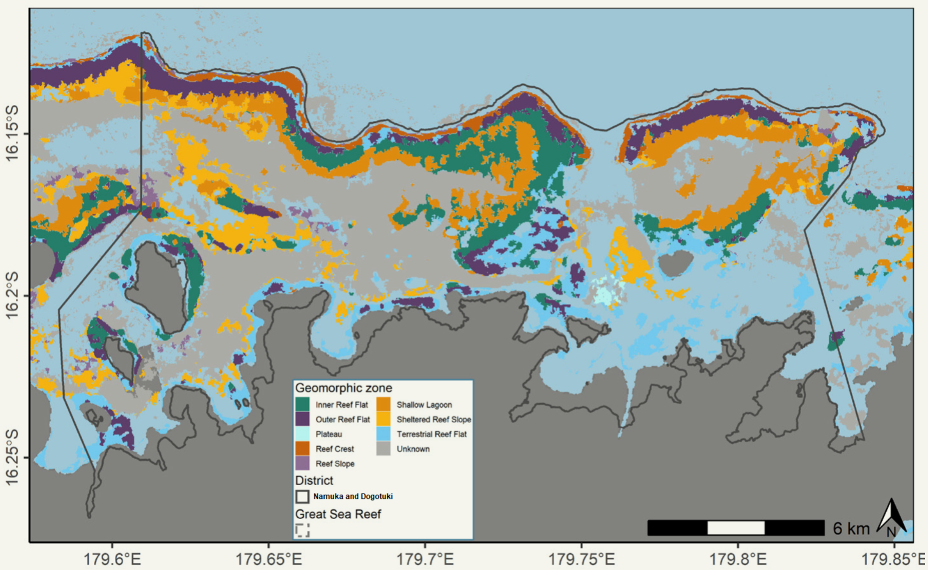


Figure 8.4.5. Mangrove extent in Namuka and Dogotuki *qoliqoli*.

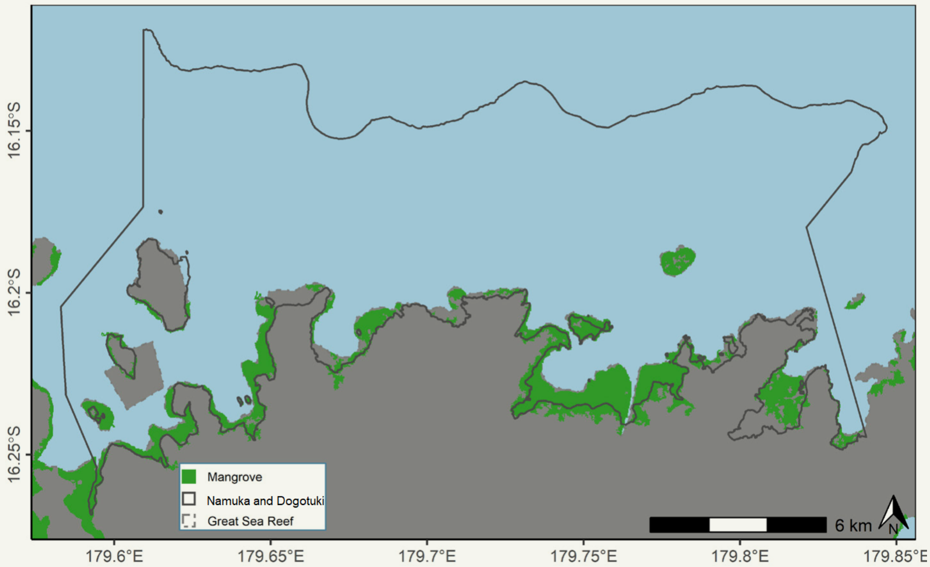


Figure 8.4.6. Mangrove change between 1996-2016 in Namuka and Dogotuki *qoliqoli*.

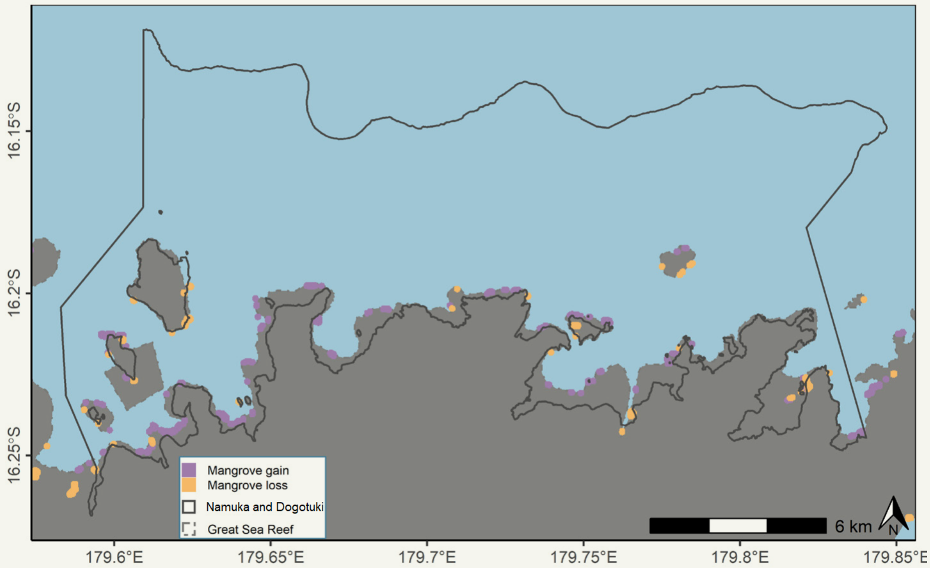


Figure 8.4.7. Seagrass cover in Namuka and Dogotuki *qoliqoli*.

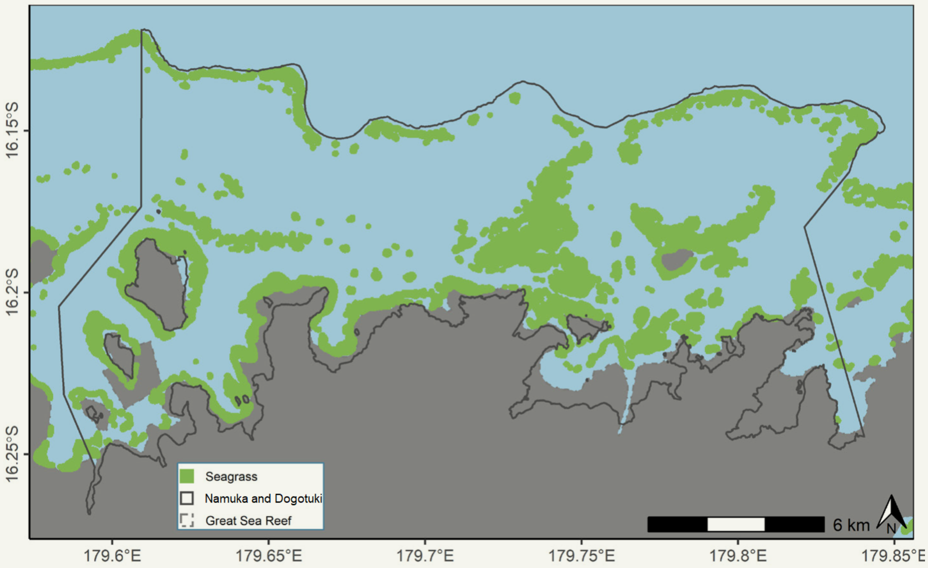
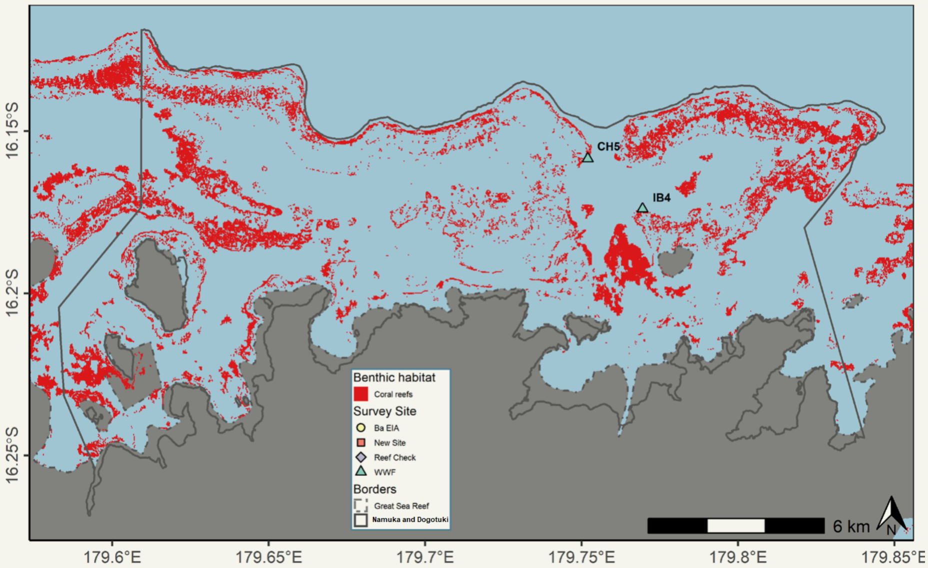


Figure 8.4.8. Survey sites in Namuka and Dogotuki *qoliqoli*.



8.4.3 Benthic cover

Hard coral cover was 29 ± 14% across reefs in Namuka and Dogotuki *qoliqoli* in 2019 (Figure 8.4.9). The second highest live benthic cover on reefs was crustose coralline algae, at 7 ± 3%. Non-living benthic cover was high in Namuka and Dogotuki, with rubble at 27 ± 1%, bare substrate at 14 ± 4%, and sand at 8 ± 5%.

The two sites surveyed in Namuka and Dogotuki were on different reef types and geographic locations. Both sites had different hard coral cover (Figure 8.4.10A), with the inner reef site having much higher cover. Macroalgae cover, however, was very similar between sites (Figure 8.4.10B).

From comparisons with historic survey data for Namuka and Dogotuki, it was *exceptionally unlikely* (W=2, p>0.99) that hard coral cover changed between baseline surveys in 2004 and the 2019 survey (Figure 8.4.11).
Though, it was *about as likely as not* (W=0, p=0.33) that algae cover has increased, from 3 ± 2% in 2004 to 8 ± 2% in 2019. It was *about as likely as not* (W=0, p=0.33) that sponge cover increased. There have been limited changes in other living benthic groups (Figure 8.4.11), though it is *likely* (W=0, p=0.22) that rubble cover has increased – from <1% historically to 27 ± 1% in 2019. Breaking apart the data between the site on the seaward barrier reef and the inner reef site suggests that hard coral cover may have declined on the seaward reef (Figure 8.4.12). However, results suggest that algae cover may have increased at both sites (Figure 8.4.12). Trends in benthic communities should be treated with caution given that data is based on two sites.

Figure 8.4.9. Benthic cover in 2019 for Namuka and Dogotuki *qoliqoli*.

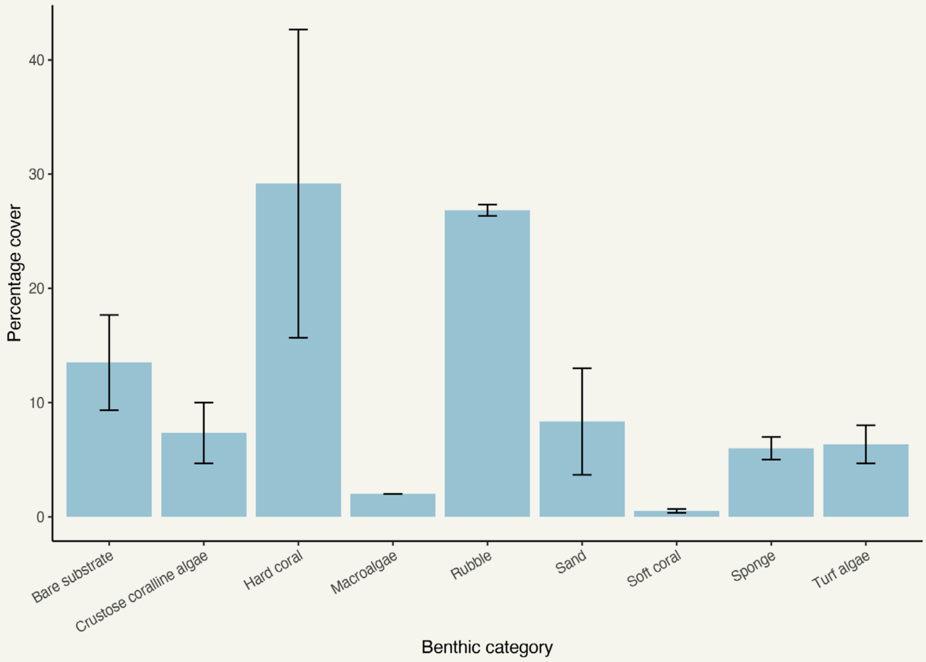


Figure 8.4.10. (A) Hard coral cover and (B) macroalgae cover by subgroup for sites within Namuka and Dogotuki *qoliqoli*.

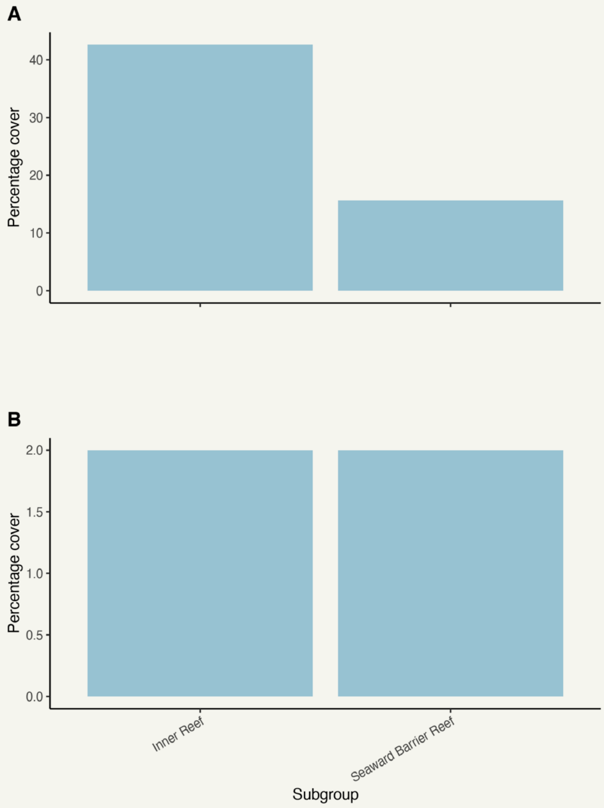


Figure 8.4.11. Change in benthic communities for Namuka and Dogotuki *qoliqoli*.

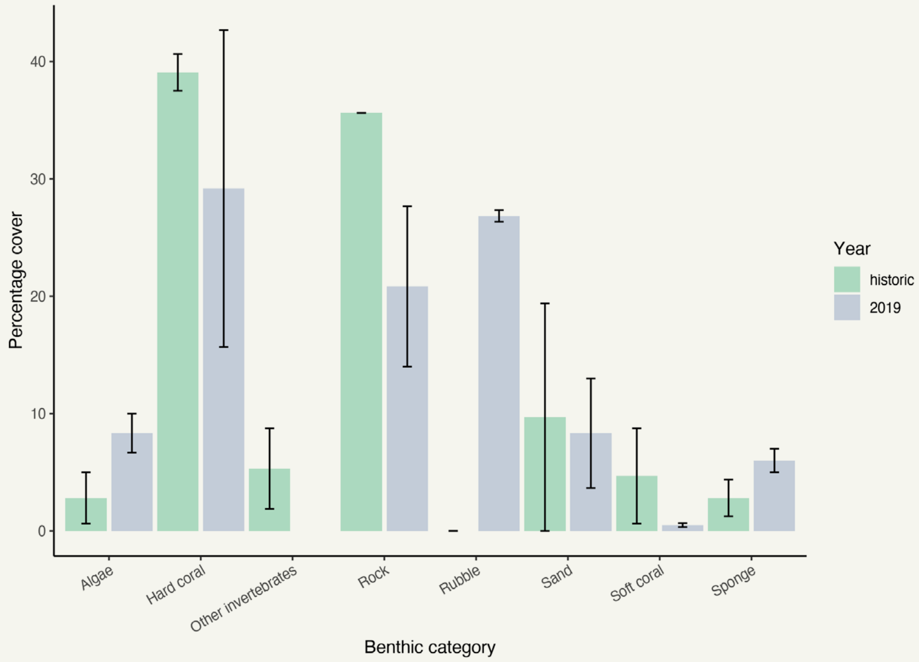
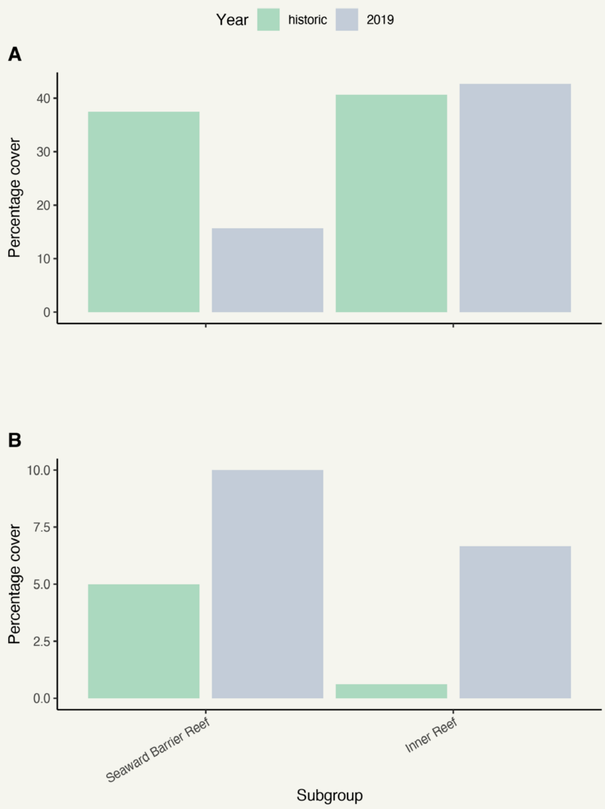


Figure 8.4.12. Change in (A) hard coral and (B) macroalgae cover for the seaward outer barrier reef and the inner reef lagoonal island sites within Namuka and Dogotuki *qoliqoli*.



