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Rapid Coastal Assessment (RapCA) in the Hihifo District, Tongatapu

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Rapid Coastal Assessment (RapCA) in the Hihifo District, Tongatapu

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ABBREVIATIONS

DoE	Department of Environment
FHR	Fish Habitat Reserve
GEF	Global Environment Facility
MEIDECC	Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communication
MLNR	Ministry of Lands and Natural Resources
MoF	Ministry of Fisheries
MPAs	Marine Protected Areas
NBSAP	National Biodiversity Strategic Action Plan
PMU	Project Management Unit
RPCU	Regional Programme Coordinating Unit
RapCA	Rapid Coastal Assessment
SMAs	Special Management Areas
SPC	Pacific Community
VEPA	Vava'u Environmental Protection Association

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ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

The Rapid Assessment of Priority Coastal Areas (RapCA) is an activity of the Global Environment Facility (GEF) funded multi-year International Waters Ridge to Reef (IW R2R) project. The IW R2R project is implemented regionally through the Pacific Community (SPC) and managed in Tonga through the project management unit within the Ministry of Lands and Natural Resources (MLNR).

The IW R2R project was launched in 2016 and encompasses a "whole of Island" approach to integrating policies, developing multi-sectoral partnerships, and working with agencies and communities to further sustainable development through participatory processes and management of natural resources.

The R2R activities identify and provide critical links and datasets from elevated land areas with flow down effects from the watershed to coastal habitats. The RapCA survey assessed the environmental condition and biodiversity of coastal habitats in terms of their location and proximity to communities and infrastructure development. Concurrent surveys were conducted with communities on livelihoods and their perceptions of changes over given periods of time. The information collected is used to support and develop integrated approaches to environmental and biodiversity management and strengthen policies and multi partnership approaches that consider social and economic perceptions. The RapCA report includes gender sensitive approaches that will ensure that use of resources and impacts of resource use by men, women and other sectors of society are considered.

These outputs will be captured under the science to policy processes of the R2R programme through Island Diagnostic Analysis (IDA) and State of Coast (SoC) reports towards formulating and supporting Coastal Management Plans.

The RapCA includes rapid assessment surveys of terrestrial and coastal habitats through data collection and identification of unique and threatened biodiversity as well as invasive species and provides analysis of data and recommendations that support an integrated approach to the protection and management of ecosystems and the communities around them. Socio-economic household surveys and water quality analysis are also conducted under a consultancy agreement with the Ministry of Lands and Natural Resources. The socio-economic survey will include sex-disaggregated data on household surveys to help assess gender participation in social and economic activities at household level.

Healthy coastal habitats and their biodiversity are critical in maintaining ecosystem services that provide for livelihood activities, economic benefits, and resilience; however, they face a myriad of threats including land degradation, pollution, unsustainable practices, overfishing, and natural disasters that are increasing in threat and impact due to anthropogenic caused climate change.

The following outlines the highlights of the biological and ecological assessment, which inform policy decisions and recommendations for future monitoring of the biodiversity and habitats as well as to livelihoods and sustainable development for the Hihifo district.

- Watershed activities from the wells and bores are mapped and provided by the GIS department of the Ministry of Lands and Natural Resources for analysis and discussion on freshwater movements from the ridge within the community and to reef coastal areas.
- Natural forest and coastal flora habitats are fragmented and dispersed between agricultural uses and community and infrastructure development, reducing some of the critical biological and environmental processes that allow for coastal land

stabilisation and are important in minimising land-based impacts such as pollution from watershed activities.

- Terrestrial biodiversity such as land birds were in low species diversity and low abundance across all the RapCa biological survey sites.
- Mangrove habitats and associate mangrove species were studied at three locations: Fo'ui, Kolovai and 'Ahau, with all three locations showing low natural regeneration (observed number of seedlings). Historical analysis from Google Earth showed limited natural growth patterns between 2005 and 2019. Mangrove species diversity was primarily *Rhizophora stylosa* and *Rhizophora samoensis* with no records of mangrove species such as *Bruguiera gymorhiza* (Tongo ta'ane) and *Xylocarpus* sp. (lekileki) within the survey locations.
- The sedimentation and mud within the mangrove habitats were very high, showing land-based activity impacts from the watershed, including wastewater and other pollution sources (discarded metal rubbish and electronics). The low elevation of coastal land also allows for sediment deposits from other coastal areas through wave and tidal movements.
- Fauna biodiversity, including crabs, birds, and insects, within the mangrove habitats was in low abundance, and observations throughout all the sites surveyed further indicate that displacement of habitats within the coastal areas is occurring.
- Intertidal mud flat sites at Fo'ui, 'Ahau and Kolovai had silt as the primary benthic cover, with Kanokupolu and Ha'atafu having primary cover of seagrass and benthic macroalgae such as Halophilia and Halimeda, which can be beneficial in reducing sedimentation on the coral reef habitats. The intertidal site of 'Ahau showed extremely high turbidity with a north-westerly wind that pushes sediments into the coastal area.
- All survey site locations had low abundance and diversity of invertebrate species. Observations in intertidal mudflats showed slightly higher abundance in habitats with primary cover of seagrass and macroalgae, indicating potential fishing pressure. The targeted consumption species, locally known as muli'one (*Dolabella auricualria*) was observed with 20 individuals on transects at Ha'atafu within the site located within the current fish habitat reserve (FHR).
- A total of 24 juvenile Muraenidae (moray eels) were observed within the seagrass habitats at Kanokupolu and Ha'atafu.
- Six fringing coral reef habitats were surveyed for analysis on the current health and status of the ecosystems with hard coral cover ranging between 45% to less than 5% cover on the sites exposed to wave action at Ha'atafu and the south-western coast of the Hihifo district. Reef fish diversity was comprised of 141 species including 85 species of non-target fish (species not valued for consumption such as damselfish, wrasses, and other families). With lower diversity were 56 species of targeted species that are important for consumption by communities and for coral reef health and resilience. Targeted fish families include grouper, emperor fish, parrotfish, surgeon fish and snappers.
- Marine invertebrates from the families Holothuridae (sea cucumbers), Cardiidae (giant clams) Trochidae (Trochus) and other subsistence or domestic economic invertebrate resources were in low abundance and diversity across all coral reef habitats.

- The survey results indicate that the intertidal and coral reef habitats are being impacted by pollution and other human activity from the watershed and in the areas where communities are located close to the waterways. These ridge to reef impacts are affecting the ecosystem services provided by these habitats.

The following are recommendations based solely on the results of the biological and ecological surveys conducted under the RapCA. Further recommendations will be made with the joint findings from the socio-economic and water quality reports.

- Emphasis on future development and environmental activities needs to be centred on dealing with land-based impacts on the coastal ecosystems due to the fragile relationship between coastal communities and ecosystems.
- Access by coastal communities to livelihood benefits from coastal habitats in Fo'ui and 'Ahau is difficult due to the excessive mud around the mangrove areas. Facilitating community access through boardwalks could be beneficial in supporting community activities such as gleaning and location of community fishing vessels, developing livelihood activities such as the promotion of eco-tourism through mangrove tours and reducing impacts to sensitive habitats and strengthening conservation management efforts. Women will benefit from better access to the fishing/gleaning areas. All planned activities should enhance inclusive gender participation.
- Mangrove habitats and shoreline flora would benefit from nature-based solutions rather than more infrastructure. A 10 m buffer is recommended from the high-water tide mark to where coastal development and/or agriculture lands should be placed. This would allow for the replanting of native coastal plants that bring beneficial nutrients to mangroves within the buffer area.
- Freshwater springs are a necessary component in healthy mangrove systems, however, currently the freshwater springs are either higher in pollutants and/or restricted due to coastal development such as the placement of roads. Improving the design of infrastructure through inclusion of culverts and/or drainage routes during development can be used to minimise restrictions to the freshwater springs.
- Reducing land-based run off from watershed activities is necessary to ensure that freshwater supplies are free of contaminants, including fertiliser and sewage.
- The mangrove habitats in Fo'ui and 'Ahau need to be monitored for sedimentation increases and changes over a 3-year period to identify the main sources of sediment increase and settling.
- More suitable habitats for the sea cucumber aquaculture under the Ministry of Fisheries would be intertidal habitats that have higher primary cover of seagrass and macroalgae and which are placed in FHRs within the special management areas (SMA) programme. This would be a more suitable habitat than intertidal areas with dominant sand/or silt areas.
- The shallow fringing coral reef adjacent to the intertidal area would benefit from being included within community SMAs. Protection of coral and reef fish populations there would promote increased resources for adjacent coral reef habitats through larval export and spill over.
- Complementary livelihood programmes that are gender inclusive would be beneficial for communities to offset the loss of ecosystem services especially in Fo'ui, Kanokopolu and 'Ahau. These activities could include developing aquaculture programmes that support environmental repair and subsistence food sources.

1 BACKGROUND

The Global Environment Facility (GEF) Pacific International Waters Ridge to Reef (IW R2R) project was launched in 2016 with 14 Pacific island countries. The project aims to provide climate resilient and integrated approaches to land, water, forests, and coastal management prioritising strategic planning, capacity building and pilot programmes that sustain livelihoods and preserve ecosystem services.

Through the Regional Programme Coordinating Unit (RPCU), 22 indicators were identified as a standard assessment of the ecological state and health of an area to be applied uniformly across participating Pacific island countries and build on national and sub-regional data and research conducted including State of Environment reporting. These indicators provide the link for Rapid Coastal Assessments (RapCA) to be undertaken within the country programme that build and strengthen regional capacity for R2R activities.

RapCA surveys are an important activity that collects and analyses snapshot information on the terrestrial and coastal ecosystems, water quality assessments and community perceptions and activities in relation to economic, social, governance and environmental indicators, using gender inclusive approaches.