8.4.4 Fish communities

A mean fish abundance for the target family/species list of 3,208 ± 85 ind/ha was recorded across all Namuka and Dogotuki sites, while mean fish biomass was 173 ± 49 kg/ha. Fish communities were dominated by herbivores by abundance (Figure 8.4.13). The most abundant fish family was Acanthuridae (847 ± 87 ind/ha), followed by Scaridae (640 ± 400 ind/ha). Herbivores were also a large proportion of reef fish biomass as well, with Acanthuridae the second largest family by biomass (44 ± 13 kg/ha), followed by Scaridae as the third largest (34 ± 16 kg/ha). The greatest biomass was for Lutjanidae (57 ± 44 kg/ha) (Figure 8.4.13). Fish abundance was similar between the two reef types, though the greatest biomass was recorded on the seaward outer barrier reef (Figure 8.4.14).

It was *exceptionally unlikely* (V=2, p>0.99) that key fisheries family abundance changed between 2004 and 2019 with 2004 surveys recording 1,670 ± 190 ind/ha compared to 1,315 ± 182 ind/ha in 2019 (Figure 8.4.15A). With only one site it is hard to make statistical comparisons, but recorded key fisheries family fish abundance was lower in 2019 than 2004 at the inner reef site (Figure 8.4.15B). It was *about as likely as not* (V=3, p=0.50) that fish biomass declined across Namuka and Dogotuki sites for the key fisheries families. Historic surveys recorded biomass at 733 ± 3 kg/ha in 2004 compared to 122 ± 51 kg/ha in 2019 (Figure 8.4.16A). Declines in biomass occurred on both reef sites (Figure 8.4.16B).

Figure 8.4.13. Fish community structure by (A) abundance and (B) biomass for Namuka and Dogotuki *qoliqoli*.

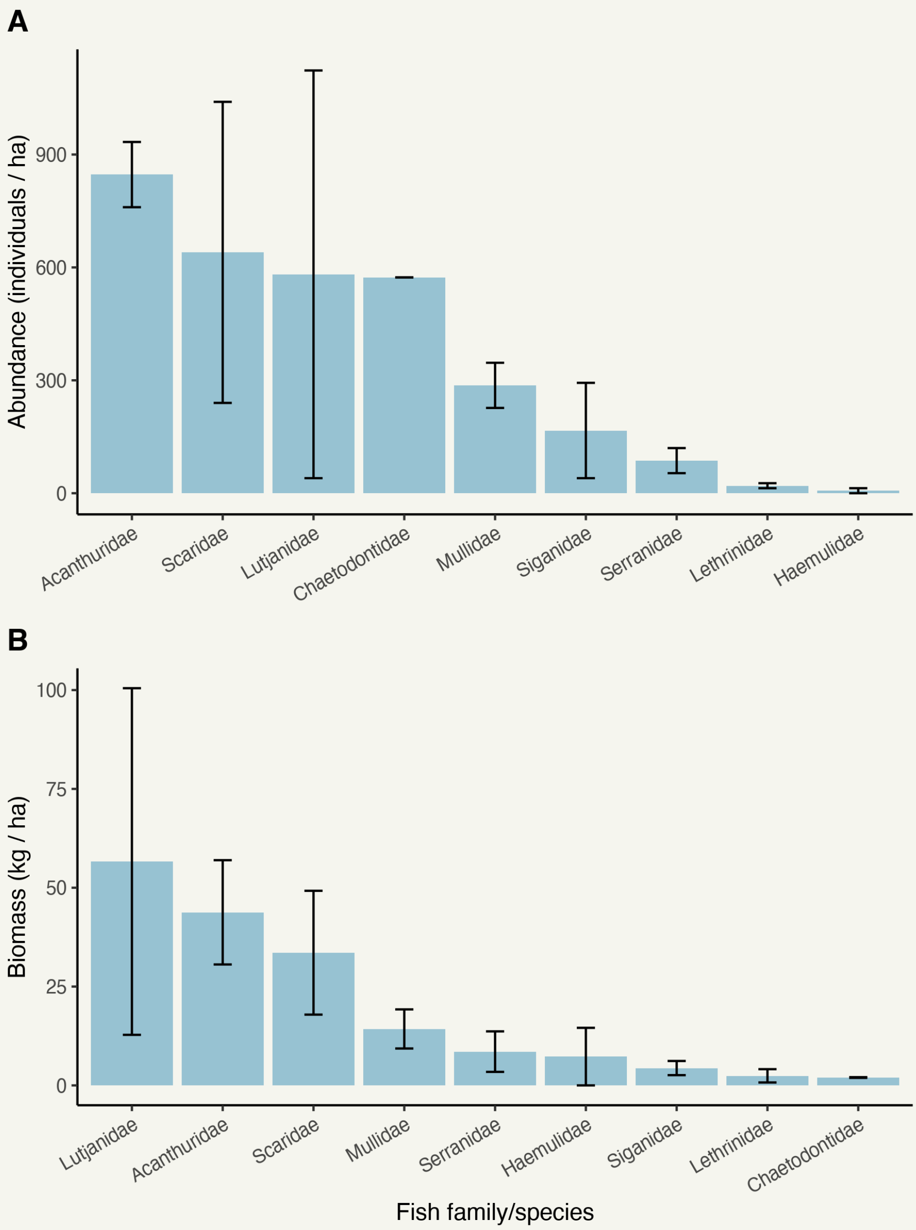


Figure 8.4.14. Overall fish (A) abundance and (B) biomass for sites surveyed in 2019 in Namuka and Dogotuki *qoliqoli*. Results divided by subgroup representing broad reef types.

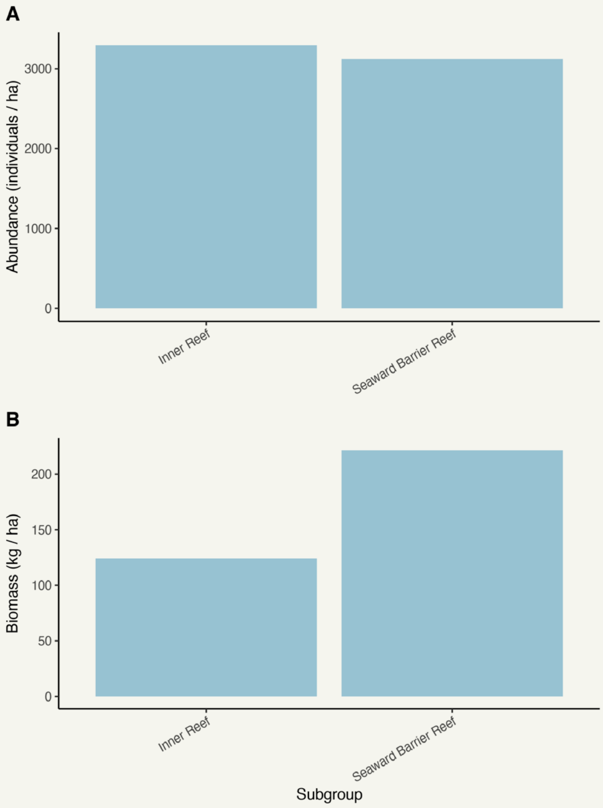


Figure 8.4.15. Change in key fisheries family abundance (Haemulidae, Lutjanidae, Scaridae, and Serranidae) for Namuka and Dogotuki *qoliqoli* for (A) all sites with historic data and (B) separately based on reef type.

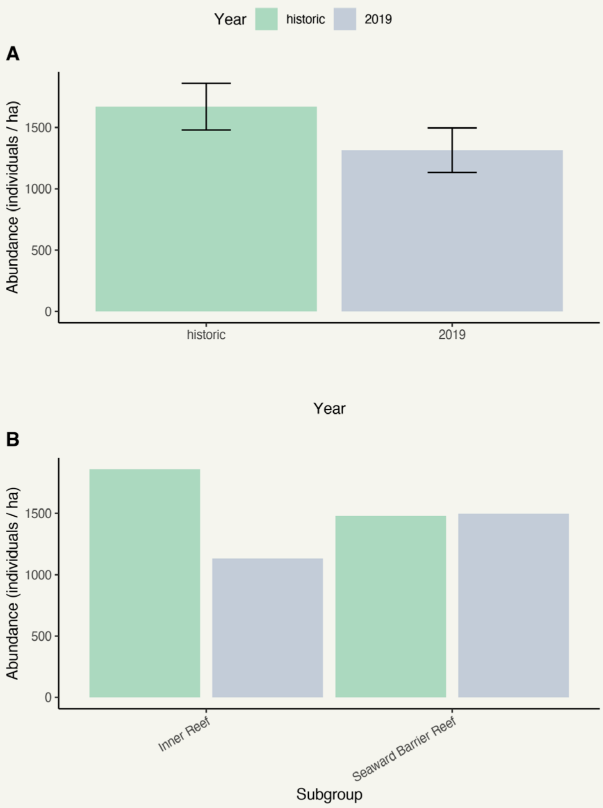
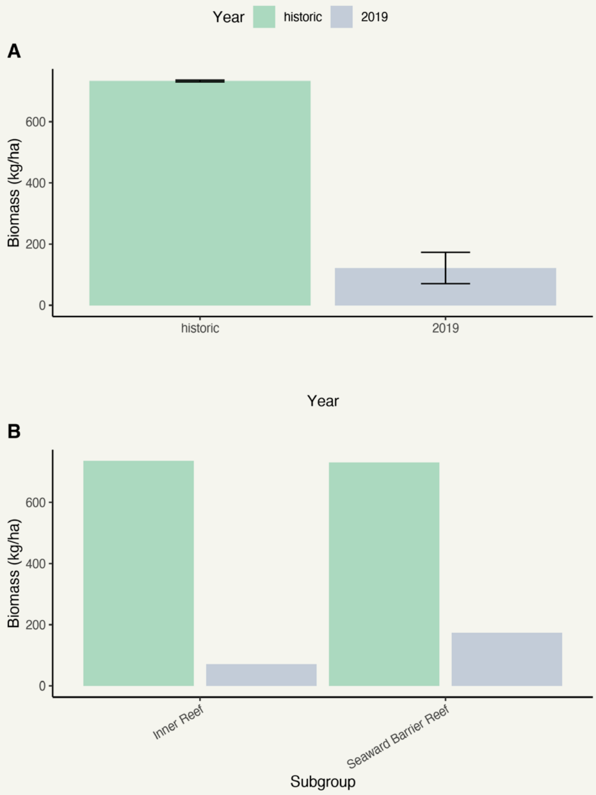


Figure 8.4.16. Change in key fisheries family biomass (Haemulidae, Lutjanidae, Scaridae, and Serranidae) for Namuka and Dogotuki *qoliqoli* for (A) all sites with historic data and (B) separately based on reef type. Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.



8.4.5 Rare Species

No humphead wrasse were recorded within Namuka and Dogotuki *qoliqoli* during the 2019 survey. At these two sites in 2004, humphead wrasse were recorded at 20 ± 20 ind/ha (Figure 8.4.17). No bumphead parrotfish were recorded in Namuka and Dogotuki *qoliqoli* in the 2019 survey, or during the historic surveys in 2004.

Serranidae abundance and biomass were 87 ± 33 ind/ha and 9 ± 5 kg/ha, respectively, across both surveyed Namuka and Dogotuki sites in 2019 (Figure 8.4.18). It was *about as likely as not* (V=3, p=0.50) that Serranidae abundance declined in Namuka and Dogotuki – with 240 ± 120 ind/ha recorded at these sites in 2004.

No sharks in the family Carcharhinidae were recorded during 2019 at Namuka and Dogotuki sites. Historic surveys recorded sharks at 40 ± 40 ind/ha in 2004 (Figure 8.4.19).

Figure 8.4.17. Humphead wrasse (*Cheilinus undulatus*) (A) abundance and (B) biomass for Namuka and Dogotuki *qoliqoli*. Each panel shows data for all sites (left of dashed vertical line) and only the sites with historic data available (right of dashed vertical line). Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.

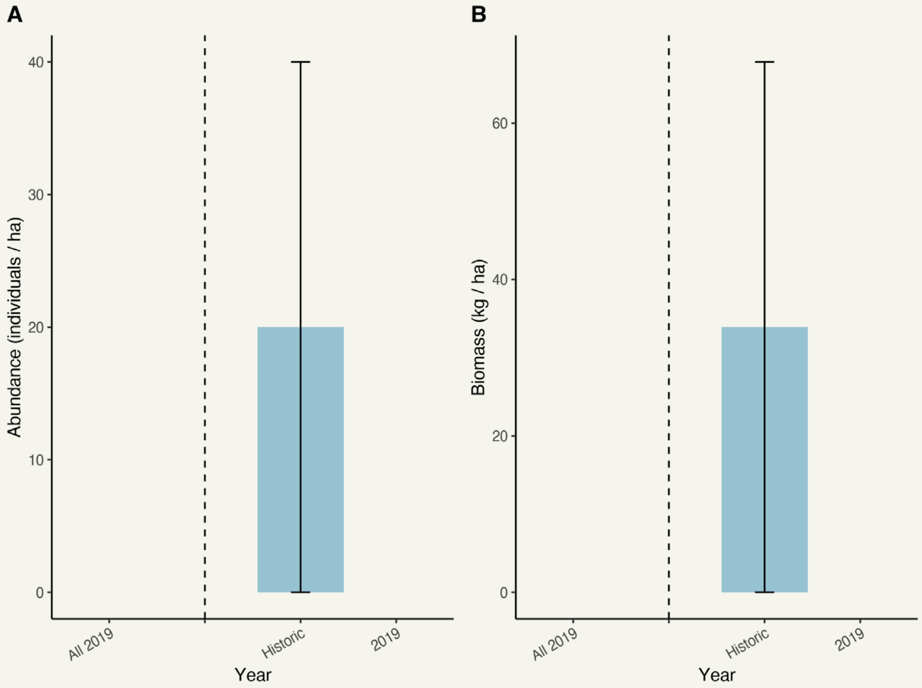


Figure 8.4.18. Serranidae (grouper) (A) abundance and (B) biomass for Namuka and Dogotuki *qoliqoli*. Each panel shows data for all sites (left of dashed vertical line) and only the sites with historic data available (right of dashed vertical line). Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.

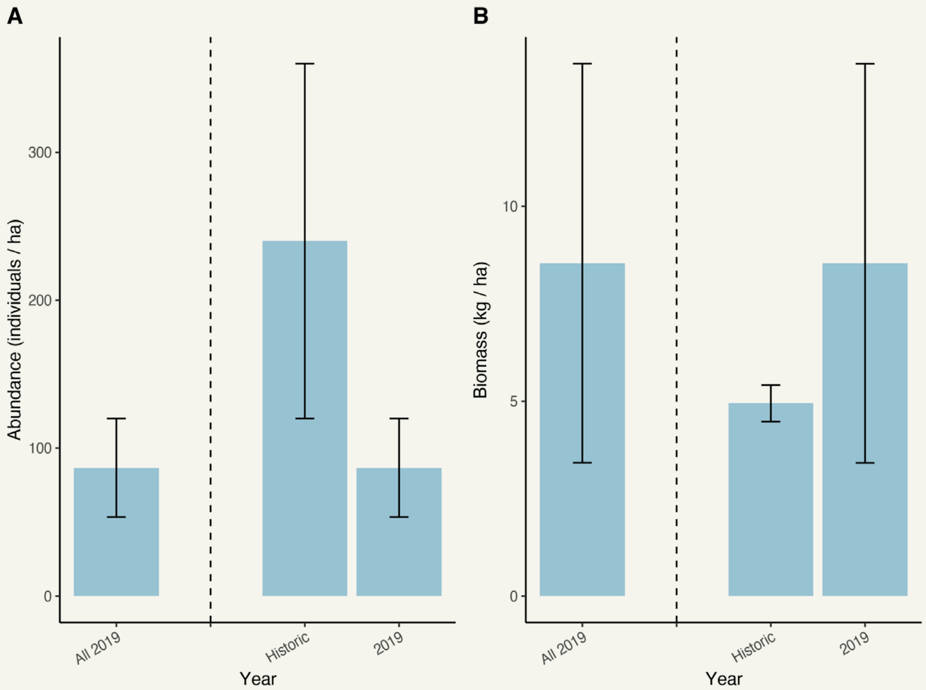
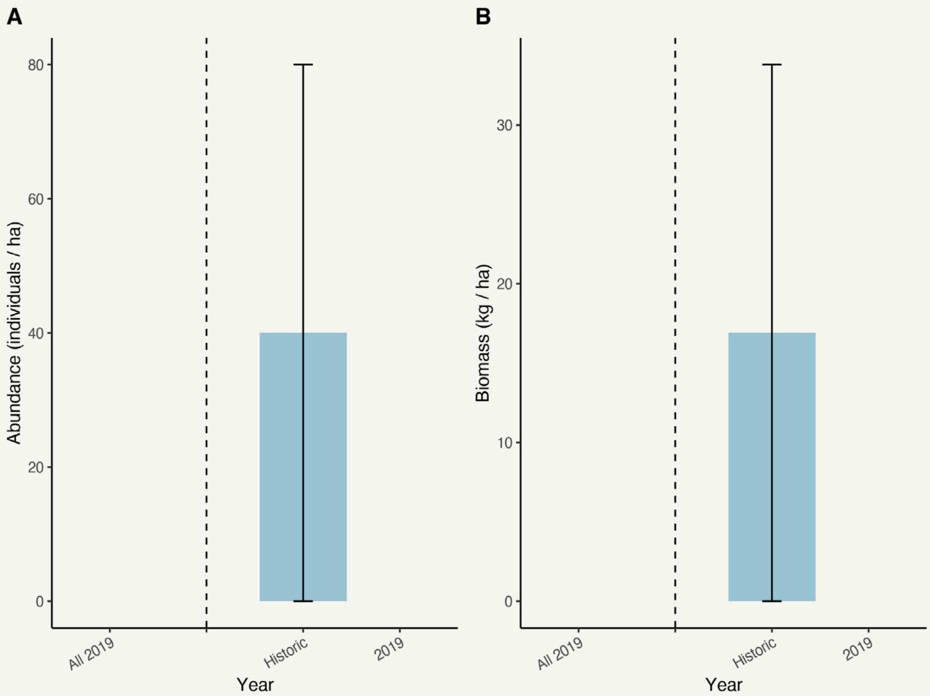


Figure 8.4.19. Carcharhinidae (shark) (A) abundance and (B) biomass for Namuka and Dogotuki *qoliqoli*. Each panel shows data for all sites (left of dashed vertical line) and only the sites with historic data available (right of dashed vertical line). Note, low shark biomass for historic comparisons is a result of all fish lengths > 45 cm being analyzed as 45 cm. Comparisons of biomass on the right of the plot assume all fish >40 cm TL are 45 cm TL.



8.5 Udu

8.5.1 Introduction and critical habitat coverage

Udu *qoliqoli* covers a single marine area of 73 km² located along the northeastern point of Macuata province on the north coast of Vanua Levu (Figure 8.5.1). The area contains a mix of shallow reef area, shallow lagoonal seabed, and mud flats. The northern edge of the *qoliqoli* is bounded by the outer edge of the fringing coastal reef. The offshore barrier reef system that runs along the north coast of Vanua Levu merges into the coastal fringing reefs of Vanua Levu in the western part of this *qoliqoli*. As the *qoliqoli* sits adjacent to Vanua Levu, there is some sedimentation impact in coastal areas from rivers and creeks flowing into the area in the western part of the *qoliqoli* (Figure 8.5.2).

Note, Allen Coral Atlas mapping currently only exists for Vanua Levu for the eastern hemisphere. The antemeridian (180° longitude) passes through Udu point, and so the coastal ecosystems of the eastern tip of Udu point are excluded from all presented ecosystem extent data. Therefore, all estimates of ecosystem extent presented within this chapter should be considered minimum estimates.

Reefs within Udu are mostly fringing along the coastline (Figures 8.5.3). In total, coral covers approximately 6 km² within the *qoliqoli*, though summing all Allen Coral Atlas benthic categories that likely contribute to broader coral reef ecosystem composition (i.e. coral/algae, microalgal mats, rock, and rubble) suggests a coverage of 12 km² of shallow reef-related ecosystems. The majority of these reefs are comprised of terrestrial reef flats (5 km²) and inner reef flats (5 km²), followed by significant areas of outer reef flats (2 km²), with other reef types also present (Figure 8.5.4).

Mangrove extent is 73 ha, with 72 ha recorded in 1996, giving a net increase of 1 ha between 1996 and 2016 (Figures 8.5.5; 8.5.6). There is limited mangrove extent in Udu, with mangroves mostly in narrow bands along the coastline. Seagrass covers approximately 3 km² within Udu *qoliqoli*, with much of this in the shallow coastal zone between the fringing reef and the Vanua Levu coastline (Figure 8.5.7).

Figure 8.5.1. Bathymetry of Udu *qoliqoli*.

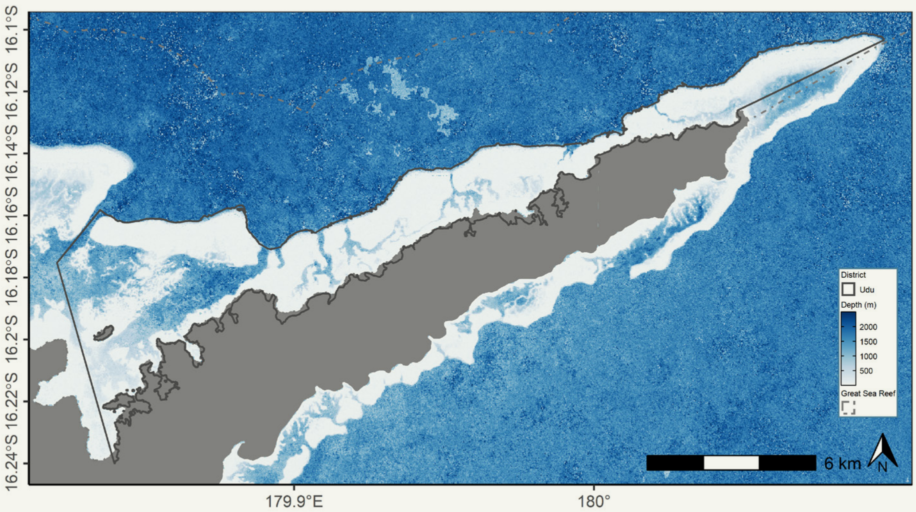


Figure 8.5.2. Sedimentation rates inside and adjacent to Udu *qoliqoli*.

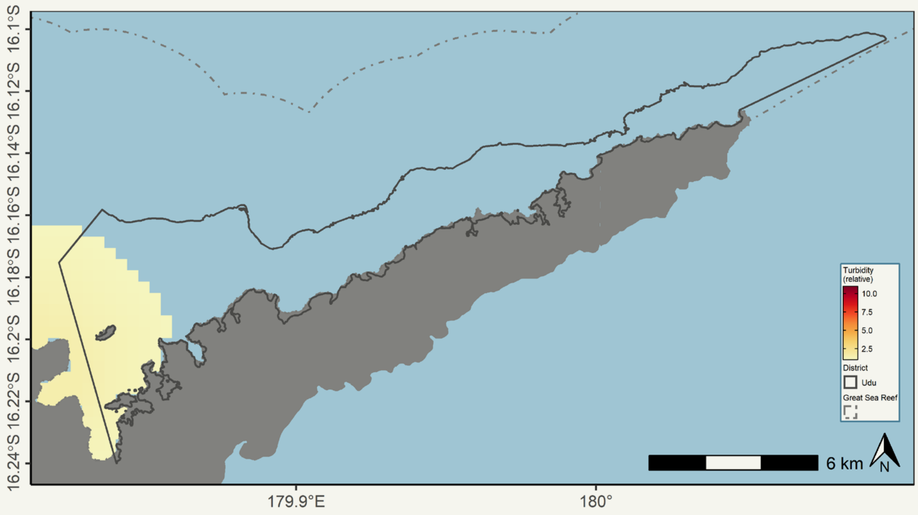


Figure 8.5.3. Coral reef extent in Udu *qoliqoli*.

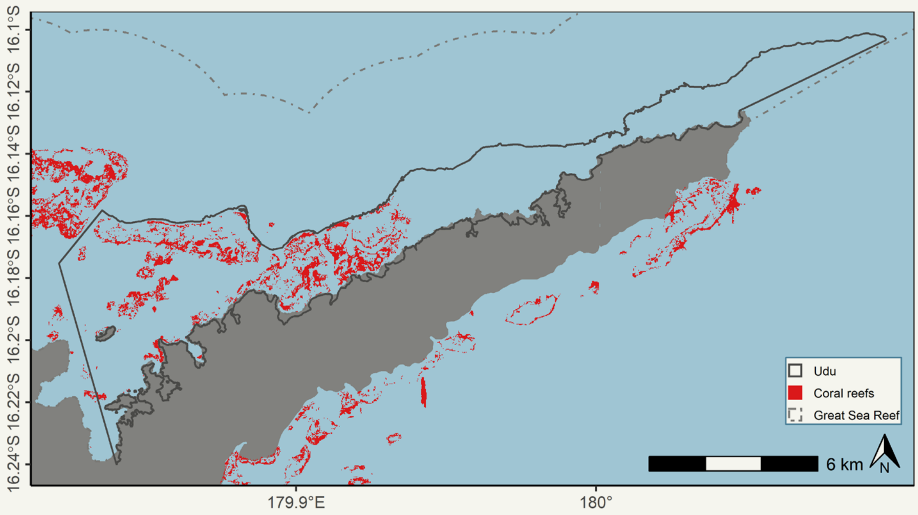


Figure 8.5.4. Coral reef geomorphic types in Udu *qoliqoli*.

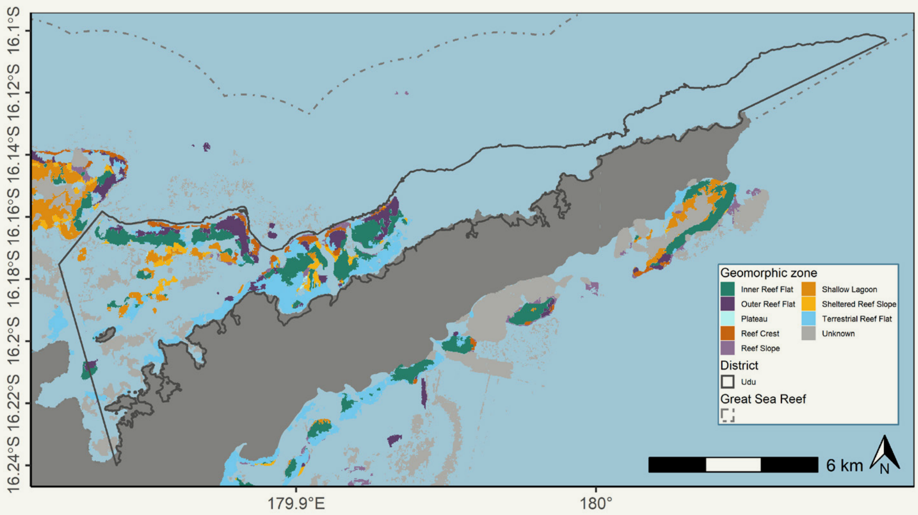


Figure 8.5.5. Mangrove extent in Udu *qoliqoli*.

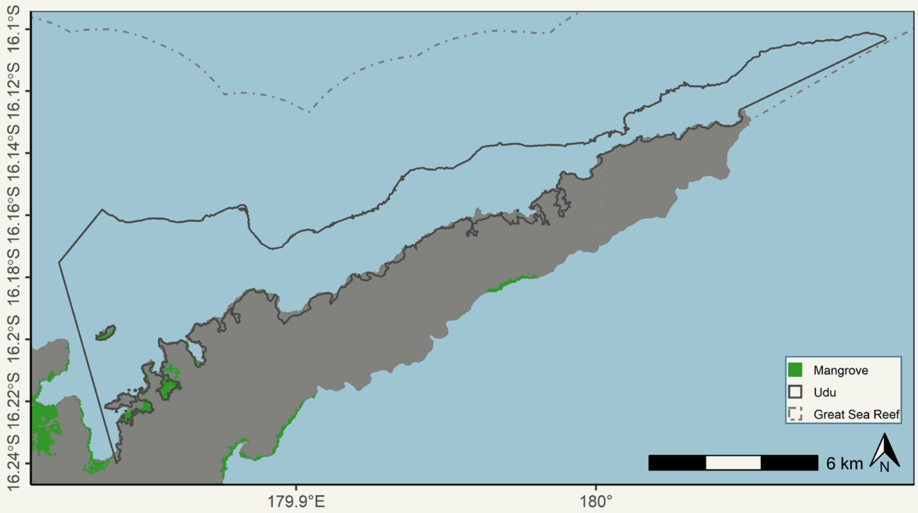


Figure 8.5.6. Mangrove change between 1996-2016 in Udu *qoliqoli*.

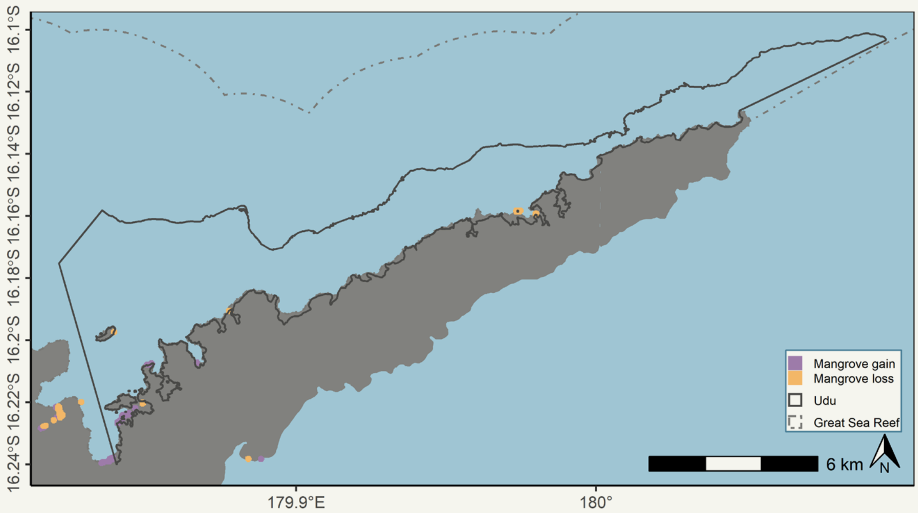
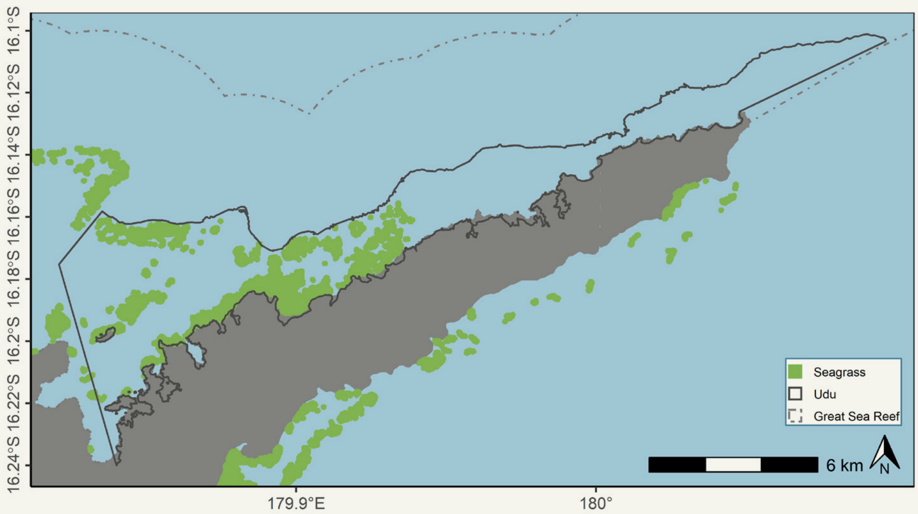


Figure 8.5.7. Seagrass cover in Udu *qoliqoli*.



8.5.2 Survey sites

Surveys were completed at two sites within Udu (Figure 8.5.8). Both of these sites were on the outer side of the fringing coastal reef and were new sites, so no historic data was available from Udu (Figure 8.5.8).

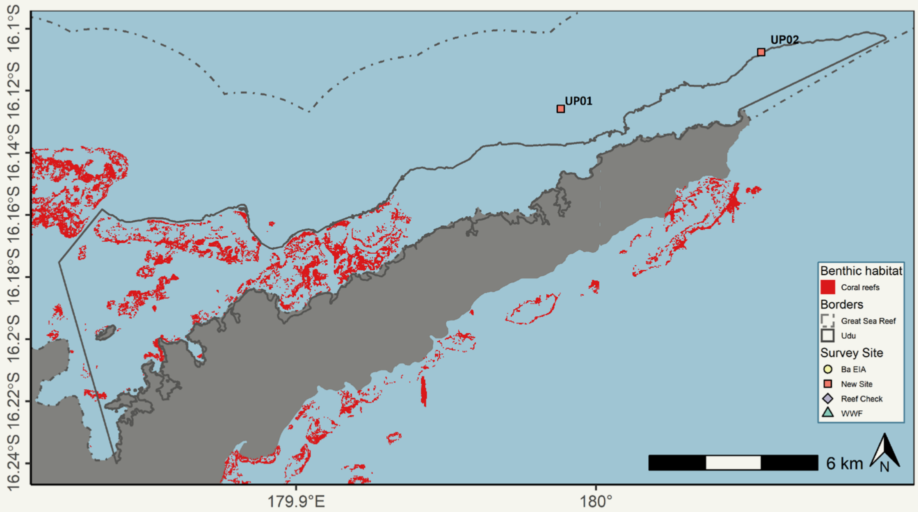


Figure 8.5.8. Survey sites in Udu *qoliqoli*.