The outputs of the RapCA will provide a basis for the development of Coastal Management Plans by providing a critical analysis on the biodiversity, status of habitats, governance, and socio-economic responses, including gender considerations. The RapCA will also inform ongoing monitoring and community programmes for the IW R2R Tonga project activities to achieve the target of conserving and protecting 90 hectares of wetlands and reducing waste pollution by 104 TN kg/year.

Coastal habitats and their biodiversity are critical components of the environment and natural resources on which people depend. The land, water and coastal resources provide ecosystem services that are beneficial to people's livelihoods and economies. These services include provisioning (food, materials, and energy), supporting (nutrient cycling, soil formation, primary production, and habitats), regulating (carbon sequestering, predation to regulate natural populations, purification of water and air) and cultural services (natural heritage, spiritual values, recreational experiences such as tourism)[1.]

When biodiversity and habitats are under pressure and impacted, the wide-ranging benefits decrease causing further stress to ecosystems.

Pollution from rising populations and coastal development located close to the watershed lead to increased nutrient enrichment, sediments and other contaminants being carried to the coastal habitats of mangroves, seagrass, and coral reefs, leading to compounding impacts on the biodiversity and ecosystem services (Comeros-Raynal et al. 2019).

Fishing pressure occurs from the higher trophic species such as piscivores, carnivores and herbivores implying that top-down fishing pressure affects the balance of the coral reef ecosystem and weakens the ecosystem services that coral reef habitats provide to livelihood and economic activities. Marine invertebrate species, including sea cucumbers, molluscs and bivalves are collected through both reef fishing and gleaning activities within the intertidal mudflats.

The Hihifo (western) or Kolovai district on the main island of Tongatapu lies approximately 10 kilometres from the main town of Nuku'alofa or the Central Business District (CBD). Within Hihifo, there are 12 communities including the outer island of 'Atata (Tonga Statistics Department 2016), however, under this programme, 6 communities were selected for the project activities. These are Fo'ui, Ha'avakatolo, Kolovai, Kanokupolu, 'Ahau and Ha'atafu.

1 Ecosystem Services Overview http://www.teebweb.org/resources/ecosystem-services/

The topographic elevation of the coastal area within Hihifo district is very low (<2 m above sea level) (Kitekei'aho 2014) with the highest elevation of 15 m above sea level situated within the middle of the island behind the community. Land subsidence has been recorded as occurring in the Hihifo district due to geological tilting from the subduction of the Pacific Plate under the Indo-Australian Plate (Tu'i'afitu Malolo et al. 2019).

Situated throughout the island and coastal area are natural streams from water lenses that collect fresh water from precipitation. These lenses also create the watershed through the island that provide households with water through the Tonga Water Board but also create streams to the coastal habitats.

The natural coastal marine habitats located near these communities combine an area of approximately 74 km^2 that include sporadic and segregated mangrove stands, a vast intertidal mud flat and a shallow fringing reef along the coastal area separated by a sand basin before the outer fringing reef.

Tidal flow and longshore currents can also deposit and move sediments around the coastal areas, there is very little available information for coastal water movements, however, one paper from 2000 shows that the area of Hihifo district has very little current flow, with some increased water flow towards the northern tip of Ha'atafu (Luick and Henry 2000).

Increasing impacts to low lying coastal communities have been recorded through sea level rise and the frequency and intensity of tropical cyclones, with TC Gita (Category 5) in February 2018 and TC Harold (Category 4) in April 2020 causing damage through intense windspeeds (Gita) and storm surge at King tide (Harold). TC Harold destroyed tourism businesses and community buildings on the south west side of the Hihifo district with an estimated TOP260 million (Pa'anga) of damages[2].

Coastal land reclamation, dredging and climate resilient infrastructure development has occurred within the Hihifo district, such as the seawall at Kanokupolu. Seawalls, through the reflection of wave energy, can increase the impacts of coastal erosion and depositing of sediment on adjacent coastal areas, thereby decreasing natural habitat function (McCue 2014). The recent State of Environment report released by the Government of Tonga, gives the most up to date and comprehensive overview of impacts (Government of Tonga 2018).

In 2002, the Ministry of Fisheries developed Special Management Areas, a community-based near-shore resource management programme. Within the SMA areas, the community develops a management plan with the objectives to "restore and replenish marine resources to previous levels and to increase resilience and livelihood benefits". Each SMA has at least one fish habitat reserve (FHR) or no-take area that are of varying sizes.

Ha'atafu and Kanokupolu have established SMAs within the Kolovai district in 2017 and 2020 respectively. A recent report on the status of SMAs shows that near-shore fish populations are increasing in some SMAs through protections provided by the FHR (Smallhorn-West et al. 2020).

This RapCA aims to strengthen biodiversity data including for terrestrial forest areas, mangroves, intertidal mudflats, and coral reefs towards providing analysis and information on critical biodiversity areas and management programmes that would enhance and secure healthier environments and livelihood benefits. Further analysis was conducted through previous survey results, reports and data collected through the socio-economic and water quality assessments.

2 http://www.tonga-broadcasting.net/?p=18331

2 METHODOLOGIES

Under the IW R2R programme, monitoring indicators were developed by the RPCU to provide established science-based indicators for the collection of data during the RapCA surveys. The indicators cover six focus areas on ecological and biological functions including habitat health, species diversity and abundance, and identification of stressors through the ridge to reef.

The field survey methodologies listed below are internationally recognised and nationally used for resource monitoring programmes within Tonga and revised to meet the indicators established by the RPCU.

2.1 Spatial Mapping

Utilising accessible platforms such as Google Earth and GIS data that is available both as open source on the internet and with permissions under the programme from the GIS department of the Ministry of Lands and Natural Resources, spatial mapping consisted of mapping of mangrove areas, identifying coastal habitats, watershed areas and areas of impact. Approximate locations for the survey sites were also determined using Google Earth, inputted to GPS units for the survey teams and adjusted as required in the field.

At each site location, general parameters were recorded before each survey. These parameters included site location, GPS coordinates, tide, observer name and general observations such as wildlife, evidence of human activities (waste, tree cutting, etc.) and observations of roaming animals (livestock and dogs) before transects were laid.

2.2 Mangroves and Forests

For the monitoring of mangroves and shoreline habitats, transects were laid perpendicular to the shore, and the observer noted the primary species of the shoreline zones (landward, mid, and seaward) (Ellison et al. 2012).

Species distribution was mapped from the landward to the seaward sides using zones along the transect tape with a radius of 15 m from the tape. Trees towards the landward side were primarily mangrove associates, whereas the seaward trees usually consisted of *Rhizophora sp.*

Canopy cover was recorded along the transect with estimations of canopy cover recorded as a scale of percentage (Table 1):

Table 1: Information on assessing canopy cover and habitat impacts for mangroves (Ellison et al. 2012)

Code	Canopy Cover (per cent)	Example
0 (No Impact)	96–100	Even canopy, no gaps, no evidence of human interference
1 (Slight Impact)	76–95	Canopy is continuous but some gaps, some regrowth, isolated bark cutting or low evidence of pigs
2 (Moderate Impact)	51–75	Broken canopy, lower regrowth and recruitment, some trees cut and stripped
3 (Rather High Impact)	31–50	Canopy is uneven, majority of area not showing regrowth, bare mud
4 (High Impact)	11–30	Few trees at canopy height, extensive clearance, some recruitment, large areas of bare mud
5 (Severe Impact)	0–10	Extensive clearance to bare mud, little recruitment, few trees remain alive

The impact type was further recorded to identify unique and varying occurrences, assigned to codes that measured whether the impact was through coastal development and infrastructure (CO), erosion (ER), extensive bark stripping or cutting of mangroves (EC/BS), sand mining activities (MI), multiple impacts which can be a combination of all the above (MU) and any other observations (OT). The analysis was based on both potential cause and level of impact on the mangroves.

During the mangrove and coastal land-side observations, visual observations over a timed period of five minutes were used to record species diversity and abundance of terrestrial fauna. Observed species included birds, invertebrates, and invasive species.

2.3 Intertidal mudflats

Transect tapes of 100 m in length were laid perpendicular to the shoreline and surveys were conducted at low tide periods. A 1 m x1 m quadrat divided into 25 cm squares, was placed at 10 m intervals along opposite sides of the transect tape. Under each square within the quadrat, the benthos cover percentage was estimated for each 25 cm square, and the results totalled for each 1 m^2 quadrat. Data was also collected on marine invertebrates along the 100 m transect tapes across a 4 m wide belt (2 m each side of the tape). Visual observations of organisms were recorded to the highest level of taxonomy known (either genus or species) and size in centimetres, measured using a ruler and recorded onto waterproof paper to be later entered into an Excel spreadsheet. Transects were repeated 3 times per site if tidal cycles allowed.

2.4 Underwater Visual Survey Methodology

The status of fish species by trophic group can indicate the overall health of reef areas. Most fishing consists of fishing down the "food web" where predators are targeted first, followed by lower-level prey species (Boaden and Kingsford 2015). When overfishing occurs, it causes an imbalance in food web dynamics and allows for smaller, non-essential species for reefs and non-targeted species for consumption to take over. Environmental impacts such as overfishing, sedimentation from waterways and pollution, stress events such as rising ocean temperatures, storm surge and infrastructure development can also be used to assess threats to coastal ecosystems. These threats endanger the health and function of coral reefs and coastal fisheries and programmes such as Special Management Areas (SMAs) can minimise these coastal impacts and strengthen the recovery and resilience of marine ecosystems.

The marine resource methodology for collecting the baseline data involved using SCUBA equipment. Site locations were identified according to the location and placement of coral reef habitats in proximity to the coastal community, mangrove, and intertidal mudflat locations. At each site, transects tapes were laid along the sea floor at depths of 10 m − 12 m and 4 m −6 m where possible. At each depth 3 m x 50 m long transects were placed along the benthos with a spacing of 5 m between each replicate.

The transect tapes were laid out by the near-shore fish observer, who began the SCUBA dive a minimum of 5 minutes before the other marine surveyors. All data was recorded onto waterproof paper and entered an Excel database at the end of each day.

2.5 Point-Intercept Transects

Point-Intercept Transects (PITs) are conducted by an observer who visually observes the morphology of the benthos on waterproof paper and clipboard directly under each 50 cm point along the transect tape. Morphological observations of the benthos were recorded, along with the health of the corals including signs of disease, scarring from predators such as crown of thorns starfish (COTs) and coral bleaching. A measure of the amount of algal growth that was present over dead or damaged coral gave an indication of the time since the damage occurred.

Coral recruitment was also recorded along the transects using a 25 cm x 25 cm quadrat made from PVC pipe, placed at 2 m intervals on opposite sides of the transect tapes. The number of coral recruits (diameter <5 cm) was recorded for each quadrat.

Photographic quadrants were also taken at each one-metre point on the transect on opposing sides of the transect tape. The photo quadrants were taken using an Olympus ITough camera and housing hand-held at a vertical distance of approximately 2 m above the transect tape.

2.6 Belt Transects

To record mobile marine invertebrates, the observer swam slowly along the transect tape recording the abundance of targeted species for consumption and indicator species of marine invertebrates over a belt transect 4 m wide (2 m on each side of the transect tape). Each transect took approximately 10 −15 minutes to perform depending on habitat variability. Targeted species included sea cucumbers (Holothuridae), giant clams (Cardiidae), trochus (Trochidae), lobster (Palinidae), octopus, crabs and other molluscs and gastropods. Observations were also recorded of coral-predating species such as crown-of-thorns starfish (*Acanthaster solaris),* and *Drupella* spp. snails.

Near-shore reef fish species were recorded along the transects over a 4 m belt (2 m on either side of the transect tape) on both the outward and return swim. The outward swim observed fish species that inhabited the water column areas above and surrounding the habitat, as these fish species are often more wary of SCUBA divers. Only fish that were in the peripheral range of the observer were recorded and fish that swam into the transect area from behind the observer were not recorded. The observer swam slowly recording the species, observing total length (cm) and abundance for each size.

Fishery component information was utilised from the Rapid Assessment of Biodiversity of the Vava'u Archipelago (Atherton et al. 2014) (Chapter 10) and information provided through the Ministry of Fisheries to define species that are targeted for consumption versus non-target species (not for consumption).

Data analysis was conducted on species diversity per site and density (n/1000 m$^{2)}$ and biomass (kg/1000 m^2) calculated at the family level. Biomass calculations were performed using the total length (TL) of the fish observed and pre-determined length-weight ratios from Fishbase[3].

The GIS department at the Ministry of Lands and Survey also provided data for watershed movements as well as condition of septic and wastewater disposal within the households at Hihifo that was used to identify ridge to reef connections within the water quality assessments and ecological and biological data.

Socio-economic data was also collected through household surveys to further identify environmental and social constraints and activities that would identify risks and support recommendations that benefit ridge to reef management and IW R2R Tonga project outcomes.

2.7 Team Members

Table 2 lists the team members for the RapCA surveys alongside their respective Ministries and roles for the data collection.

Table 2: Team members with their roles and respective Ministries that undertook the fieldwork for the RapCA surveys.

Name	Ministry/Organisation	Role
Karen Stone	Vava'u Environmental Protection Association	• Principal Investigator • Marine invertebrates (intertidal) • Coral reef fish
Viliami Fatongiatau	Ministry of Fisheries	• Benthic Habitat (Intertidal) • Marine Invertebrates (Coral reefs)
Tevita Havea		Photo Quadrats (Coral reef)
Hulita Fa'anunu		Benthic Habitat (Intertidal)
Tu'amelie Fusimalohi	Department of Environment (MEIDECC)	• Benthic Habitat (Intertidal) • Coral Habitat Cover • Coral Recruitment
'Ana Maea Tupou	Ministry of Lands and Natural Resources	• Benthic Habitat (Intertidal) • Mangroves
Nikolasi Heni		
Nimo Ngauamo		Research Support

The field team was also supported by the personnel shown in Table 3.

3 Froese, R., and D. Pauly. Editors. 2019. FishBase. World Wide Web electronic publication. www.fishbase.org, version (08/2019).

Table 3: Individuals and agencies who provided support and assistance for the RapCA surveys.

Silia Leger	MLNR/NRD/R2R
Melenaite Esera	MLNR/NRD/R2R
Kaati Hakaumotu	MLNR/NRD/R2R
Seina Kara	MLNR/NRD/R2R
Kilisitina Moala	MLNR/NRD/R2R
Ange Pale	MLNR/NRD/R2R
Tomailangi Fonua	MLNR/NRD
Fakatoulelei Kolomalu	MLNR/LGIS
Pupunu Tukuafu	MLNR/LGIS
Sioeli Lolohea	MLNR/LGIS

3 RESULTS

The following provides the analysis of the data collected during the RapCA assessment conducted between 6 and 21 May 2020. The results would be used to identify ridge to reef processes and impacts such as links between run off and pollution, human use and settlement, and environmental and biological conditions of habitats and species.

3.1 Site Locations

Site locations were identified prior to the surveys using Google Earth as an indicator of the habitat locations, and sites were also chosen in proximity to the locations of a ridge to reef aspect including watershed movements, distance from community and potential scale and level of impact to the monitoring indicators (Figure 1).

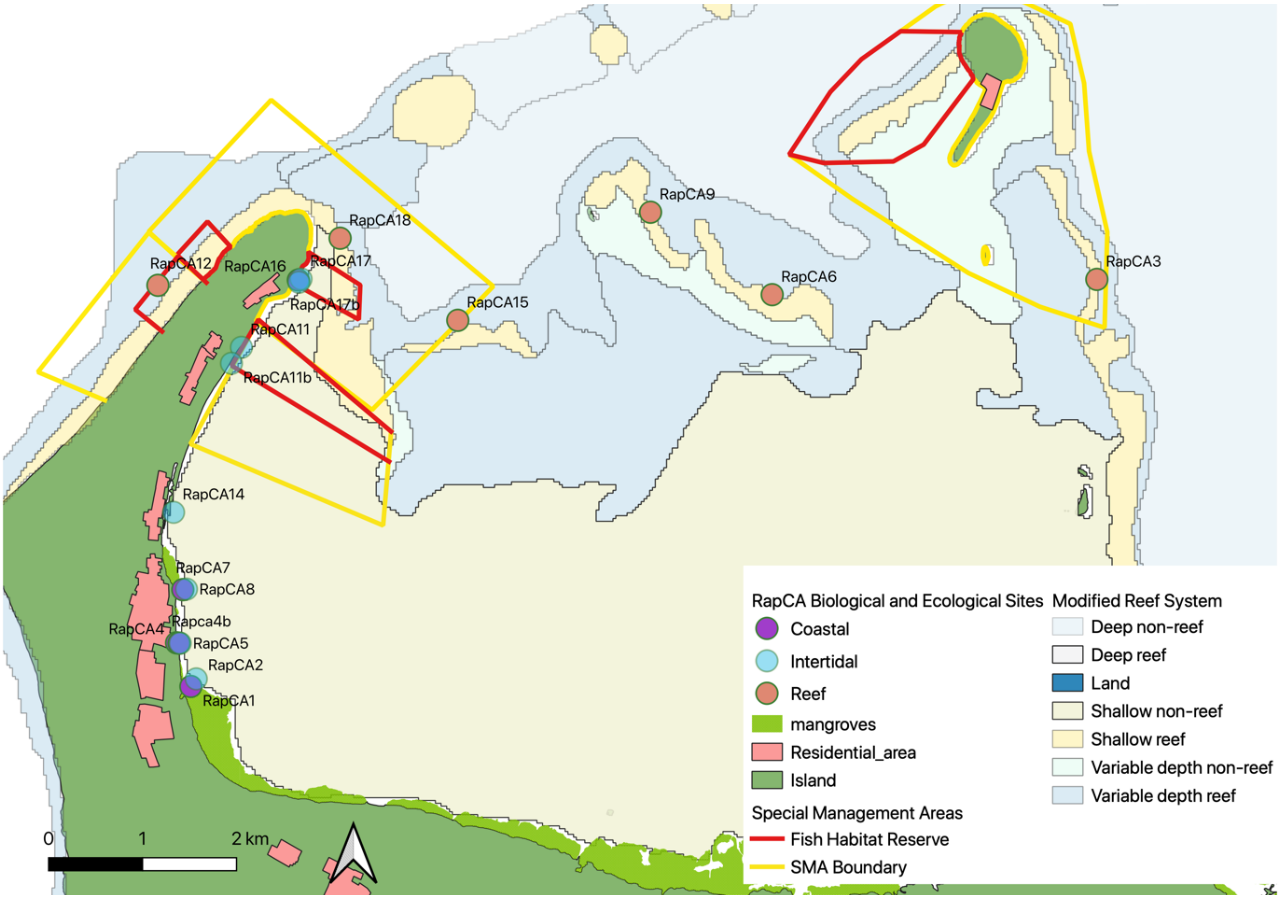

Figure 1: Map showing the locations for coastal, intertidal mudflat and coral reef habitats under the RapCA biological surveys conducted 6 to 21 May 2020.

Since communities located within proximity (<250 m) of shoreline habitats and adjacent to water streams can have varying impacts to habitats and biodiversity, RapCA12 was located to the west of the Hihifo peninsula without direct proximity to any community. However, the coastal areas have been heavily developed for tourism.

Table 4 shows demographic data for the surveyed communities (Tonga Statistics Department 2016) alongside the distance of each community from the coral reef sites. Coral reef sites at RapCA15 and RapCA18 were situated within 5 km of all the communities, which could accumulate impacts from other areas through tidal and current movements.

Table 4: Population and approximate distance in kilometres of reef locations surveyed in comparison to coastal sites within the 6 surveyed communities excluding RapCA12 on the outer western reef.