8.5.3 Benthic cover

Hard coral cover was 73 ± 2% across reefs in Udu *qoliqoli* in 2019 (Figure 8.5.9). This represents the *qoliqoli* with the highest coral cover of all *qoliqoli* surveyed. The second highest live benthic cover on reefs was soft coral, at 10 ± 1%. Non-living benthic cover was generally low in Udu, with rubble and sand <1% and bare substrate at 12 ± 4%.

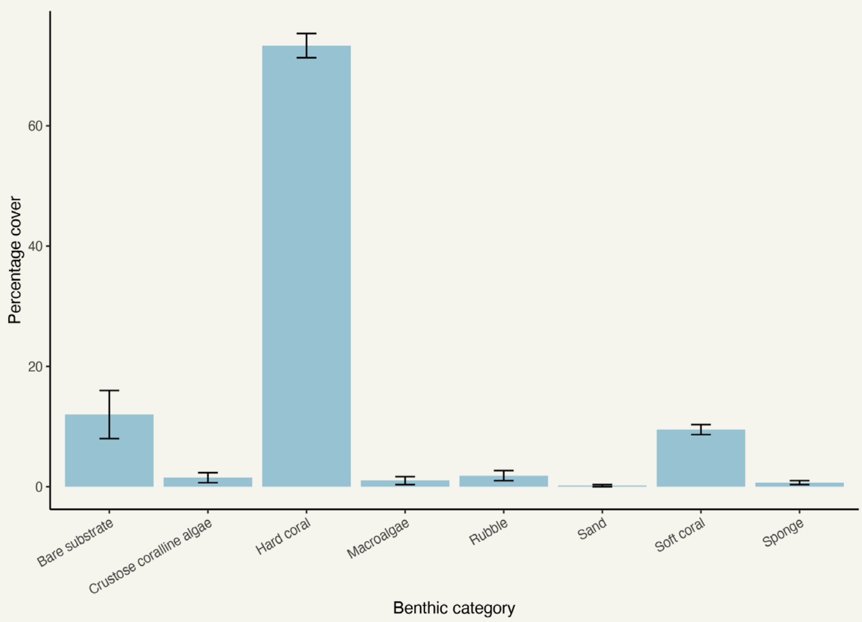


Figure 8.5.9. Benthic cover in 2019 for Udu *qoliqoli*.

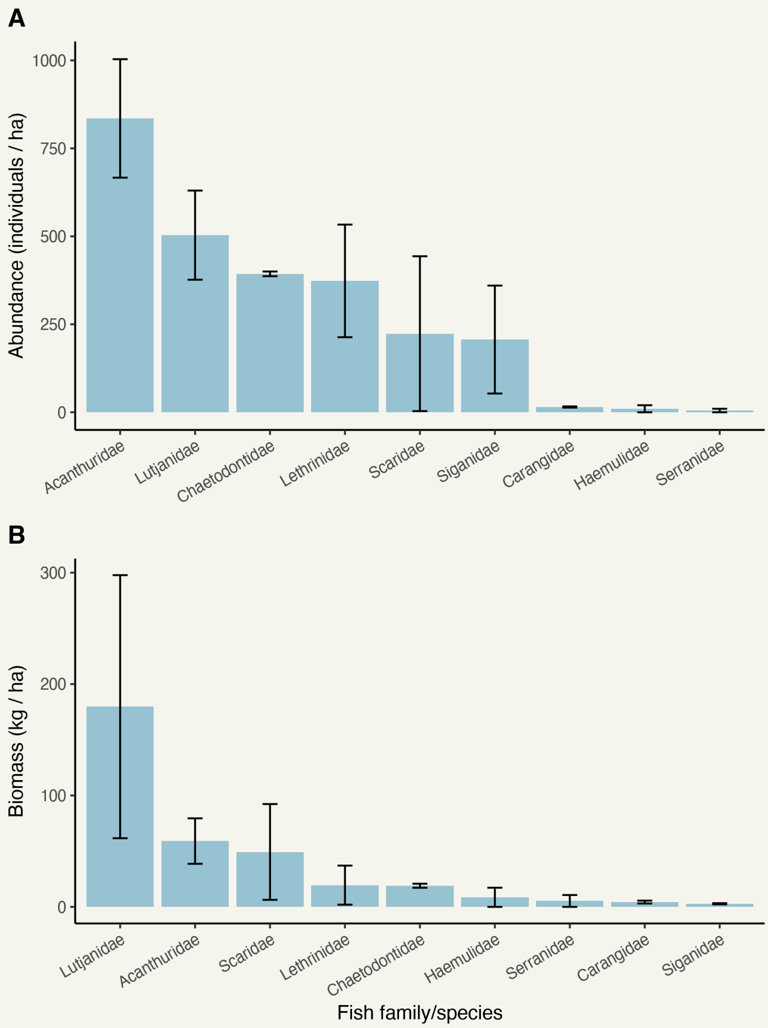
8.5.4 Fish communities

A mean fish abundance for the target family/species list of 2,565 ± 522 ind/ha was recorded across both Udu sites, while mean fish biomass was 348 ± 202 kg/ha. Both herbivores and carnviores made up a large proportion of the fish communities by abundance (Figure 8.5.10). The most abundant fish family was Acanthuridae (835 ± 168 ind/ha) followed by Lutjanidae (503 ± 127 ind/ ha). The largest family by biomass was Lutjanidae (180 ± 118 kg/ ha), which was very dominant in the community, with Acanthuridae (59 ± 20 kg/ ha) and Scaridae (49 ± 43 kg/ha) the second and third largest family by biomass (Figure 8.5.10).

8.5.5 Rare Species

No humphead wrasse, bumphead parrotfish, or sharks were recorded within Udu *qoliqoli* during the 2019 survey. Serranidae abundance and biomass was 5 ± 5 ind/ha and 5.3 ± 5.3 kg/ha, respectively, across both surveyed Udu sites in 2019.

Figure 8.5.10. Fish community structure by (A) abundance and (B) biomass for Udu *qoliqoli*.



8.6 Wailevu

8.6.1 Introduction and critical habitat coverage

Wailevu *qoliqoli* covers a single marine area of 41 km² located along the north coast of Macuata province on the north coast of Vanua Levu (Figure 8.6.1). The area contains a mix of shallow reef area, mangrove forests, and mud flats. The *qoliqoli* is bounded on three sides by other *qoliqoli*, with Qoliqoli Cokovata to the west and north, and Labasa 1 to the east. The entire *qoliqoli* is therefore adjacent to shore and enclosed within the offshore barrier reef system that runs along the north coast of Vanua Levu – though the *qoliqoli* does not extent as far offshore as the barrier reef. As the *qoliqoli* sits adjacent to Vanua Levu, there is sedimentation impact across the whole *qoliqoli* (Figure 8.6.2).

Figure 8.6.1. Bathymetry of Wailevu *qoliqoli*.

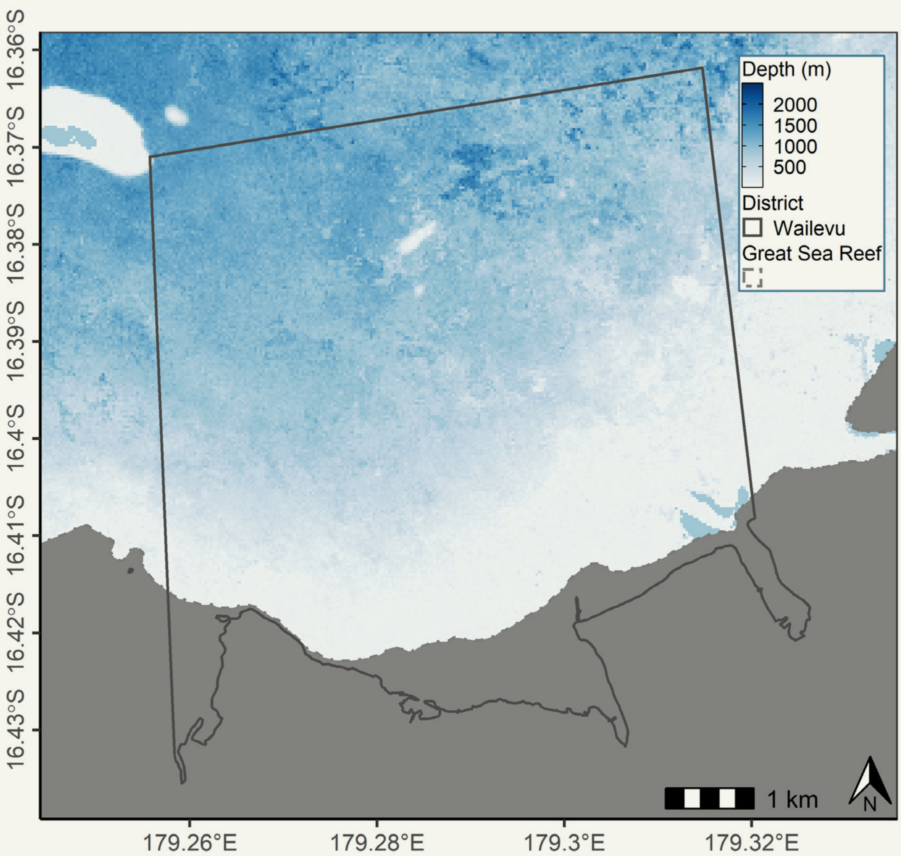
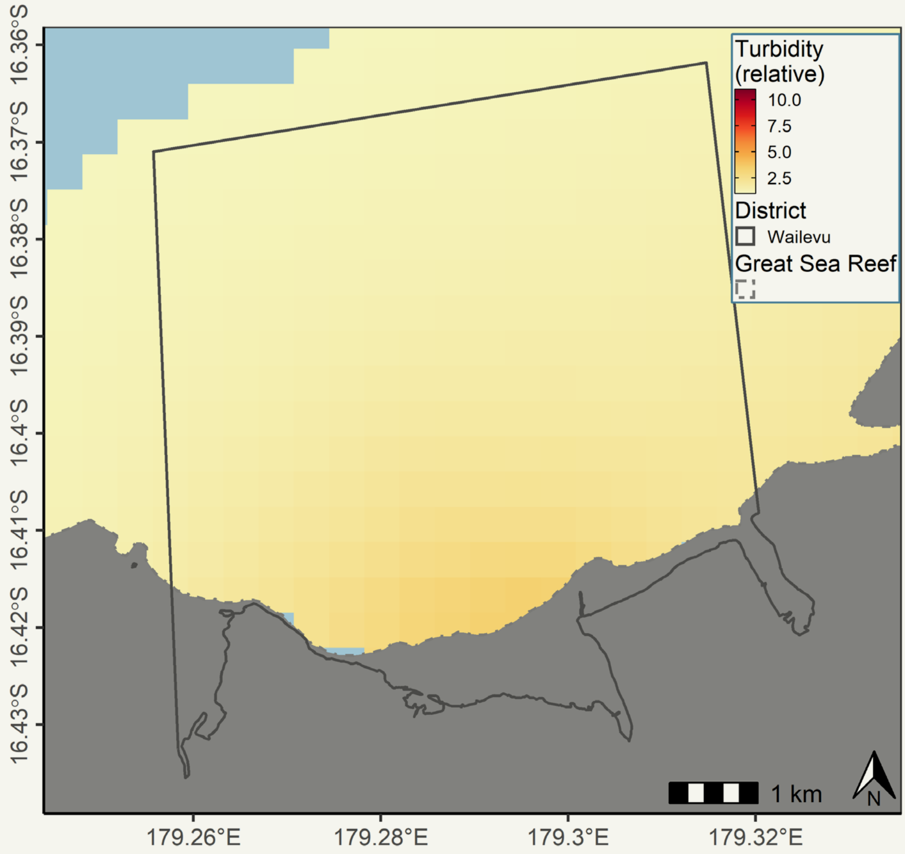


Figure 8.6.2. Sedimentation rates inside and adjacent to Wailevu *qoliqoli*.



Reefs within Wailevu are fringing along the coastline or small patch reefs within the center of the *qoliqoli* (Figure 8.6.3). In total, coral covers approximately 3.18 km^2 within the *qoliqoli*, and summing all Allen Coral Atlas benthic categories that likely contribute to broader coral reef ecosystem composition (i.e. coral/algae, microalgal mats, rock, and rubble) does not suggest a much larger coverage – at 3.32 km^2. The majority of these reefs are comprised of areas on terrestrial reef flats (3.62 km^2) and plateaus (1.26 km^2), with other reef types also present (Figure 8.6.4).

Mangrove forests form a dense coastal band in Wailevu *qoliqoli*. Mangrove extent is 399.55 ha, with 400.14 ha recorded in 1996, giving a small net loss of 0.59 ha between 1996 and 2016 (Figures 8.6.5; 8.6.6). This low net loss, however, hides that there has actually been more mangrove change. Between 1996 and 2016, 1.64 ha of mangroves were lost, while mangroves expanded to cover 1.05 ha of area that did not have them (Figure 8.6.6). Seagrass covers approximately 2 km^2 within Wailevu *qoliqoli*, with much of this in the shallow coastal zone, fringing along the Vanua Levu coastline (Figure 8.6.7).

Figure 8.6.3. Coral reef extent in Wailevu *qoliqoli*.

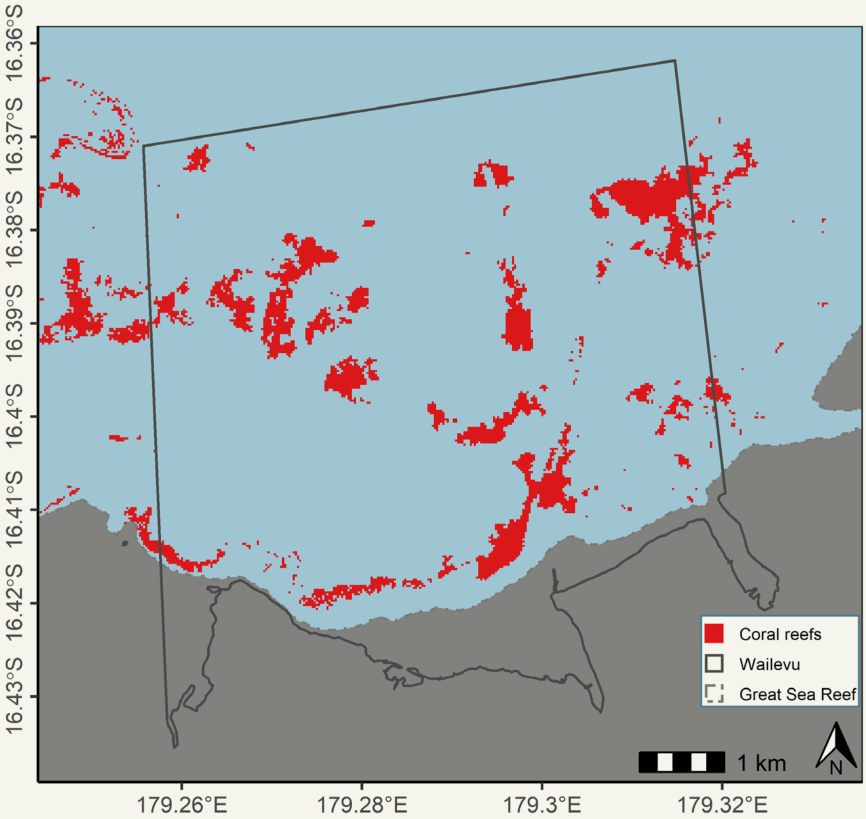


Figure 8.6.4. Coral reef geomorphic types in Wailevu *qoliqoli*.