Community	Population	Male	Female	RapCA3 (km)	RapCA6 (km)	RapCA9 (km)	RapCA15 (km)	RapCA18 (km)
Fo'ui	657	344	313	10.55	7.4	7	4.8	5
Ha'avakatolo	195	91	104	10.4	7.3	6.7	4.5	4.6
Kolovai	618			10.2	6.9	6.3	4	4
'Ahau	393	183	210	10	6.75	6	3.6	3.4
Kanokupolu	332	157	175	9.2	5.7	4.7	2.4	1.7
Ha'atafu	269	140	129	8.5	5	3.8	1.8	0.7

3.2 Terrestrial Biodiversity

There were no resources or scientific surveys online on the studies conducted within the Hihifo district on terrestrial flora, with the only references to ecological surveys conducted within the survey sites being primarily focused on the mangrove habitats in 'Ahau and Kolovai under the Department of Environment. Limited data and information are available on terrestrial based biodiversity and habitats and the diagnostic survey for coastal protection ((McCue 2014).

The landward coastal terrestrial areas are split between private land, either through ownership or hereditary parcels under the Lands Act 1988, for either agriculture or housing through the Government of Tonga. Land ownership in Tonga is a highly debated issue with only men having legal rights to obtain land. Land inheritance rights are passed through male heirs; women have no independent land rights unless they acquire a lease; however, widows are permitted to continue to hold their deceased husband's land for life if they do not remarry. Land reforms were recommended by the Royal Land Commission of Enquiry, however, no changes were made on the rationale that 'it has never been the traditional role of Tongan women to do heavy and hard labour work, which was associated with farming' (Govt of Tonga 2019).

Figure 2 utilises the data provided from IUCN on approximate land cover within Tonga and shows primary land uses divided between cropland (purple) and coconut cropland (yellow). Two saline identified wetlands were located inshore at Fo'ui and Kanokupolu (blue). Natural woodland areas are indicated in dotted areas and are located on the west side of the communities and tip of Ha'atafu.

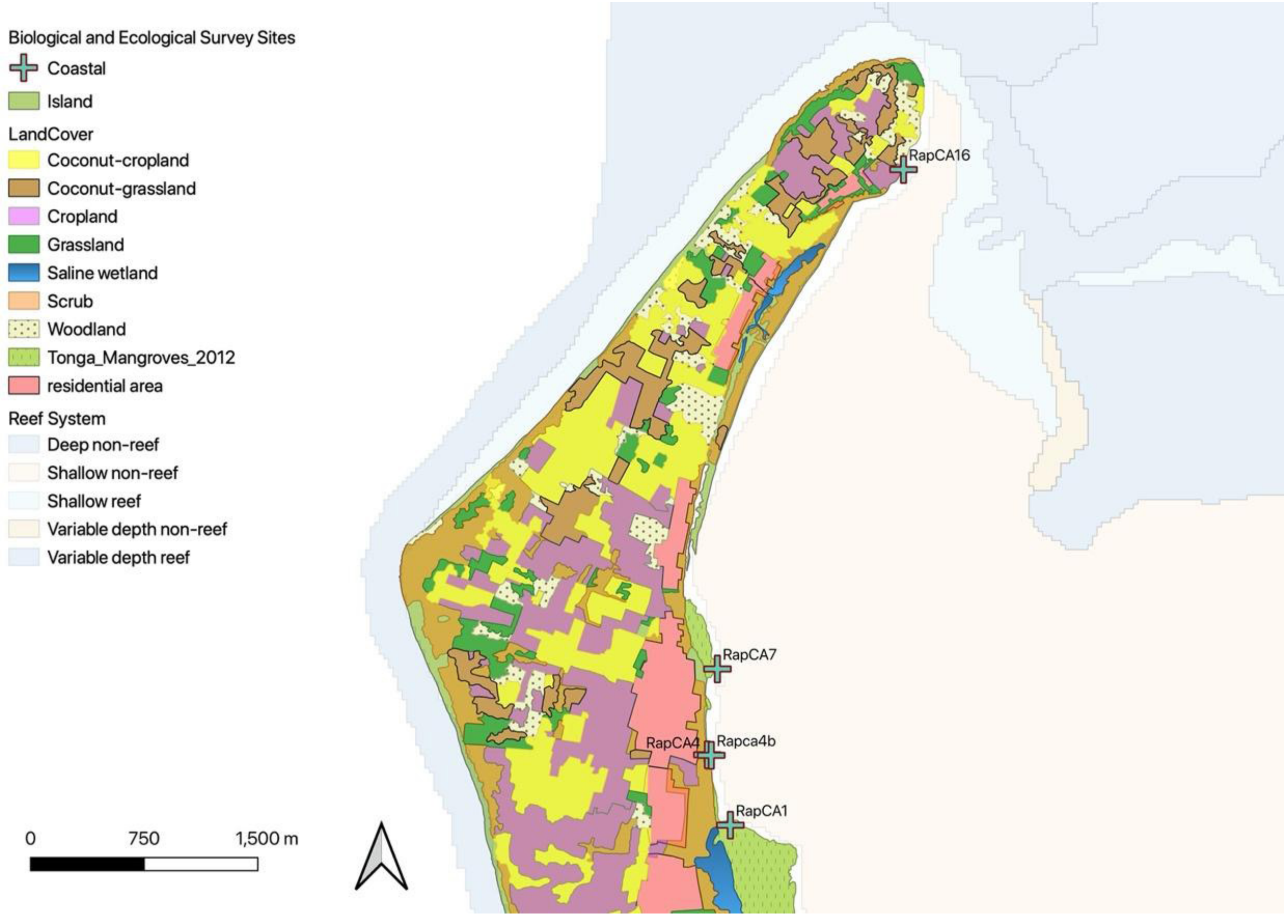

Figure 2: Map showing land uses for the Hihifo district and relative to the coastal survey sites under the RapCA. GIS data was provided by IUCN.

Agricultural land is primarily used for subsistence crops such as cassava, yam, yautia, sweet potato and taro with high percentages of pesticide use (71% of households in Tongatapu) (Ministry of Agriculture, Food, Forests and Fisheries et al. 2015).

Coastal infrastructure such as road development and climate resilient programmes have dispersed the natural coastal habitats (Figure 3) separating flora areas and decreasing natural protection and benefits from coastal vegetation. The coastal infrastructure also can impact upon natural watershed movements such as freshwater springs along the coastal area that are beneficial to the flora and mangrove habitats.

Figure 3: Road area between Kanokupolu and Ha'atafu showing the fragmentation of coastal flora areas.

3.2.1 Birds

There were very few observations of terrestrial bird species during the RapCA surveys due to the limited terrestrial habitat available. Seabirds were observed in the coastal waters areas prior to the transect based methodology. Table 5 shows the bird species visually and audibly observed and the total abundance.

Table 5: Species of land and seabirds (avifauna) observed during the RapCA surveys and the abundance of species across all sites.

Scientific Name	Common Name	Tongan Name	Abundance
Fregata ariel	Lesser Frigate bird	Lofa, Helekosi	1
Sterna sp	Tern		2
Egretta sacra	Reef Heron	Motuku	2
Aplonis tabuensis	Polynesian Starling	Misi	2 (assumed, heard)
Pycnonotus cafer	Red-vented bulbul	Manufo'ou, Fuiva	1
Todiramphus chloris	Collared Kingfisher	Sikota	2

3.3 Water

Figure 4 shows the location of natural streams (blue lines) and freshwater movements from the lenses as well as the discharge of wastewater within communities in relation to the coastal areas. This map will be used to identify risks to natural ecosystems within the coastal areas, including mangroves and intertidal areas. Waste, including sewage and wash water, will permeate through the soils to the coastal habitats increasing point source pollution.

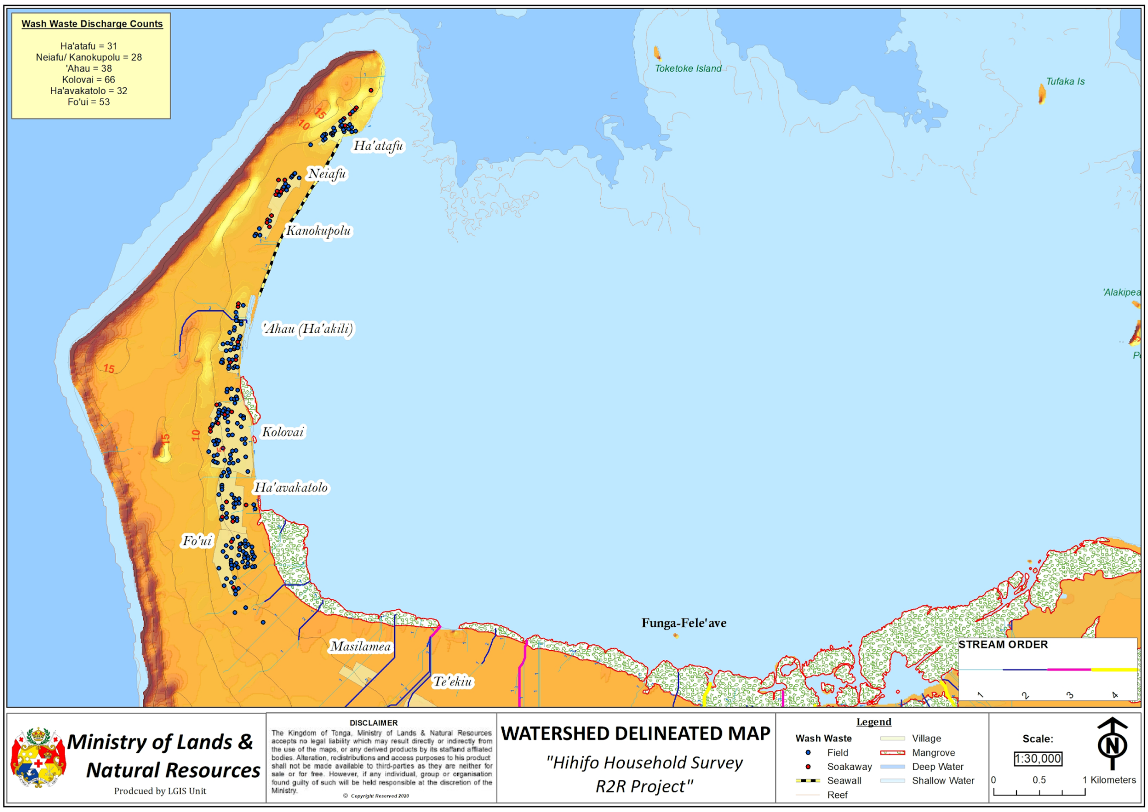

Figure 4: Watershed delineated map showing the location of wastewater discharge for the Hihifo district: analysis was conducted through the household surveys and maps created by the GIS dept, Ministry of Lands and Natural Resources.