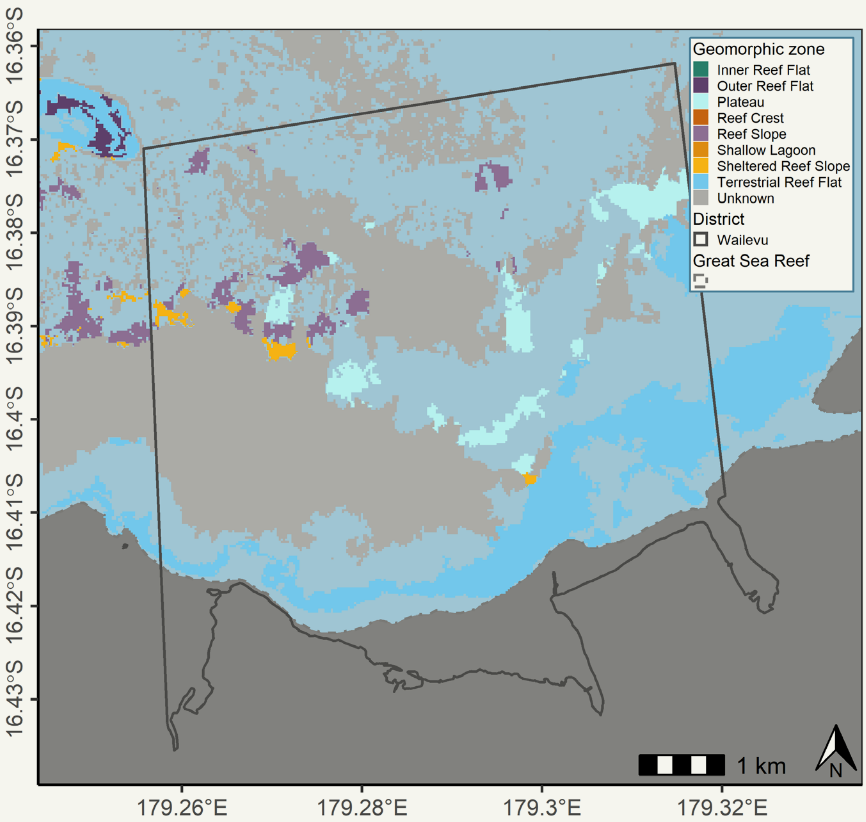


Figure 8.6.5. Mangrove extent in Wailevu *qoliqoli*.

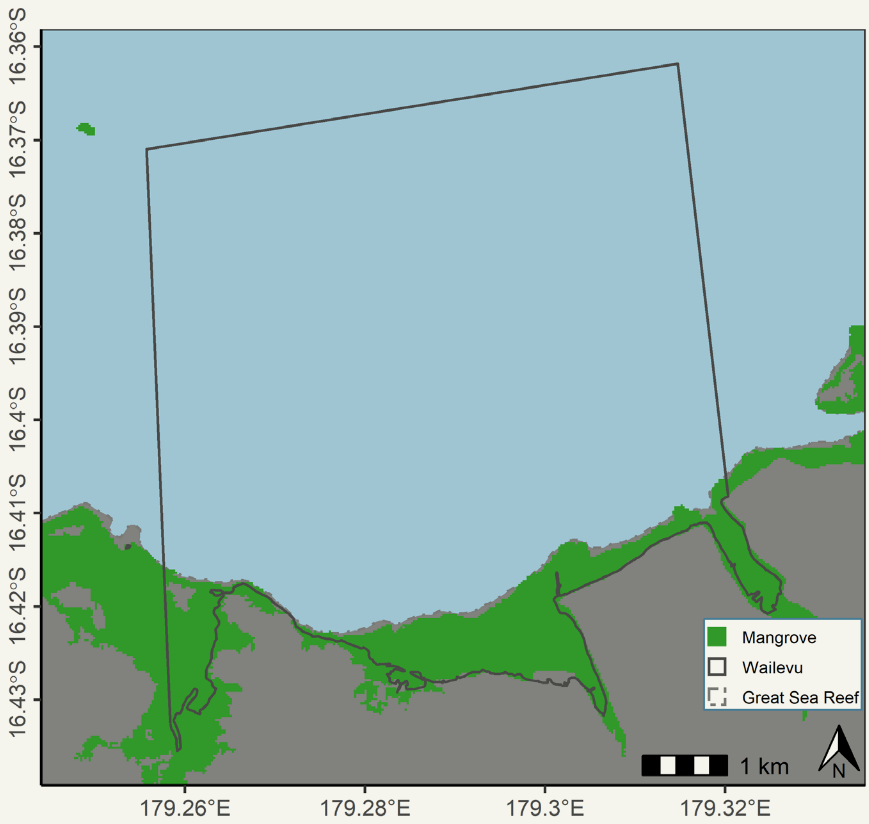


Figure 8.6.6. Mangrove change between 1996-2016 in Wailevu *qoliqoli*.

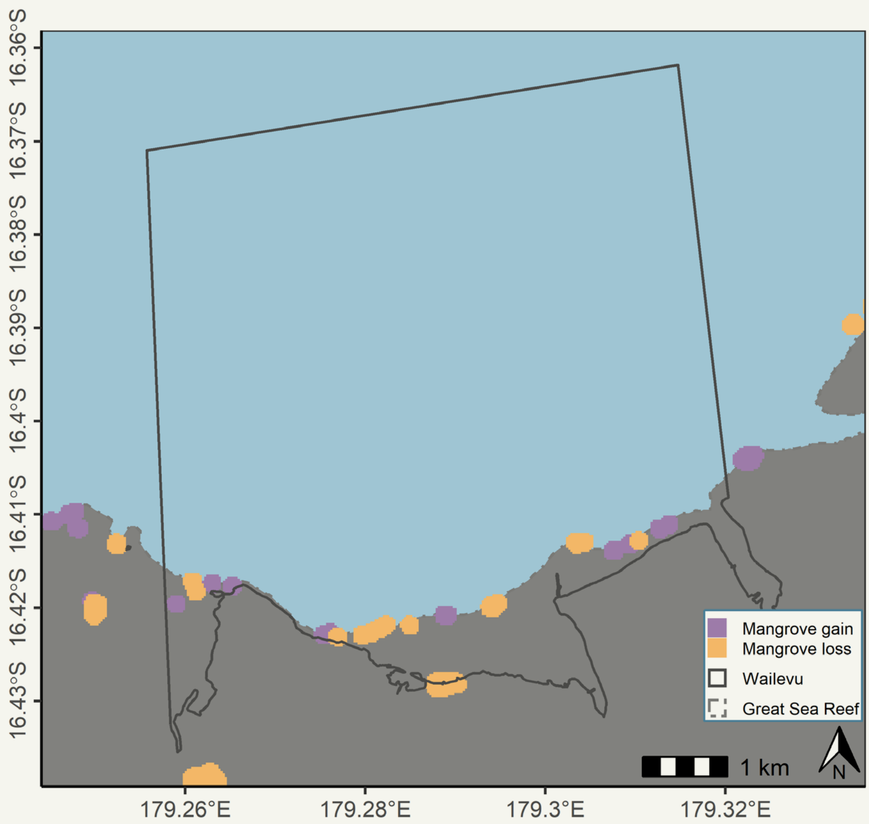
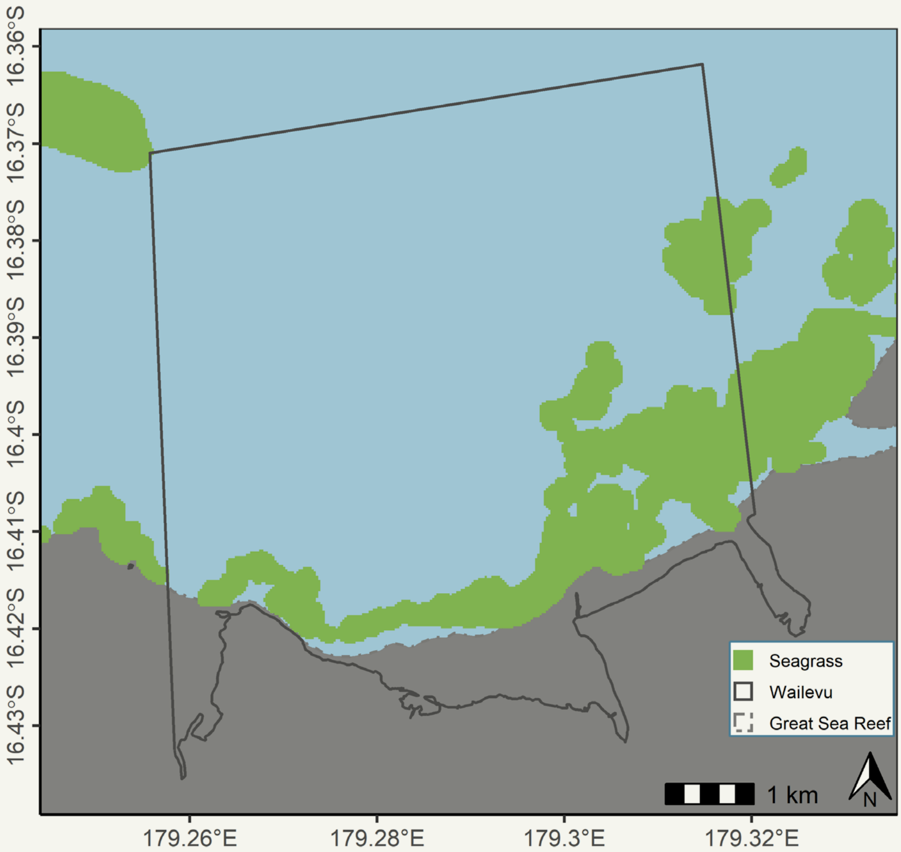


Figure 8.6.7. Seagrass cover in Wailevu *qoliqoli*.



8.7 Labasa 1

8.7.1 Introduction and critical habitat coverage

Labasa 1 *qoliqoli* covers a single marine area of 37 km² located along the north coast of Macuata province on the north coast of Vanua Levu (Figure 8.7.1). The area contains a mix of mangrove forests and mud flats. The *qoliqoli* is bounded by other *qoliqoli*, with Qoliqoli Cokovata to the north and east, and Wailevu to the west. The entire *qoliqoli* is therefore adjacent to shore and enclosed within the lagoon formed by the offshore barrier reef system – though the *qoliqoli* does not extent far offshore into the lagoon, with Mali Island lying to the north and outside the *qoliqoli* boundary. As the *qoliqoli* sits adjacent to Vanua Levu, and especially extensive river and mangroves systems, there is sedimentation impact across the whole *qoliqoli* (Figure 8.7.2).

Figure 8.7.1. Bathymetry of Labasa 1 *qoliqoli*.

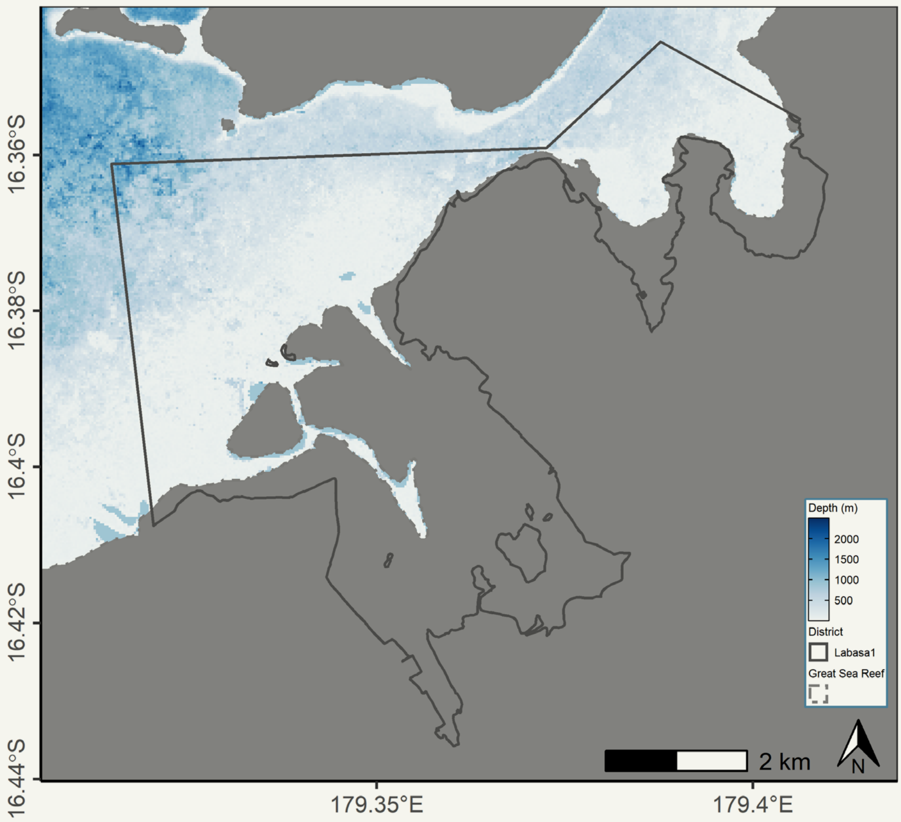
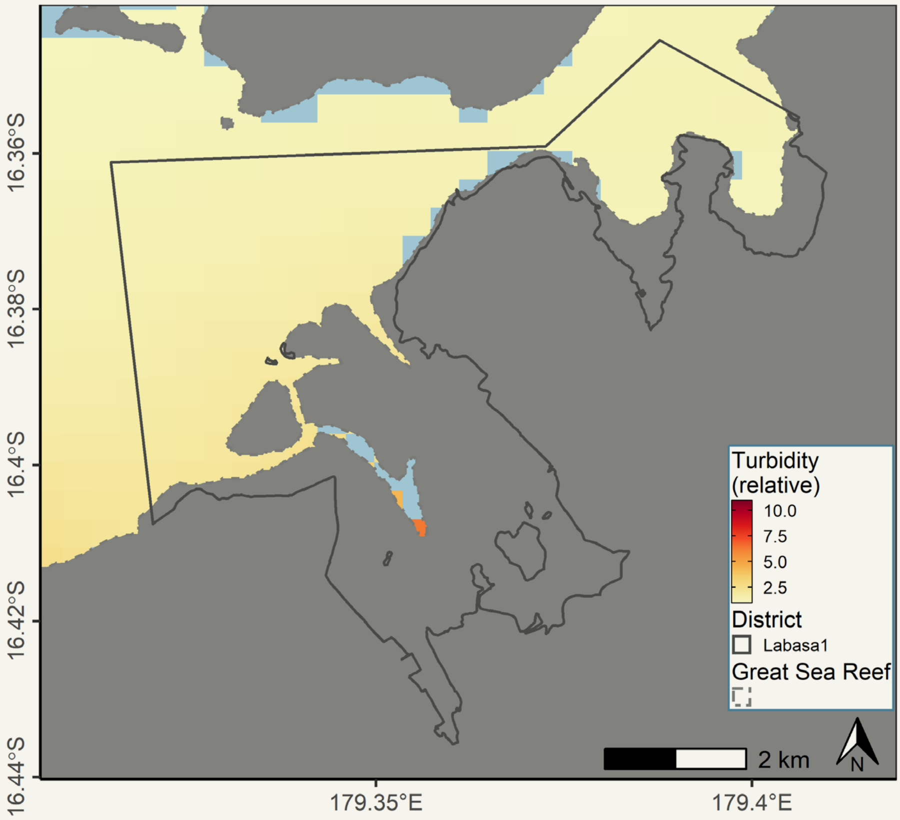


Figure 8.7.2. Sedimentation rates inside and adjacent to Labasa 1 *qoliqoli*.



There are few developed reefs within Labasa 1, with those that exist being shallow patch reefs that rise up within the lagoon within the north and center of the *qoliqoli* (Figure 8.7.3). In total, coral covers approximately 43.7 ha within the *qoliqoli*, though summing all Allen Coral Atlas benthic categories that likely contribute to broader coral reef ecosystem composition (i.e. coral/algae, microalgal mats, rock, and rubble) suggest a coverage of 71 ha for reef related ecosystems. The majority of these reefs are comprised of areas of terrestrial reef flats (344 ha) and reef crests (21 ha), with few other reef types also present (Figure 8.7.4).

Mangrove forests form a substantial part of the *qoliqoli* area, and form a dense forest between the coast and Labasa city. Mangrove extent is 1,549 ha, with 1,555 ha recorded in 1996, giving a net loss of 5.75 ha between 1996 and 2016 (Figures 8.7.5; 8.7.6). This low net loss, however, hides that there has actually been more mangrove change. Between 1996 and 2016, 8.55 ha of mangroves were lost, while mangroves expanded to cover 2.80 ha of area that did not have them (Figure 8.7.6). Seagrass covers approximately 250 ha within Labasa 1 *qoliqoli*, with much of this across the shallow seabed in the center of the *qoliqoli* (Figure 8.7.7).

Figure 8.7.3. Coral reef extent in Labasa 1 *qoliqoli*.

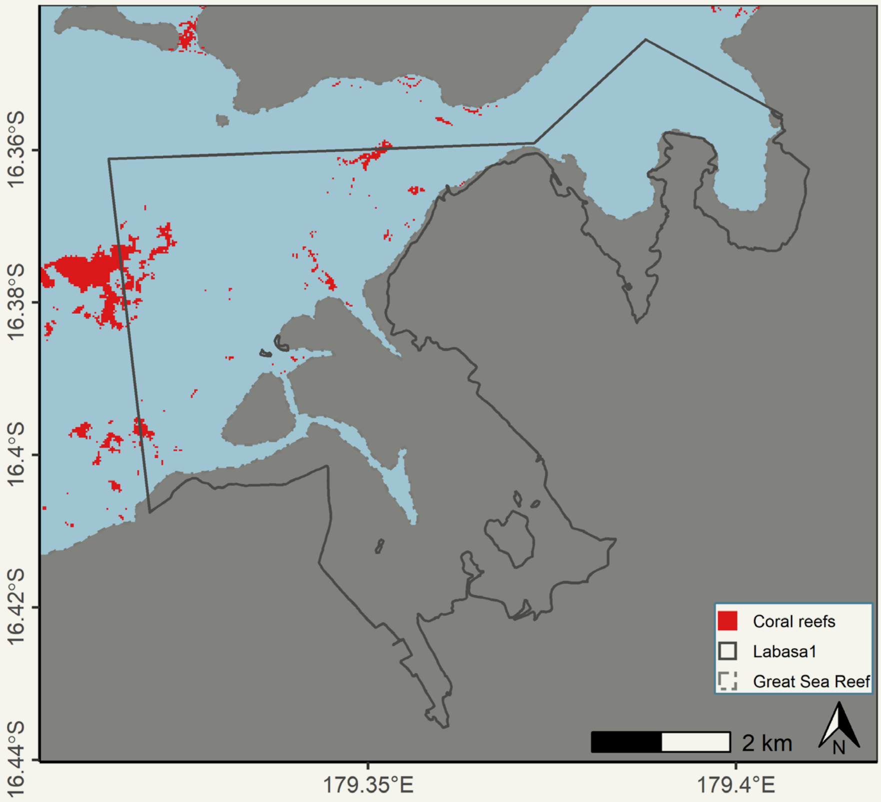


Figure 8.7.4. Coral reef geomorphic types in Labasa 1 *qoliqoli*.