3.4 Coastal

3.4.1 Mangroves

Three locations of mangrove areas were studied through the RapCA assessments at Fo'ui, 'Kolovai and 'Ahau (Figure 5). Locations were chosen to study areas of mid-biodiversity potential and to understand and identify impact issues. Within each of the three locations, mangrove species diversity was very low with limited densities of associate mangrove species (Table 6). Two transects (4a and 4b) were conducted at one site due to the division of a road in the middle.

Table 6: Species distribution of coastal mangrove habitats with *Rhizophora stylosa* (tongo) and *Rhizophora samoensis* (tongo) being seaward species and *Exoecaria agallocha* (Feta'anu), *Ficus oblique* (Ovava), *Hibiscus tiliaceaus* (fau), Morinda citrofolia and *Vitex trifolia* being coastal species.

Site	*Exoecaria agallocha*	*Ficus oblique*	*Hibiscus tiliaceaus*	*Morinda citrifolia*	*Rhizophora samoensis*	*Rhizophora stylosa*	*Vitex trifolia*
RapCA1						x	
RapCA4	x	x	x	x			x
RapCA4b	x		x		x	x	
RapCA7					x	x	

The areas studied showed that mangrove impacts were high to very high within the sites, with RapCA1 and RapCA7 impact level 5 (canopy <10%) and level 3 (canopy between 31% and 50%) (Figure 5). Both sites RapCA1 and RapCA7 showed low natural regeneration occurring with extensive bare mud patches between small stands of *R. stylosa* and *R. samoensis* (Figure 6b).

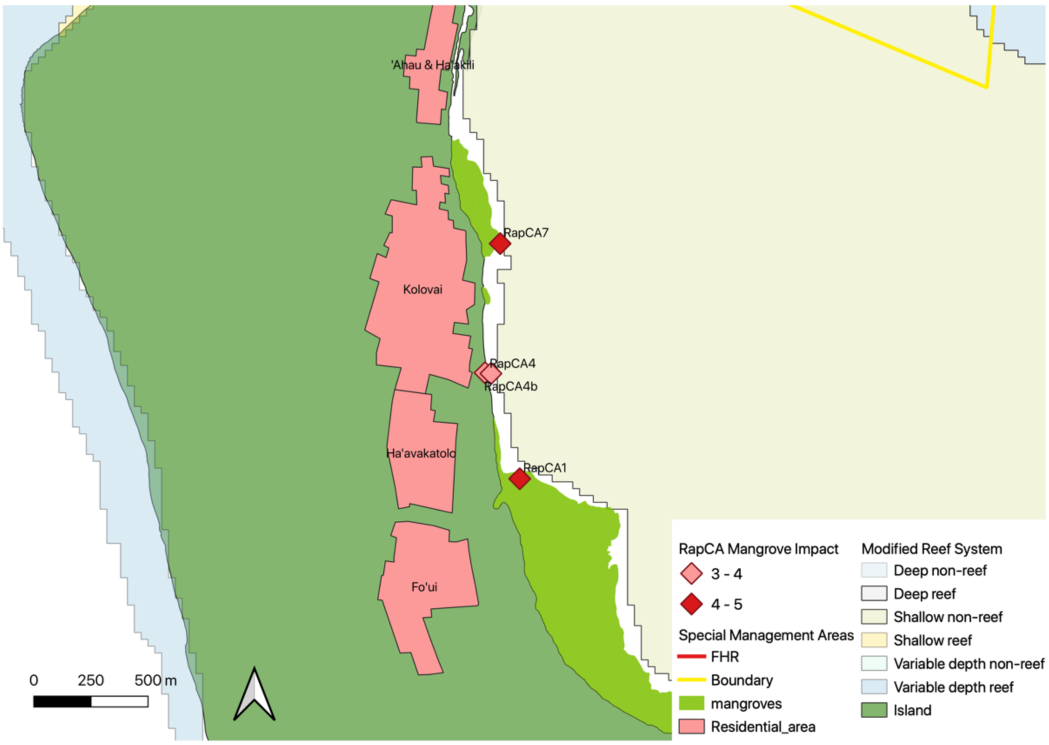

Figure 5: Map showing the mangrove and coastal habitat locations with relevant impact scale to the habitat.

Impacts were recorded as multiple impacts (MU) across all sites, including pig damage, inorganic waste pollution (garbage disposal) and anthropogenic stressors such as infrastructure and poor drainage (Figure 6a). There was little evidence of cultural use of the mangroves such as bark stripping or cutting for firewood.

Figure 6: Coastal habitats showing multiple impacts in two locations. 6a is from the coastal site at RapCA4 and 6b from the mangrove location at RapCA7.

Figure 6a shows site RapCA4, which is located on the land side of the coastal area. The soils, despite being terrestrial, have limited drainage ability creating a saline marsh habitat that restricts terrestrial plant growth.

The historical images below are taken from Google Earth. Both sites RapCA1 (Figure 7) and RapCA7 (Figure 8) show limited expansion of the mangrove habitats over the 14-year period with larger changes to sedimentation and land-based run off.

Figure 7: Google Earth images showing historical data on mangrove changes in 2005 to 2020. Yellow line represents the boundary of mangrove habitat in Fo'ui (RapCA1) in 2005.

Between the historical observations from Google Earth as shown in Figure 7 (spanning 2005 to 2020) at Fo'ui there has been little natural expansion through regeneration to the north of the yellow line, with regeneration occurring away from the shoreline area and to the outer extents of the mangrove forest.

In the mangrove area at ‘Ahau (Figure 8) historical imaging on Google Earth shows low natural regrowth of mangroves, with increases in furrows from watershed and run off increases shown by the red arrow in the 2020 image. It was also noted that there has only been a slight increase in coastal development (households) during that period (yellow arrow).

Figure 8: Google Earth images showing historical data on mangrove changes in 2005 and 2020. Yellow line represents the boundary line of mangroves at ‘Ahau (RapCA7) in 2005, the orange arrow indicates the trapped water area shown in Figure 9b.

The dumping of waste and trapped water areas was observed in ‘Ahau (Figure 9). These areas were tested through water quality assessment for further analysis and recommendations. These areas are directly linked to the mangrove habitats with terrestrial vegetation having been removed.

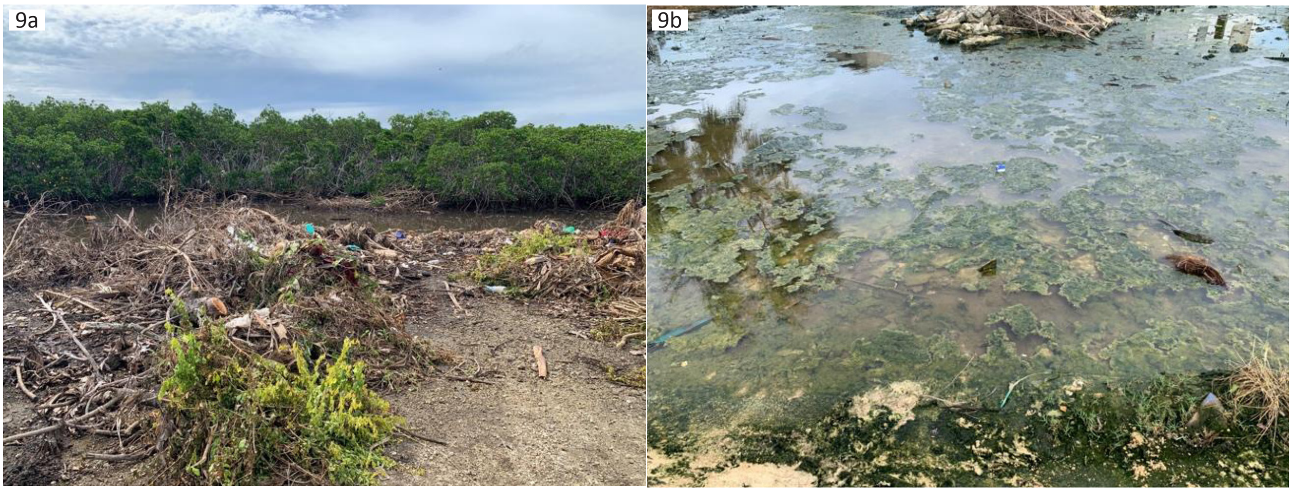

Figure 9: Images taken during the RapCA assessment at the land-based side of RapCA7 in ‘Ahau. 9b shows a small water area in reclaimed land.

Figure 10 shows polluted waters within natural streams depositing into the mangrove habitat at Fo’ui. This water pollution can impact upon the natural regeneration of mangrove and the health of soils and mud deposits for species.

Figure 10: Images taken at RapCA1 in the mangrove habitat in Fo'ui showing wastewater run off to the mangrove areas and entry point for pollutants.

3.4.2 Intertidal Mud Flats

The intertidal mudflats represent a large and expansive area of the Hihifo peninsula, where a total of five sites were surveyed, with sites RapCA11 and RapCA17 having transects both inside and outside of the FHR for future analysis (Figure 11 and 12).

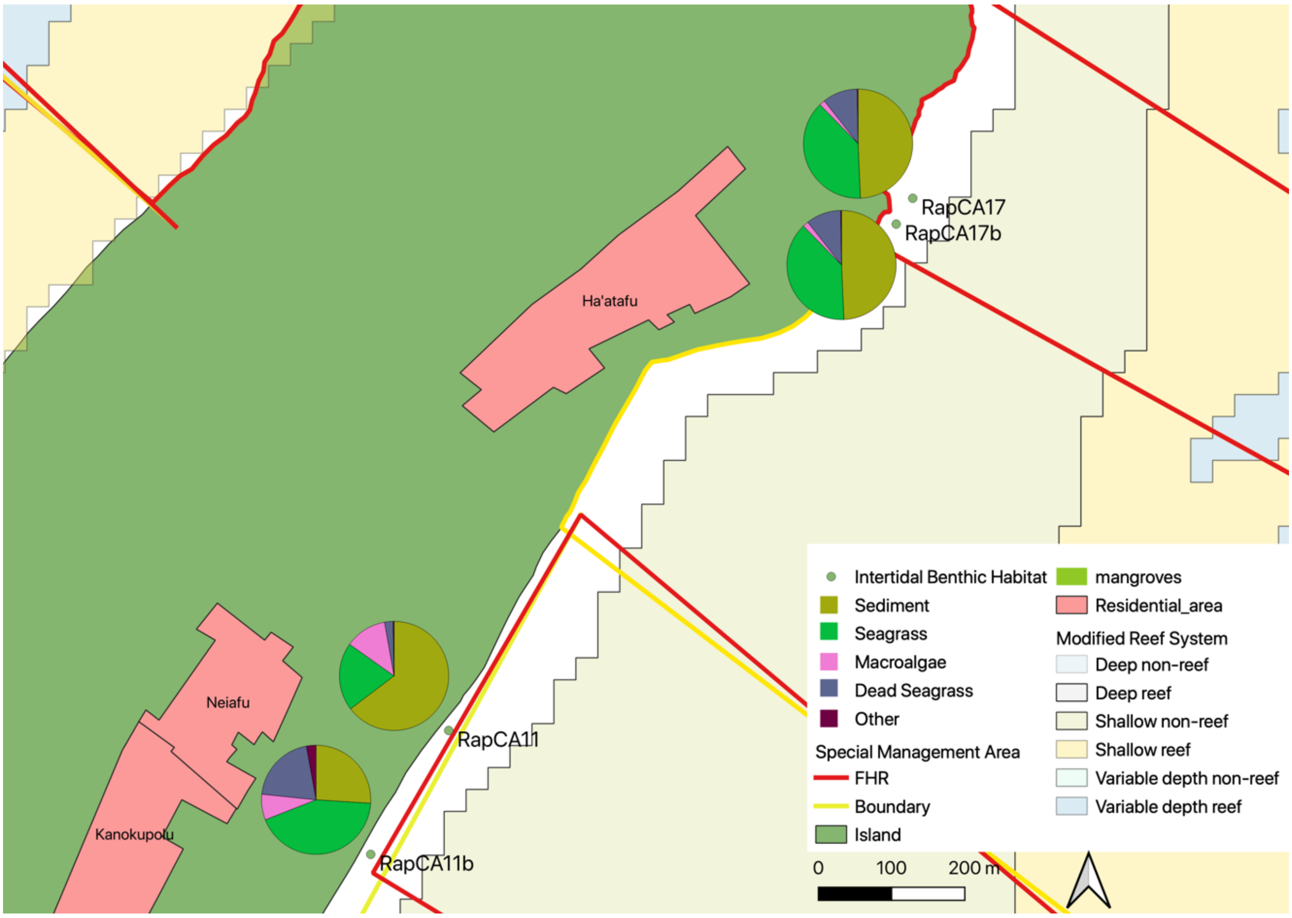

Figure 11: Map showing the average per cent cover of primary benthic habitats within the RapCA sites for the Hihifo district sites 11 (Kanokupolu) and 17 (Ha'atafu) within the SMAs.

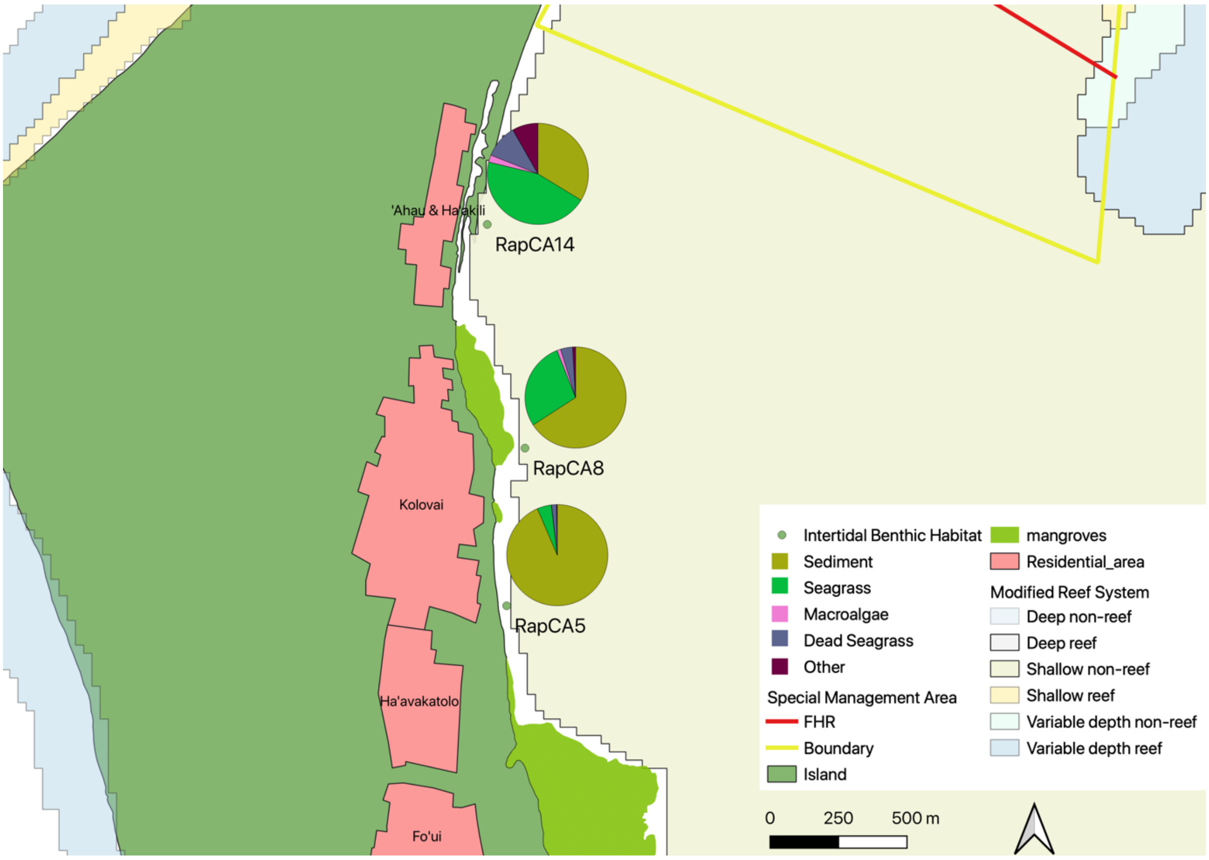

Figure 12: Map showing the average per cent cover of primary benthic habitats within the RapCA sites for the Hihifo district sites RapCA5, RapCA8 and RapCA14.

Sediment (silt) is the primary type of benthic habitat at three (RapCA11, RapCA5 and RapCA8) of the seven locations studied with the site at Kolovai showing over 90% silt cover across the transects. Towards the northern tip at Ha'atafu (RapCA17) and Kanokupolu (RapCA11), a lower percentage cover of silt was observed (Figure 13).

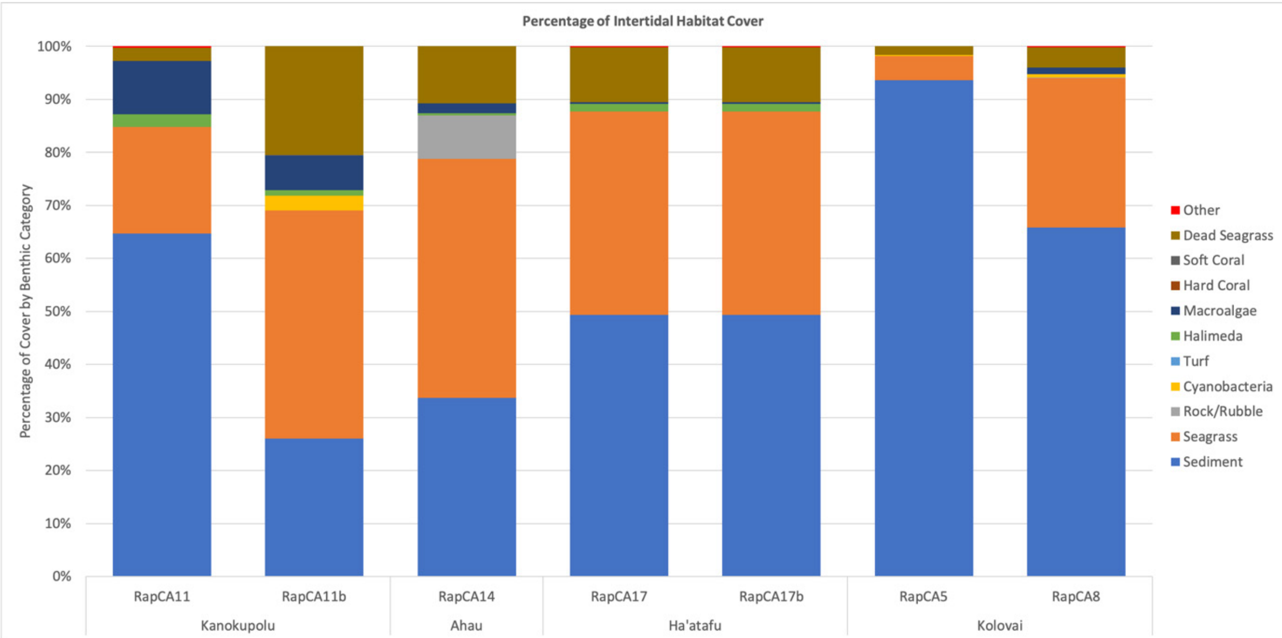

Figure 13: Bar chart showing the percentage of benthic habitat cover of the intertidal mudflats located within the Hihifo study area where the Sediment category includes both sand and silt components and Others category includes sponge, dead coral.