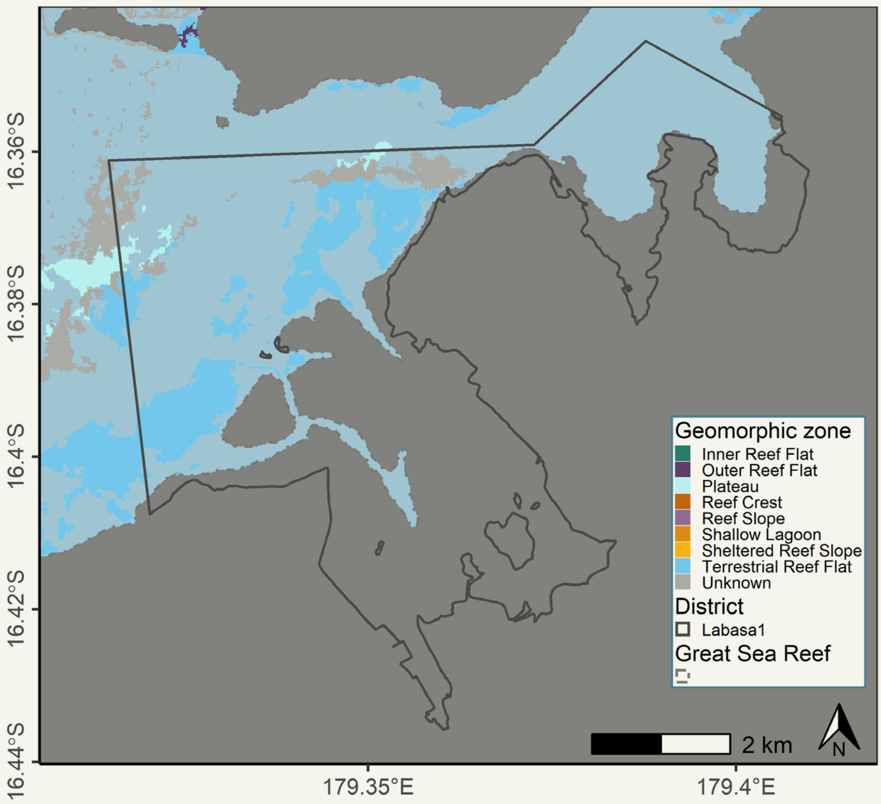


Figure 8.7.5. Mangrove extent in Labasa 1 *qoliqoli*.

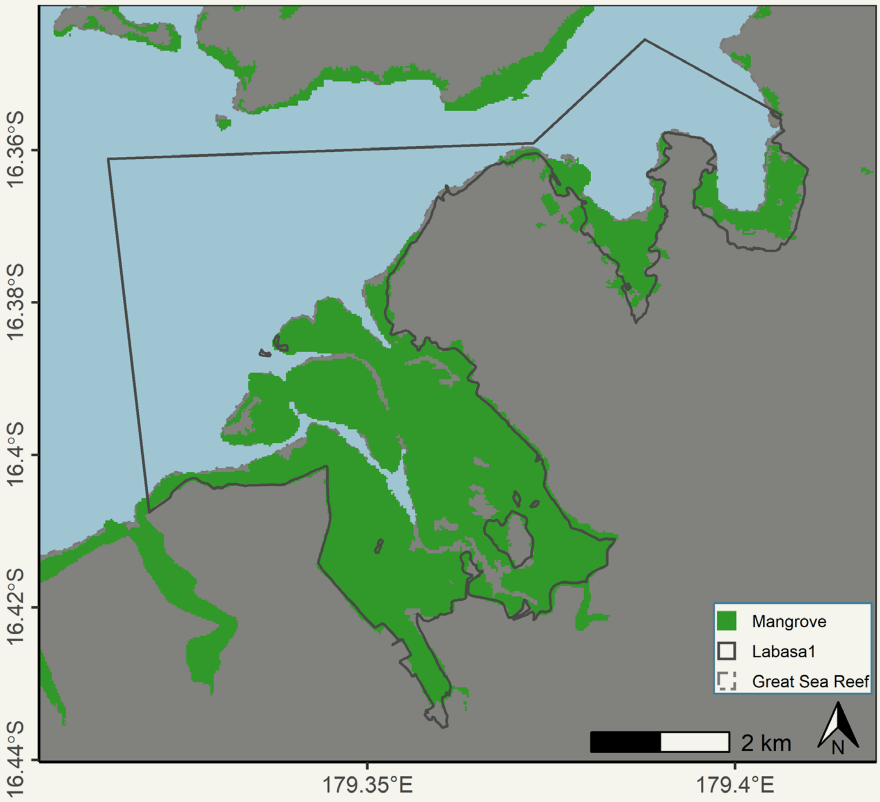


Figure 8.7.6. Mangrove change between 1996-2016 in Labasa 1 *qoliqoli*.

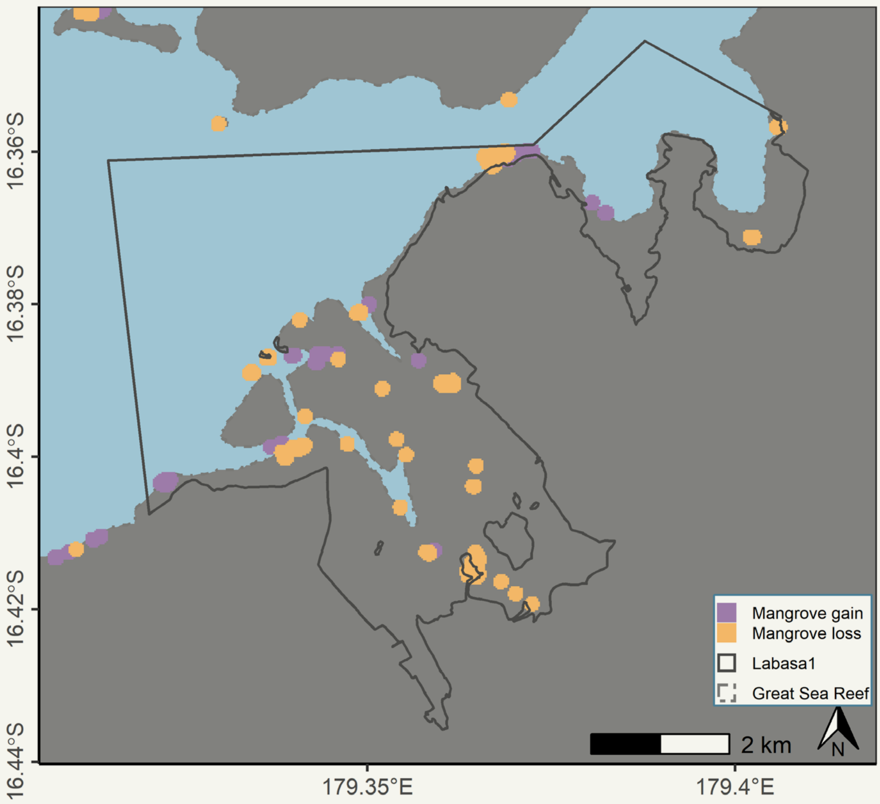
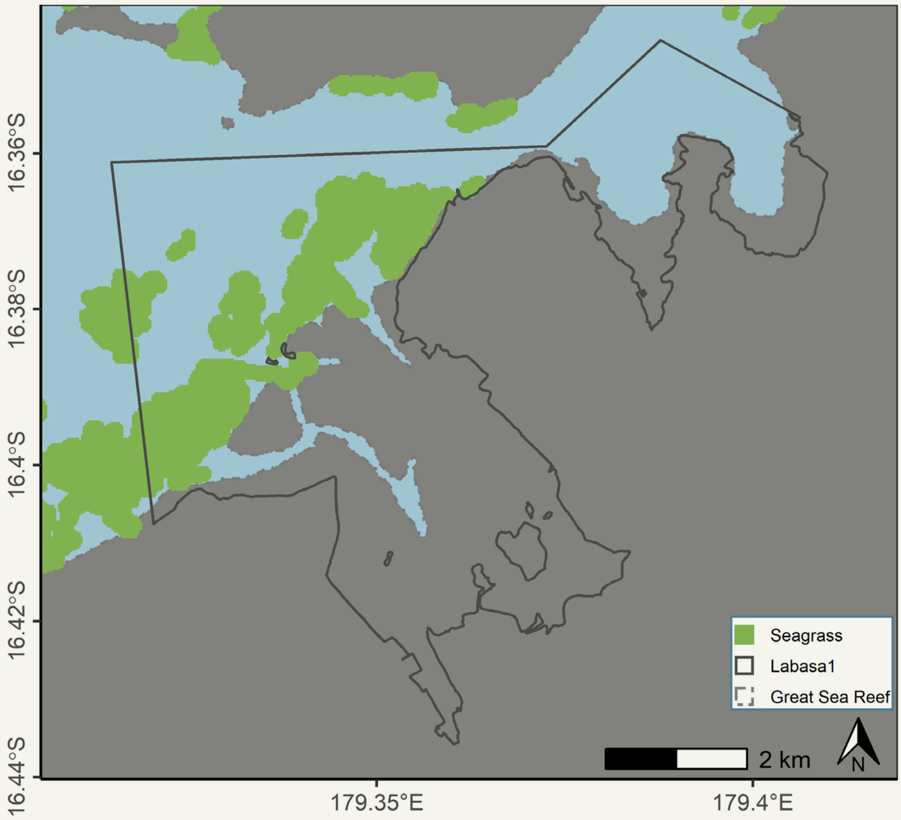


Figure 8.7.7. Seagrass cover in Labasa 1 *qoliqoli*.



8.8 Labasa 2

8.8.1 Introduction and critical habitat coverage

Labasa 2 *qoliqoli* covers a single marine area of 29 km² located along the north coast of Macuata province on the north coast of Vanua Levu (Figure 8.8.1). The area contains a mix of coral reefs, mangrove forests, and mud flats. This *qoliqoli* also includes part of the inner of the two parallel barrier reef sections that occur along the north coast of Macuata. The *qoliqoli* is bounded on by other *qoliqoli*, with Qoliqoli Cokovata to the west and north, and Nadogo to the east. The entire *qoliqoli* is therefore bounded by the shore to the south and the inner of the double barrier reefs to the north. While the *qoliqoli* sits adjacent to Vanua Levu, there are no major rivers flowing into this *qoliqoli* which limits direct sedimentation impact (Figure 8.8.2).

Figure 8.8.1. Bathymetry of Labasa 2 *qoliqoli*.

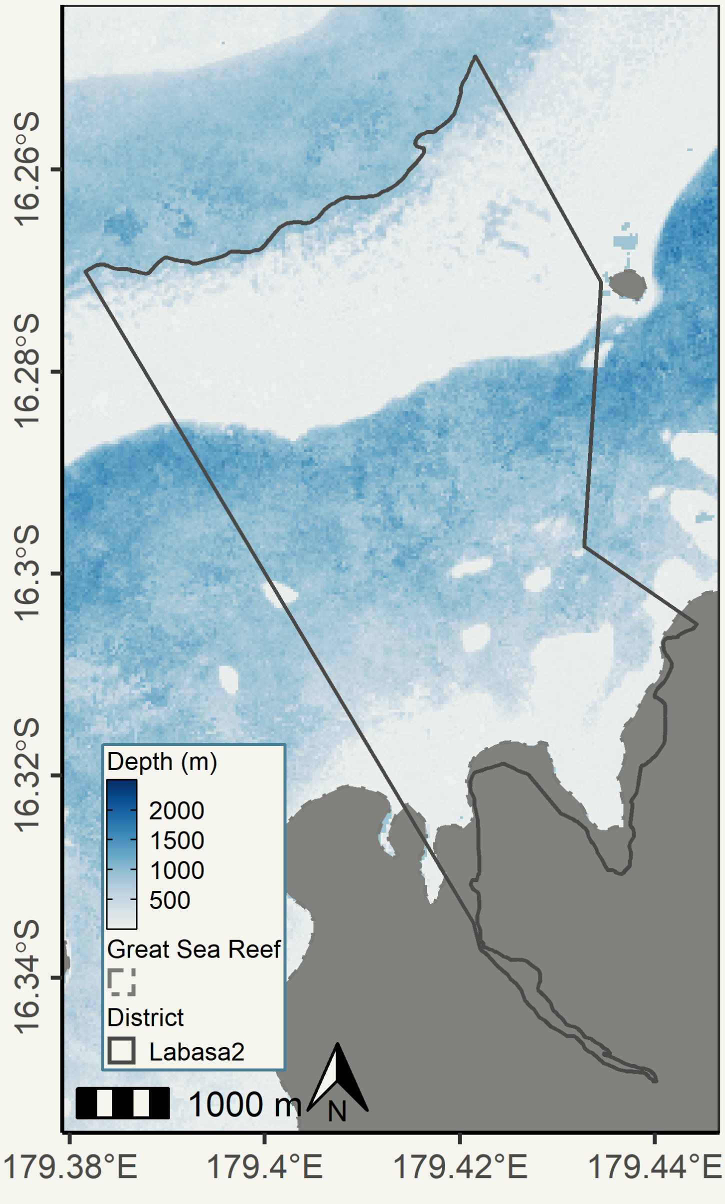
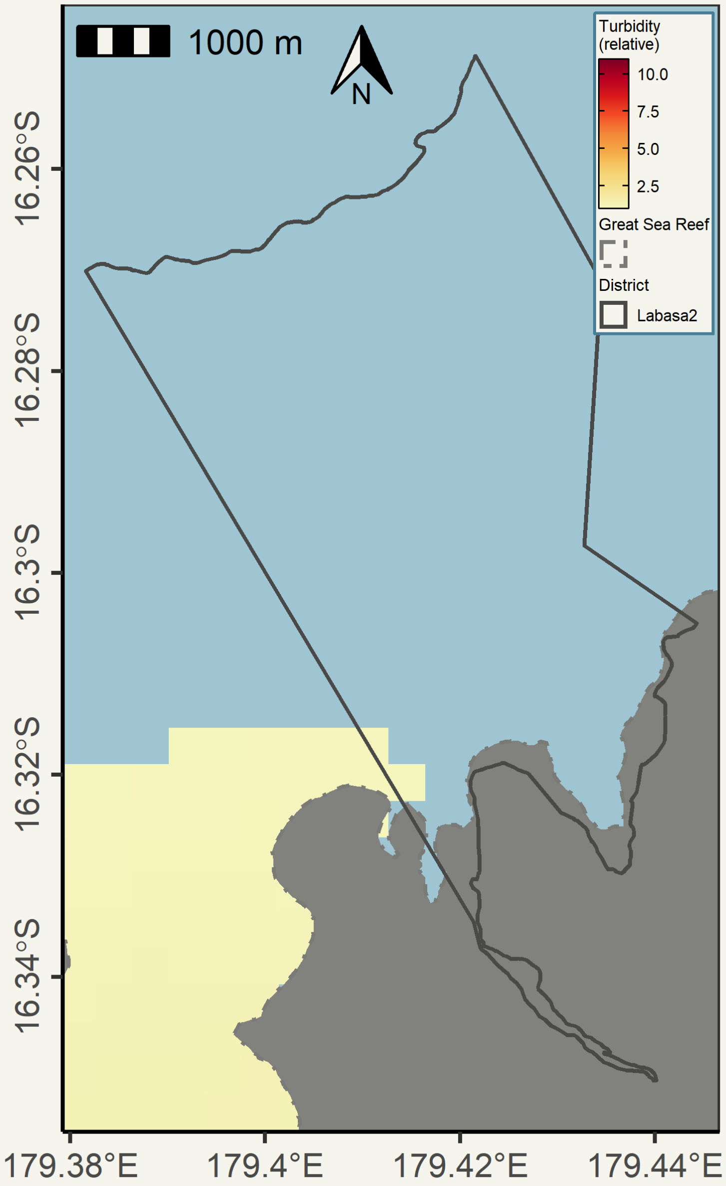


Figure 8.8.2. Sedimentation rates inside and adjacent to Labasa 2 *qoliqoli*.