Sites RapCA11b, RapCA14 and RapCA17b had higher seagrass cover (*Thalassia testudinum*) with percentage cover of 43, 45 and 77 respectively. RapCA5, located between Ha'avakatolo and Kolovai had <5% cover by seagrass.

Dead seagrass was observed at each site, with higher percentages at RapCA11b, 14 and 17. The death of seagrass can be through an accumulation of pollution, ocean temperatures and stress, however, the breakdown of dead seagrass can also provide nutrients to the intertidal ecosystem.

Visual observations and reference materials (Pakoa et al. 2014) as well as photographs were used to identify marine plants such as the diminutive seagrass *Halophilia ovalis,* the green alga *Halimeda* sp. and the brown algae *Dictoyata bartayresiana* and *Hormophysa cuneiformis* (Figs 14, 17), which grew together with the larger seagrass *Thalassia testudinum*.

Figure 14: The brown alga (*Hormophysa cuneiformis*) tangled with seagrass found at all intertidal sites.

3.4.3 Marine Invertebrates

Marine invertebrates monitored within the intertidal mudflats were primarily burrowing species or species that rely on the nutritional and habitat benefits of seagrass and macroalgae such as sea cucumbers (holothurians), molluscs and sea urchins (Figure 15)

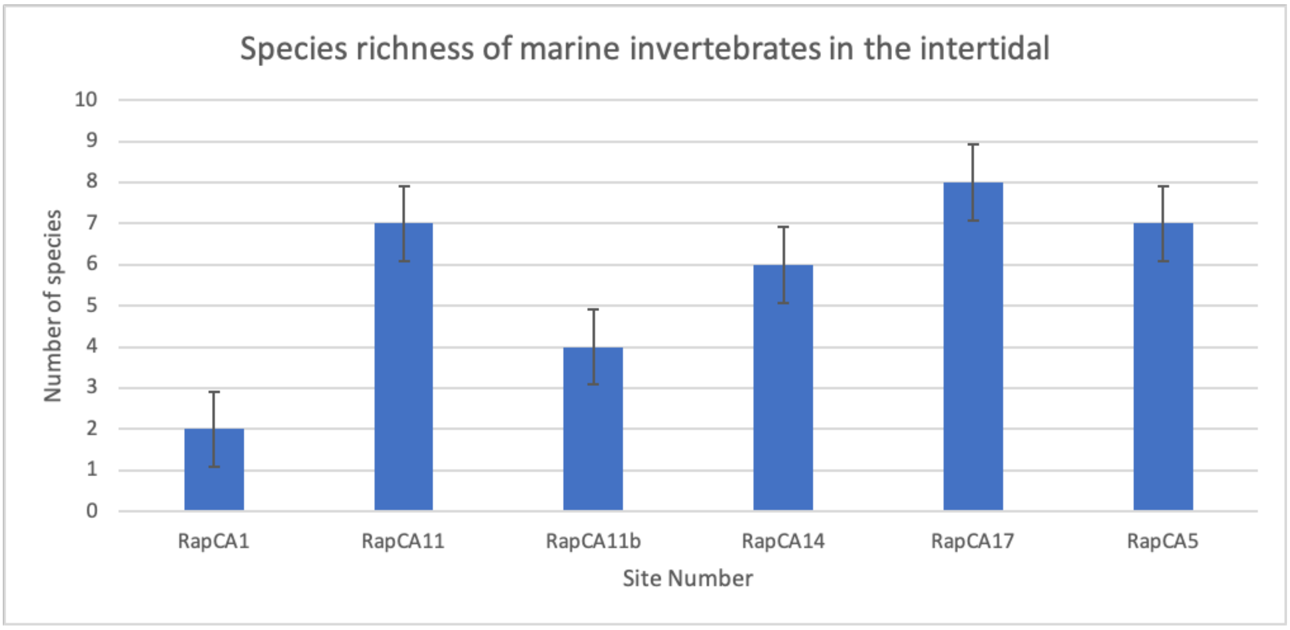

Figure 15: Chart showing species richness of marine invertebrates located within the intertidal mudflats and associated habitats. Error bars represent standard error (±SE).

Species diversity and abundance was higher across sites at RapCA5, RapCA11 and RapCA17. The two sites were located within the SMAs at Kanokupolu and Ha'atafu, respectively, coinciding with higher benthic cover of seagrass and macroalgae (Figure 15).

Mulione or the big-eared sea hare (*Dolabella auricularia*, Aplysiidae) which is a targeted marine invertebrate for subsistence (Friedman et al. 2009) was only observed within the seagrass beds at RapCA17 (Figure 16).

Across all the intertidal survey sites, low species diversity and abundance was observed, which indicates continued harvesting pressure through gleaning and fishing activities, and secondary links to impacts from environmental issues such as pollution and disturbed habitats.

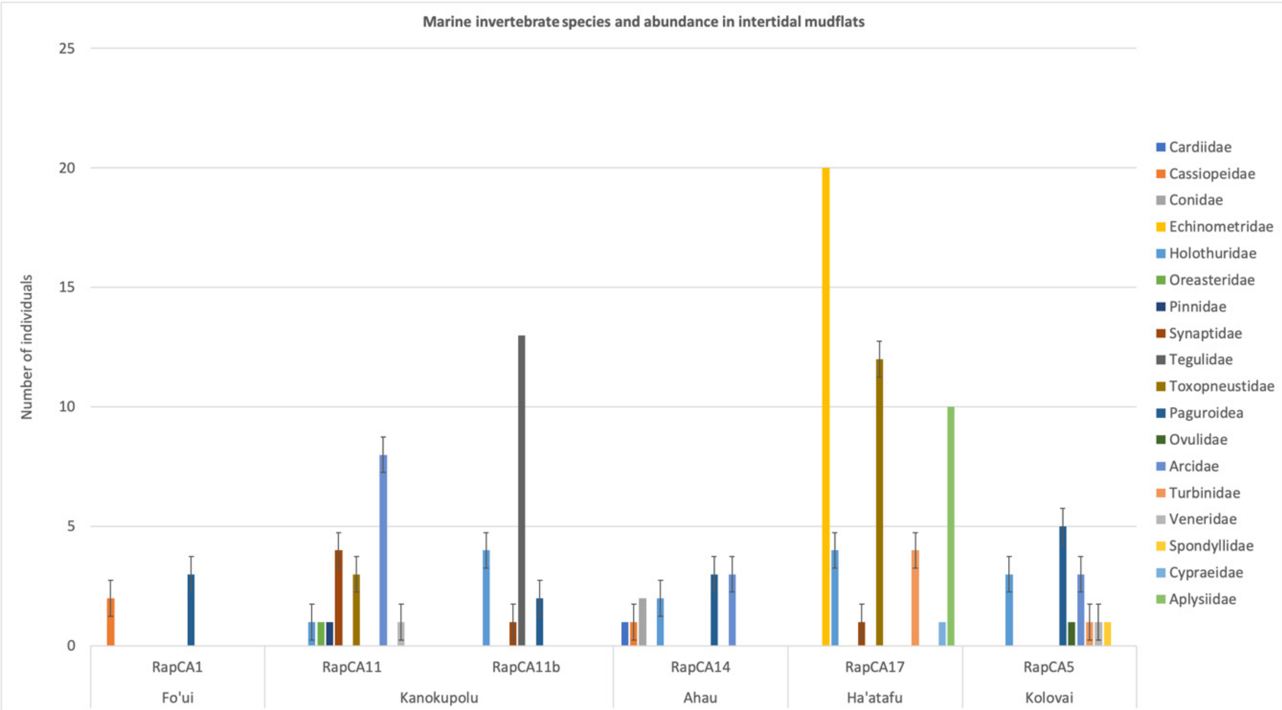

Figure 16: Chart showing species diversity and abundance for marine invertebrates in the intertidal mudflat transects. Error bars represent standard error (±SE)

Figure 17: Macroalgae (*Dictyota bartayresiana*) in the intertidal mudflats provide habitat for juvenile marine invertebrates shown here with juvenile sea cucumber (*Holothuria sp*) (<3 cm).

3.4.4 Near-shore Fish

Juvenile moray eels (Muraenidae) were observed in abundance (20 individuals) at RapCA11 within the FHR and SMA at Kanokupolu (Figure 18).

Figure 18: Juvenile moray eels (Muraenidae.) were observed in the intertidal habitats within the SMA and FHR at Kanokupolu (RapCA11).

Fish species were not observed during the intertidal mudflat transects, however *Terapon jarbua*, (Terapontidae) and *Ellochelon vaigiensis* (Muglidae), were observed during the high tide periods.

3.5 Coral Reefs

Coral reef site surveys were conducted using SCUBA equipment; survey depths were between 4 m and 8 m where the coral platforms and fringing reefs occur. Depths of 10 m to 12 m within the Hihifo area are primarily a sand basin.

3.5.1 Coral Habitat

Benthic analysis was conducted on the data collected from the PITs on each transect to determine percentage cover across the sites. Sites within closer proximity to communities (<5 km) at RapCA12, RapCA18 and RapCa15 had very low live hard coral cover between 4% and 12% as shown in Figure 19 whereas RapCA3, RapCA6 and RapCA9 had between 28.4% and 44.7% coral cover and are distanced between 3 km and 10 km from communities.