There are extensive developed reefs within Labasa 2, particularly along the barrier reef at the north of the *qoliqoli*, but also from shallow patch reefs that rise up within the lagoon within the *qoliqoli* (Figure 8.8.3). In total, coral covers approximately 3.2 km^2 within the *qoliqoli*, though summing all Allen Coral Atlas benthic categories that likely contribute to broader coral reef ecosystem composition (i.e. coral/algae, microalgal mats, rock, and rubble) suggest a coverage of 8.5 km^2 for reef related ecosystems. The majority of these reefs are comprised of areas of inner reef flats (4.7 km^2), outer reef flats (3.7 km^2), and terrestrial reef flats (2.7 km^2), with other reef types also present (Figure 8.8.4).

Mangrove forests form a narrow fringe along the coastline in the *qoliqoli*. Mangrove extent is 133.29 ha, with 131.61 ha recorded in 1996, giving a net gain of 1.68 ha between 1996 and 2016 (Figures 8.8.5; 8.8.6). This net gain, however, hides that there has actually been more mangrove change. Between 1996 and 2016, 0.44 ha of mangroves were lost, while mangroves expanded to cover 2.11 ha of area that did not have them (Figure 8.8.6). Seagrass covers approximately 258 ha within Labasa 2 *qoliqoli*, with much of this across the shallow seabed adjacent to the Macuata coastline or associated with the barrier reef in the north of the *qoliqoli* (Figure 8.8.7).

Figure 8.8.3. Coral reef extent in Labasa 2 *qoliqoli*.

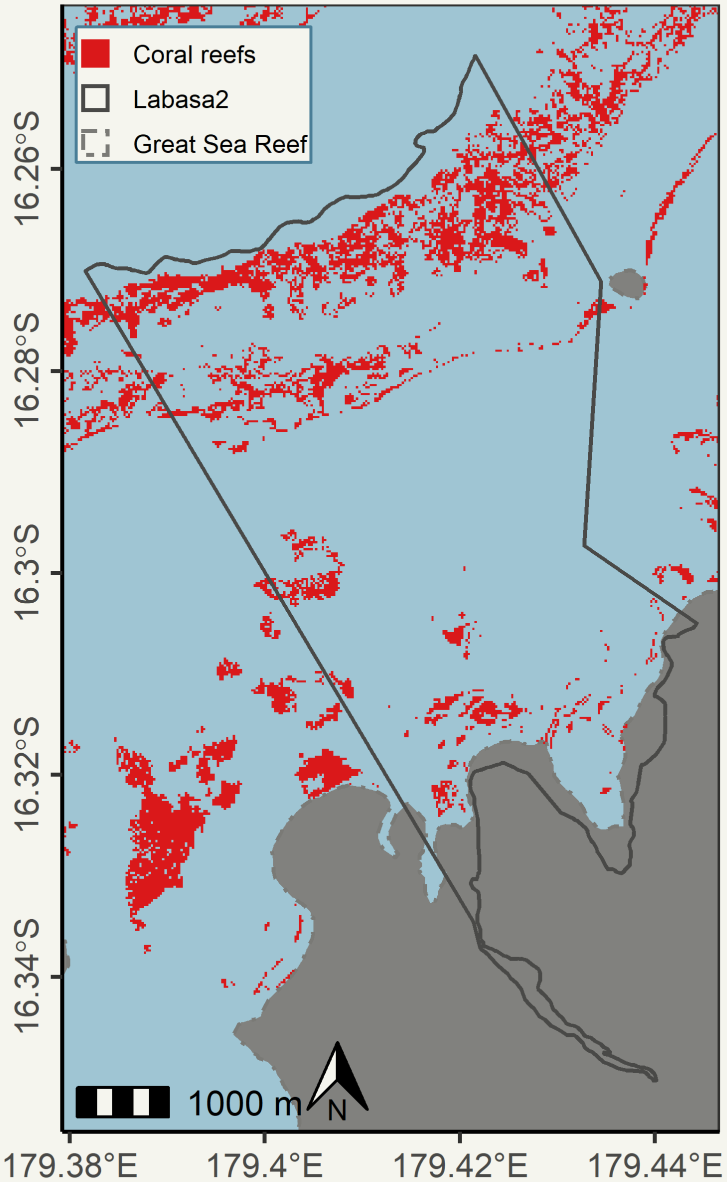


Figure 8.8.4. Coral reef geomorphic types in Labasa 2 *qoliqoli*.

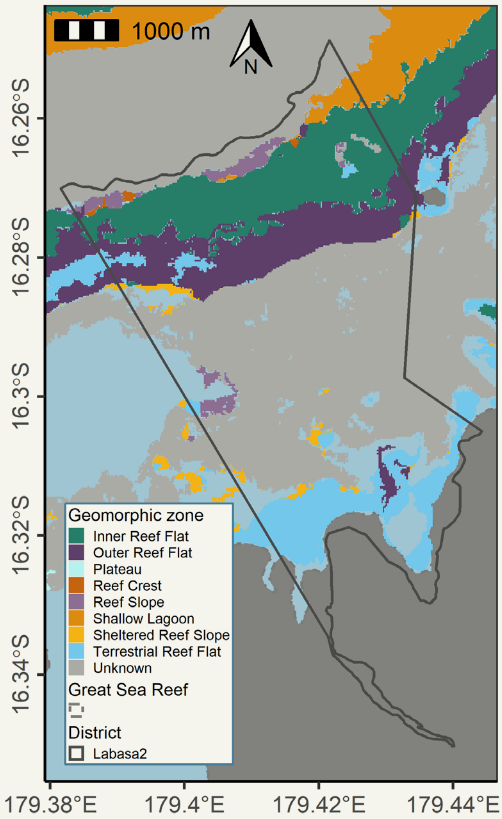
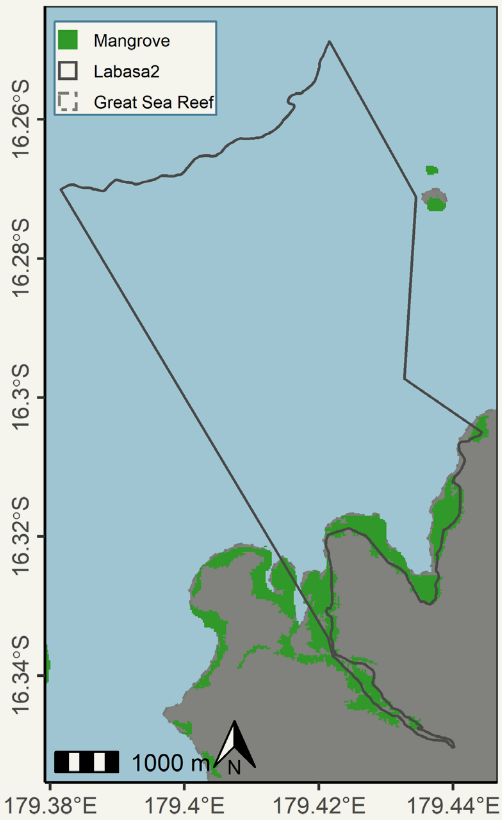


Figure 8.8.5. Mangrove extent in Labasa 2 *qoliqoli*.



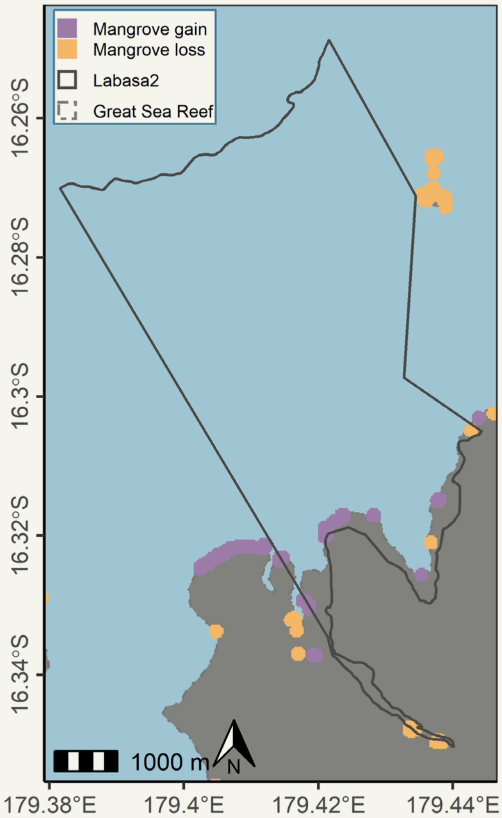


Figure 8.8.6. Mangrove change between 1996-2016 in Labasa 2 *qoliqoli*.

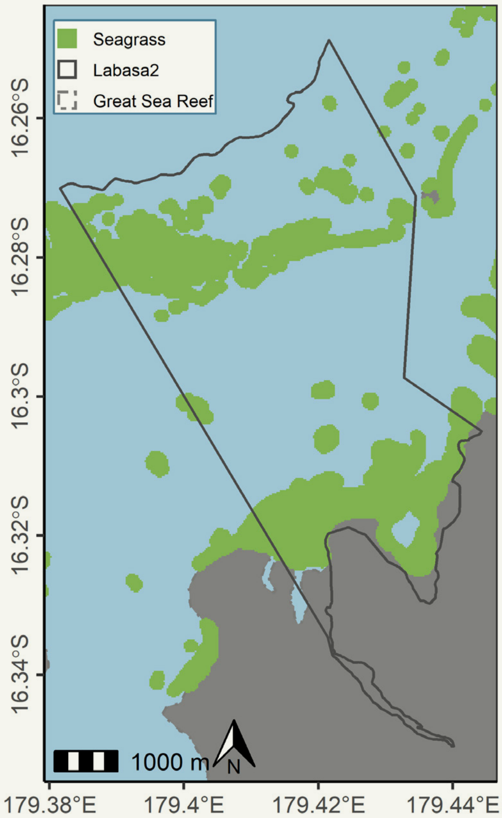


Figure 8.8.7. Seagrass cover in Labasa 2 *qoliqoli*.

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A young grouper photographed at a “cleaning station” on a reef surrounding Yadua island, Fiji. Here, the fish hover almost motionlessly and wait to be cleaned by cleaner wrasses who pick parasites off their scales. Groupers are notoriously overfished and hardly found in many reef systems across Fiji. Great Sea Reef Survey, Fiji.

PART C

Survey protocols and supporting materials.

This survey used standardized and rigorous monitoring methods to survey coral reef benthic habitats and fish communities.

This Part describes all field methods in greater depth, with additional data collection sheets.


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9 SURVEY PROTOCOL

This chapter contains the survey protocol that was written in advance of the 2019 GSR survey and refined during the pre-survey workshop in Lautoka. It covers the methods used for coral reef surveys during the 2019 GSR survey. The protocol is based on three previous protocols:

- WWF protocol developed for coral reef surveys in Indonesia (Ahmadia et al. 2013)
- Reef Check survey methods
- Methods used by the 2004 WWF GSR survey

These different protocols have been combined to enable this survey to be adapted to Fijian context by including sea cucumber and giant clam surveys and incorporate fish families that were previously surveyed in the 2004 WWF GSR survey that are not in standard WWF Indonesia protocol. Much of the text in this protocol is from Ahmadia et al. (2013), though has been edited to make the additions noted above.

9.1 Site Characteristics

Recording site characteristics is important to enable future surveys to return to the same monitoring site and also because this information is needed for data analyses. The following site characteristics should be recorded for each site:

- Reef type: atoll, fringing, lagoon, barrier, patch
- Reef slope (the angle of the substrate surveyed): wall, flat, slope

- Reef zone (location on the reef surveys were conducted): crest, fore reef, back reef
- Exposure: exposed, semi exposed, sheltered, very sheltered
- Latitude and longitude of starting point
- Reef direction (which shoulder is the reef on when swimming along the transect): right or left
- Notes: Anything else that might influence the reef communities or aid in finding the location of the site (e.g. nearby island or feature on land or sea).

9.2 Sampling Event Details

The following sampling event details should be recorded during each survey at a site:

- Site
- Date
- Depth
- Latitude and longitude at survey start
- Observers for benthic, small fish, and big fish
- Underwater visibility (in meters)
- Current strength during survey: high, moderate, low
- Notes: anything else that might influence the reef communities or any mishaps or conditions that did not allow data to be collected.

9.3 Fish communities

Underwater visual census methods are the most effective methods for monitoring coral reef fishes, particularly in remote locations (Choat and Pears 2003). Coral reef fish populations (focusing on key fisheries species) will be surveyed using underwater visual census methods described by English et al. (1997), Wilkinson et al. (2003), Sweatman et al. (2005) and Green and Bellwood (2009).

Fish belt transects are used as they provide a high degree of precision for most fisheries species and herbivores and are suitable for monitoring for multiple objectives (e.g. fisheries and resilience) (Green and Bellwood 2009). This method provides the most effective technique for monitoring coral reef fishes that are amenable to visual census techniques. In this survey we plan to prioritize fish and benthic surveys at 10 m depth on reef slopes. The survey plan focuses on increasing the number of monitoring sites – accepting that only one depth band will be surveyed per site. These depths are recommended for a number of reasons:

1) Depending on the reef profile, the depth between 3-8 m can often be an "intermediate" area and so are unlikely to be consistently representative of either reef crests or reef slopes across different sites.

2) A target depth of 10 m (and maximum depth of 12 m) is recommended to minimize the risks that divers will run out of air before completing the surveys or suffer decompression sickness.

3) For measuring one depth across different sites, 10 m is generally considered to be representative of coral reef sites.

9.3.1 Belt transects

Reef fishes will be surveyed using 3 x 50 m transects at each site. Each survey will consist of two observers swimming along transects placed parallel to the reef crest at a target depth of 10 m (8-12 m depth range acceptable). Observers will count and estimate the size—total length (TL)—of individual fish of the target fish families/species (Figure 9.3.1). Each observer will record different size groups of fish and use different transect widths as follows:

- Observer #1 (small fish observer) will swim 1-2 m above the substratum, counting and estimating the size of small to medium sized individuals (0 - 40 cm TL) of the target species using a transect width of 5 m (2.5 m either side of the observer). Care should be taken to accurately estimate the width of the transect and fish found outside this range should not be counted. If a fish is on the edge of the survey area, the observer should count it if more than half its body is inside the area. Since this observer has to count the most individuals and species, he/she should be an experienced fish observer. Observer #1 sets the pace of the transect, and so must regularly look behind to ensure that the rest of the survey team is following, and they are within reach for the roll master to signal the transect end.
- Observer #2 (big fish observer) will swim slightly behind and above Observer #1 to provide a better view of the larger area and to minimize disturbance to small fishes by the passage of the divers. This observer will swim 3 m above the substratum, counting and estimating the size of all large individuals (>40 cm TL) of targeted species using a wider transect width of 20 m (10 m either side of the observer). Care should be taken to accurately estimate the width of the transect and fish found outside this range should not be counted. Since this observer will be counting mostly large fish, he/she should be an experienced observer who can estimate the size of large fish with a high degree of precision.

A third person (roll master) will lay the transects following immediately behind the observers rolling out the tape, attaching it to the bottom every few meters. The roll master must let the observers know when each transect has started and ended usually by banging on their tank or tugging on the observer's fins. Transects should be laid consecutively along a depth contour of 10 m parallel to the reef crest. Because the transects will be used for assessing the benthic community it is extremely important that the transects are laid correctly. The transects must be located close to the benthos and follow the contour of the reef, avoid overhangs and caves and attached at regular intervals. The roll master must ensure the fish observers are swimming slowly enough so he or she is able to lay the transect correctly and is able to communicate with them at the start/end of each transect. With experienced divers or smaller teams, it may be possible for the small fish observer to lay the transect tape as they conduct their survey.

Once reaching the end of a transect, Observer #1 should wait for all other divers to complete their surveys before moving onto the next transect. Each of the three transects should be separated by approximately a 5 m gap.

Each fish observer will:

- Count all individuals of species from the fish family/species list and size group within the area of the transects and estimate the size of each fish counted.
- If a large fish school is encountered, the number of fish in the school should be estimated and the average length of fish in the school recorded.
- For fish in the 0-40 cm size range – each fish will be assigned to size categories. 10 cm size categories will be used (i.e. 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm).
- For fish larger than 40 cm – the total length of each fish should be estimated to the nearest 10 cm.
- All data will be recorded directly onto slates or pre-prepared datasheets printed on underwater paper.

In order to calculate fish density and biomass accurately, transect widths for small fish and big fish must be accurately maintained by each observer. The area of each transect surveyed by Observer #1 is 250 m2 (50 m x 5 m), while the area of each transect surveyed by Observer #2 is 1,000 m2 (50 m x 20 m).

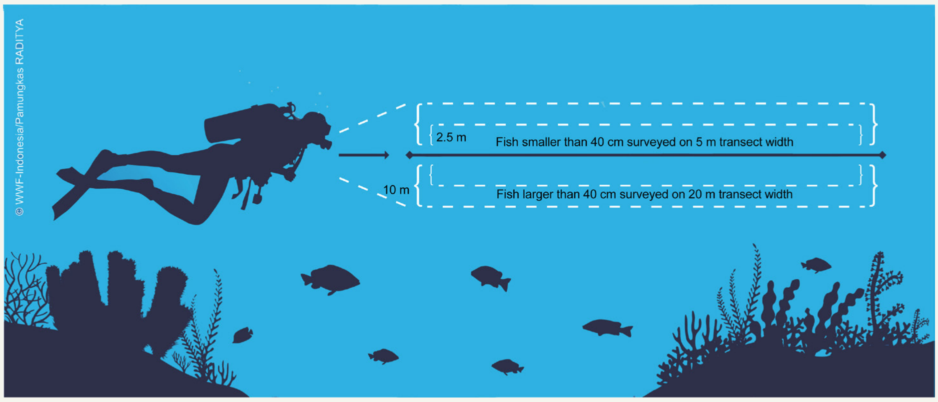

Figure 9.3.1. Fish belt transect. Fish less than 40 cm total length should be recorded on a 5 m transect width – which equates to 2.5 m either side of the observer. Fish greater than 40 cm total length should be recorded on a 20 m transect width – which equates to 10 m either side of the observer. Adapted from Amkieltiela and Wijonarno (2015).

9.3.2 Belt transect fish species list

Fish families/species to monitor are included below (Table 9.3.1), which includes both key fisheries species and herbivores that play a critical role in coral reef resilience (Green and Bellwood 2009). Species include:

- coral reef and coastal pelagic species that are likely to benefit from MPAs, i.e. not pelagic species such as tuna that move over 100s to 1,000s of km,
- species targeted by local subsistence/artisanal/commercial fishers
- indicator species of reef health
- species that observers can identify accurately
- species that are suitable to counting by underwater visual census i.e. not cryptic or nocturnal species
- coral reef species common to the site and the reef type being surveyed
- Fish should be identified to species level, or the most accurate taxonomic level possible.

Table 9.3.1. Target fish families and species for recording on the belt transects.

Family	Species to record	Common name
Acanthuridae	All	Surgeonfish
Carangidae	All	Jacks and Trevally
Carcharhinidae	All	Sharks
Chaetodontidae	All	Butterflyfish
Dasyatidae	All	Rays
Haemulidae	All	Sweetlips
Labridae	*Cheilinus undulatus*	Humphead wrasse
Lethrinidae	All	Emperors
Lutjanidae	All	Snapper
Mobulidae	All	Mobula/Manta rays
Mullidae	All	Goatfish
Muraenidae	All	Moray eels
Myliobatidae	All	Eagle rays
Scaridae	All	Parrotfish
Scombridae	All	Mackerel
Serranidae	All	Groupers
Siganidae	All	Rabbitfish
Sphyraenidae	All	Barracuda

9.3.3 Minimizing disturbance to fish communities while counting

It is important to minimize disturbance to the fish populations one is counting at each site by not driving the boat over the census area, by the fish observers being the first people to swim through the survey area, by swimming very quietly while surveying, and by waiting for at least five minutes after getting in the water before starting the survey (Green and Bellwood 2009). Transect tapes should be laid by the roll master following the fish observers or by the small fish observer as they are recording fish. Transects should never be run out ahead of the observers, since many fish species are disturbed by the passage of a diver.

9.4 Benthic communities: Point Intercept Transects

A Point-Intercept Transect (PIT) method is used to measure the cover of corals and other sessile benthic invertebrates, algae and substrate type. The PIT method is fast, efficient, and provides good estimates of cover of benthic communities provided sufficient survey points are used (Hill and Wilkinson 2004). The results can be compared to Line Intercept Transect (LIT) data if this has been used at sites on previous surveys. This method has been used extensively in the Pacific Islands, including Samoa and the Solomon Islands (Green 1996; Green 2002; Hughes 2006; Hamilton et al. 2007).

9.4.1 Method

The benthic observer swims along the transects deployed by the reef fish team (see above) and records the life form category immediately below the tape at 0.5 m intervals along the transect starting at 0.5 m and finishing at 50 m (Figure 9.4.1). With 100 points per transect, and three transects per site, this gives a total of 300 benthic points recorded per site. If the tape is not lying on or directly over the reef, points should be selected on the reef slope at the same depth and immediately adjacent to the tape on the reef slope.

The observer should identify broad benthic categories (Table 9.4.1), and for hard corals the life form should be identified. If the observer can identify hard coral genera accurately then genera should be recorded as well in addition to life form. It is important to record both genera and life form as some genera (e.g. Acropora, Porites, can take more than one life form). Life forms are included in Table 9.4.1 and are sourced from English et al. (1997). Data should be recorded on slates or pre-prepared datasheets printed on underwater paper. The benthic observer should follow the roll master along the transect tapes as these are being laid, keeping with the survey group.

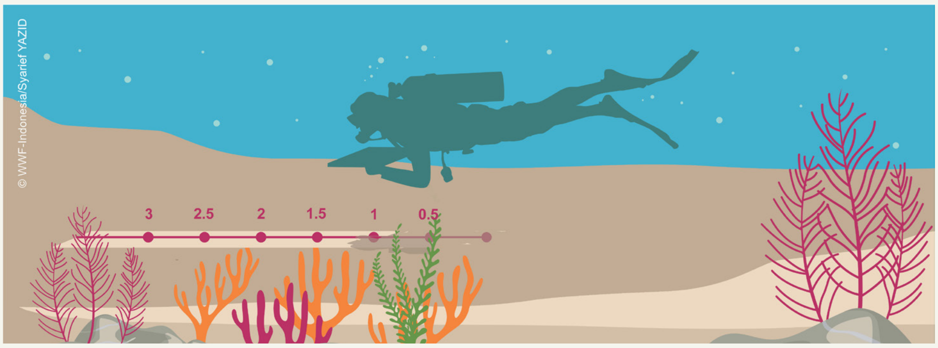

Figure 9.4.1. Point intercept transect – recording benthic cover at 0.5 m intervals. Adapted from Amkieltiela and Wijonarno (2015), based on Wilson and Green (2009).

Table 9.4.1. Benthic categories to record.

<table>
<tr><th>Category</th><th colspan="2">Name</th><th>Symbol</th></tr>
<tr><td rowspan="14">Hard corals</td><td rowspan="4">Acropora Coral</td><td>Acropora branching</td><td>ACB</td></tr>
<tr><td>Acropora encrusting</td><td>ACE</td></tr>
<tr><td>Acropora submassive</td><td>ACS</td></tr>
<tr><td>Acropora table</td><td>ACT</td></tr>
<tr><td rowspan="6">Non-Acropora Coral (record genus if known)</td><td>Coral branching</td><td>CB</td></tr>
<tr><td>Coral encrusting</td><td>CE</td></tr>
<tr><td>Coral foliose</td><td>CF</td></tr>
<tr><td>Coral massive</td><td>CM</td></tr>
<tr><td>Coral submassive</td><td>CS</td></tr>
<tr><td>Coral mushroom</td><td>CMR</td></tr>
<tr><td rowspan="4">Non-scleractinia Coral</td><td>Coral Millepora</td><td>CME</td></tr>
<tr><td>Coral Tubipora</td><td>CTU</td></tr>
<tr><td>Coral Heliopora</td><td>CHE</td></tr>
<tr><td>Dead coral</td><td>DC</td></tr>
<tr><td rowspan="2">Hard coral health</td><td rowspan="3">Add to the end of hard coral code</td><td>Bleached coral</td><td>B</td></tr>
<tr><td>Diseased coral</td><td>DI</td></tr>
<tr><td>Soft coral</td><td>Soft coral</td><td>SC</td></tr>
<tr><td rowspan="3">Algae</td><td rowspan="8">Other</td><td>Turf Algae</td><td>TA</td></tr>
<tr><td>Halimeda</td><td>HA</td></tr>
<tr><td>Macroalgae</td><td>MA</td></tr>
<tr><td rowspan="4">Other Biota</td><td>Sponge</td><td>SP</td></tr>
<tr><td>Hydroids</td><td>HY</td></tr>
<tr><td>Black coral</td><td>BC</td></tr>
<tr><td>Other</td><td>OT</td></tr>
<tr><td rowspan="4">Available substrate</td><td rowspan="4"></td><td>Dead coral</td><td>DC</td></tr>
<tr><td>Bleached coral</td><td>BC</td></tr>
<tr><td>Rock</td><td>RCK</td></tr>
<tr><td>Crustose coralline algae</td><td>CCA</td></tr>
<tr><td rowspan="3">Mobile substrate</td><td rowspan="3"></td><td>Sand</td><td>S</td></tr>
<tr><td>Silt</td><td>SI</td></tr>
<tr><td>Rubble</td><td>RB</td></tr>
</table>

9.5 Other Benthic invertebrates: Belt Transects

Belt transects will be used to survey other key benthic invertebrate species.

9.5.1 Method

If team sizes allow, a dedicated diver can swim with the benthic observer to record invertebrates. This diver should slowly swim in an "S" shape along the transect searching for invertebrates on the target list (Table 9.5.1). If teams do not allow a dedicated invertebrate surveyor, following completion of the fish belt transects, the fish observers will become invertebrate observers and record invertebrates on the return along the three transects. The small fish takes the left of the transect tape, while the big fish observer takes the right side of the transect tape. Both observers slowly swim back along the transects recording invertebrates within 2.5 m of their assigned side of the transect tape. When combined between the two observers this is equivalent to a 5 m transect width. Invertebrate observers should slowly swim in an "S" shape pattern on their assigned side of the transect tallying the abundance of the target invertebrate species. Size estimates are required for sea cucumber species, there should be recorded using 10 cm size categories for individuals <40 cm (i.e. 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm). For individuals >40 cm the actual size should be recorded. Data should be recorded on slates or pre-prepared datasheets printed on underwater paper.

Table 9.5.1. Invertebrate species to record.

Invertebrate Group	Species	Common name
Starfish		
	Acanthaster planci	Crown-of-thorns
Sea cucumbers		
	Actinopyga mauritiania	Surf redfish
	Bohadschia marmorata	Brown sandfish
	Holothuria edulis	Pinkfish
	Holothuria fuscogliva	White teatfish
	Holothuria nobilis	Black teatfish
	Holothuria scabra	Sandfish
	Stichopus chloronotus	Greenfish
	Thelenota ananas	Prickly redfish
Giant Clams (Tridacna spp.)		
	Tridacna spp.	Giant clams
Triton shell	*Charonia tritonis*	
Trochus shells	*Trochus* spp.	

10 DATA COLLECTION SHEET

The following data collection sheets were printed on underwater paper and used during the 2019 GSR survey. Sheets were printed double sided and set up to allow space for four transects to be recorded, though in the survey we only conducted three transects per site.

Contents begin from the next page.

Site Information and Boat Checklist

Dive number: Date: Team: Boat lead:

Target survey location (GPS):

Before departure:

Item	Present	Item	Present
Radio (check function)		GPS	
Bailer		Paddles	
Flares		Anchor and rope	
First aid kit		Fuel	
Hot water flask		Sun protection	
Oxygen kit including tank		Drinking water	

Remind divers to check they have all dive equipment, transect tapes, and slates with pencil.

Upon arrival at survey site:

Item	Complete	Item	Complete
Radio check with boat		Current & weather check	
Oxygen kit including tank		Drinking water	

Brief dive & discuss local dive site conditions and contingency planning for current/weather.

Required info	Site info
Transect start location (GPS coordinates)	
Exposure	Very sheltered / Sheltered / Semi-exposed / Exposed
Reef type	Atoll / Barrier / Fringing / Lagoon / Patch
Reef zone	Back reef / Crest / Fore reef / Pinnacle / Channel

Name	Buddy group #	Pre dive - planned			Time in	Time out	Post dive - actual		
		Dive Time	Depth	Air in			Dive Time	Depth	Air out

Following the dive:

Complete above dive log, and radio boat to confirm diving complete.

Required info	Site info
Surveyed reef slope	Flat / Slope / Wall
Visibility	Bad (<1 m) / Poor (1-5 m) / Fair (5-10 m) / Excellent (10+ m)
Current	High / Moderate / Low
Tide	Falling / High / Low / Rising / Slack
Any other observations:	

Small Fish Observer Sheet (2 pages)

Site: Depth: Date: Observer:

Fish Species	Transect 1				Transect 2			
	0-10 cm	10-20 cm	20-30 cm	30-40 cm	0-10 cm	10-20 cm	20-30 cm	30-40 cm
Chaetodontidae								
Acanthuridae								
Scaridae								
Siganidae								
Mullidae								
Haemulidae								
Lethrinidae								
Lutjanidae								
Serranidae								
Carangidae								
Muraenidae								
Others								

Fish Species	Transect 3				Transect 4			
	0-10 cm	10-20 cm	20-30 cm	30-40 cm	0-10 cm	10-20 cm	20-30 cm	30-40 cm
Chaetodontidae								
Acanthuridae								
Scaridae								
Siganidae								
Mullidae								
Haemulidae								
Lethrinidae								
Lutjanidae								
Serranidae								
Carangidae								
Muraenidae								
Others								

Record all fish species less than 40 cm total length (tip of the snout to end of tail) of the following families: Acanthuridae, Carangidae, Carcharinidae, Chaetodontidae, Dasyatidae, Mobulidae, Myliobatidae, Haemulidae, Lethrinidae, Lutjanidae, Mobulide, Mullidae, Muraenidae, Myliobatidae, Scaridae, Scrombidae, Serranidae, Siganidae, Sphyraenidae. Also record any Cheilinus undulates <40 cm.

Big Fish Observer Sheet (2 pages)

Site: Depth: Date: Observer:

Species	Transect 1							Transect 2						
	40-50 cm	50-60 cm	Record abundance & size of larger fish					40-50 cm	50-60 cm	Record abundance & size of larger fish				
Acanthuridae														
Scaridae														
Siganidae														
Mullidae														
Haemulidae														
Lethrinidae														
Lutjanidae														
Serranidae														
Carangidae														
Muraenidae														
Scrombidae														
Sphyraenidae														
Cheilinus undulatus														
Sharks, Rays, others														

Species	Transect 1							Transect 2						
	40-50 cm	50-60 cm	Record abundance & size of larger fish					40-50 cm	50-60 cm	Record abundance & size of larger fish				
Acanthuridae														
Scaridae														
Siganidae														
Mullidae														
Haemulidae														
Lethrinidae														
Lutjanidae														
Serranidae														
Carangidae														
Muraenidae														
Scrombidae														
Sphyraenidae														
Cheilinus undulatus														
Sharks, Rays, others														

Record all fish species greater than 40 cm total length (tip of the snout to end of tail) of the following families: Acanthuridae, Carangidae, Carcharinidae, Chaetodontidae, Dasyatidae, Mobulidae, Myliobatidae, Haemulidae, Lethrinidae, Lutjanidae, Mobulide, Mullidae, Muraenidae, Myliobatidae, Scaridae, Scrombidae, Serranidae, Siganidae, Sphyraenidae. Also record any Cheilinus undulates >40 cm.

Other Invertebrate Observer Sheet (2 pages)

Site: Depth: Date: Observer:

Sea cucumber	Transect 1				Record size for >40 cm
	0-10 cm	10-20 cm	20-30 cm	30-40 cm	
Surf redfish *Actinopyga mauritiania*					
Brown sandfish *Bohadschia marmorata*					
Pinkfish *Holothuria edulis*					
White teatfish *Holothuria fuscogliva*					
Black teatfish *Holothuria nobilis*					
Sandfish *Holothuria scabra*					
Greenfish *Stichopus chloronotus*					
Prickly redfish *Thelenota ananas*					

Record abundance of key invertebrates:

Invertebrate group	Transect 1	Transect 2
Acanthaster planci		
Giant Clams (*Tridacna* spp.)		
Triton shell		
Trochus		
Other notable invertebrates:		

Sea cucumber	Transect 2				Record size for >40 cm
	0-10 cm	10-20 cm	20-30 cm	30-40 cm	
Surf redfish *Actinopyga mauritiania*					
Brown sandfish *Bohadschia marmorata*					
Pinkfish *Holothuria edulis*					
White teatfish *Holothuria fuscogliva*					
Black teatfish *Holothuria nobilis*					
Sandfish *Holothuria scabra*					
Greenfish *Stichopus chloronotus*					
Prickly redfish *Thelenota ananas*					

Sea cucumber	**Transect 3**				**Record size for >40 cm**
	0-10 cm	**10-20 cm**	**20-30 cm**	**30-40 cm**	
Surf redfish *Actinopyga mauritiania*					
Brown sandfish *Bohadschia marmorata*					
Pinkfish *Holothuria edulis*					
White teatfish *Holothuria fuscogliva*					
Black teatfish *Holothuria nobilis*					
Sandfish *Holothuria scabra*					
Greenfish *Stichopus chloronotus*					
Prickly redfish *Thelenota ananas*					

Record abundance of key invertebrates:

Invertebrate group	**Transect 1**	**Transect 2**
Acanthaster planci		
Giant Clams (*Tridacna* spp.)		
Triton shell		
Trochus		
Other notable invertebrates:		

Sea cucumber	**Transect 4**				**Record size for >40 cm**
	0-10 cm	**10-20 cm**	**20-30 cm**	**30-40 cm**	
Surf redfish *Actinopyga mauritiania*					
Brown sandfish *Bohadschia marmorata*					
Pinkfish *Holothuria edulis*					
White teatfish *Holothuria fuscogliva*					
Black teatfish *Holothuria nobilis*					
Sandfish *Holothuria scabra*					
Greenfish *Stichopus chloronotus*					
Prickly redfish *Thelenota ananas*					

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