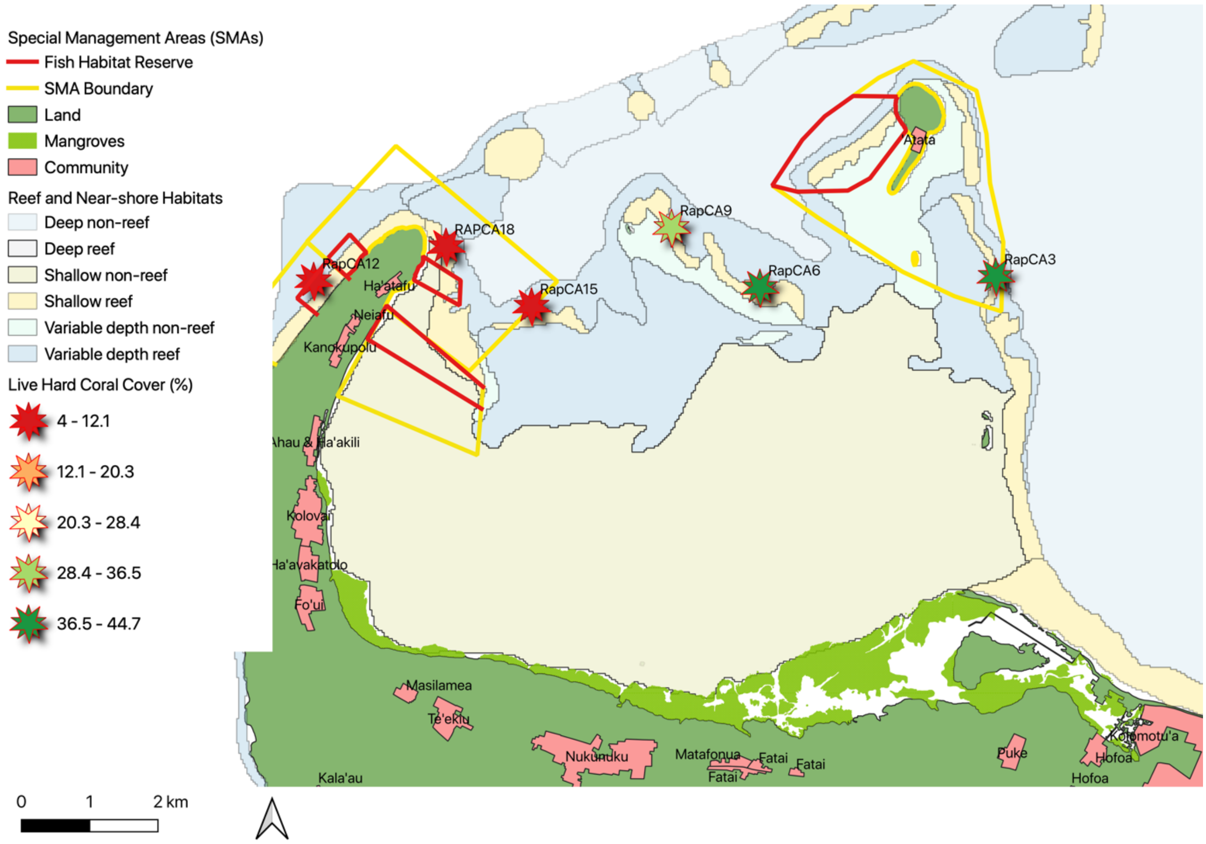

Figure 19: Map showing the coral reef assessment sites under the RapCA with the percentage of live hard coral cover per site and proximity of coral reef sites to community locations.

Dead coral cover was higher at RapCA sites 15 (67%), RapCA9 (51%) and RapCA 18 (74%), some of which is attributed to recent and previous storm surge damage (Figure 19).

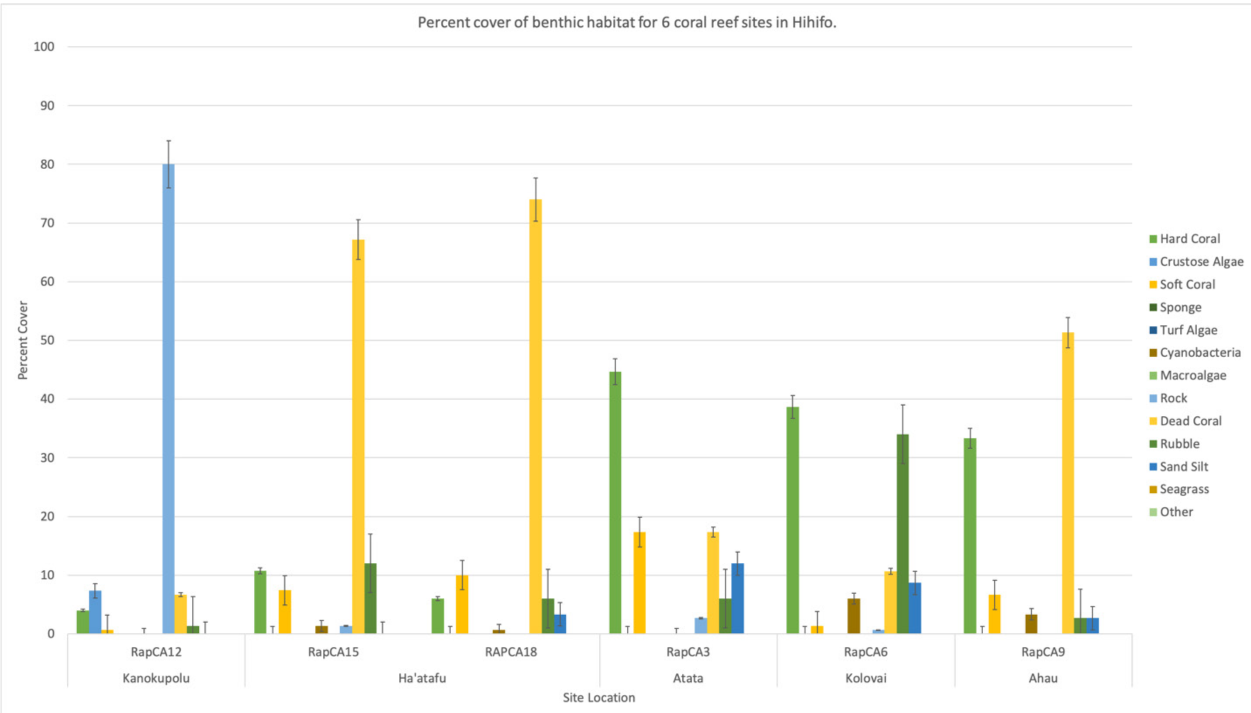

Figure 20: Chart showing the percentage of cover for the benthic habitats at the 6 coral reef sites. Error bars represent standard error (±SE)

Crustose coralline algae (CCA) which is an important component in reef building were only recorded in the PITs at RapCA12 with 7% cover (Figure 20).

Figure 21: Plate coral showing damage from storm surge on RapCA15.

Cyanobacteria and turf algae were found across all sites with observations made at RapCA12 showing large covers of the cyanobacterial filamentous algae *Lyngbya* sp which hinders coral recruitment and development (Kuffner et al., 2006) (Figure 22). *Lyngbya* sp. is also the main diet of some damselfish species and the increasing cover of this cyanobacteria can indicate an algal shift of the ecosystem through overfishing of higher trophic species, especially herbivores and grazers such as parrotfish and surgeonfish.

RapCA12 is located within the exposed reef FHR of Kanokupolu on the western side of the island. This site had very low coral reef cover (<5%) with limited ability of reef development (Figure 20).

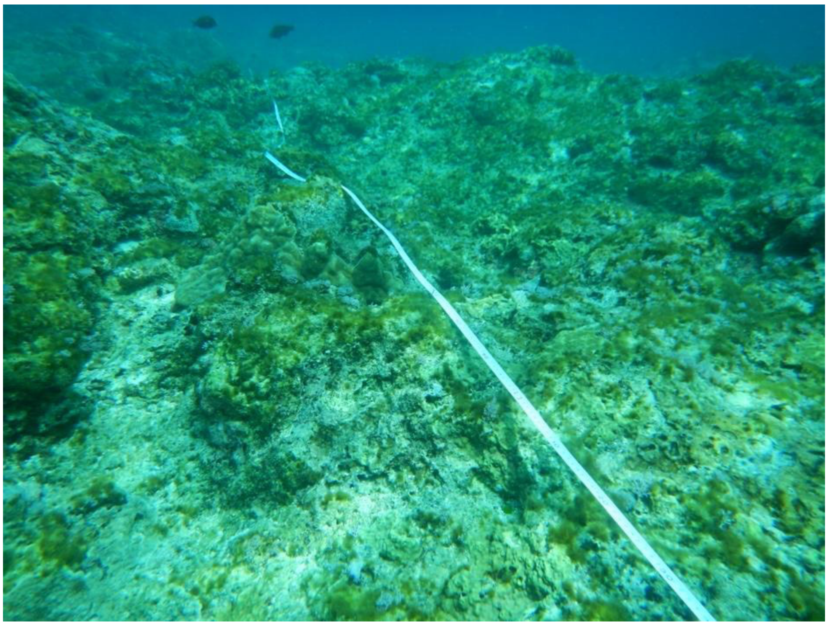

Figure 22: Habitat photo taken from RapCA12 showed very low coral cover (<5%) with filamentous algae over the benthic habitat.

Coral recruitment (corals <5 cm in diameter) was observed in a 25 cm x 25 cm quadrat. Recruitment was recorded per quadrat at 2 m intervals along the PITs. RapCA6 had the highest number of recruits with 225 recorded and RapCA12 had no observance of coral recruitment.

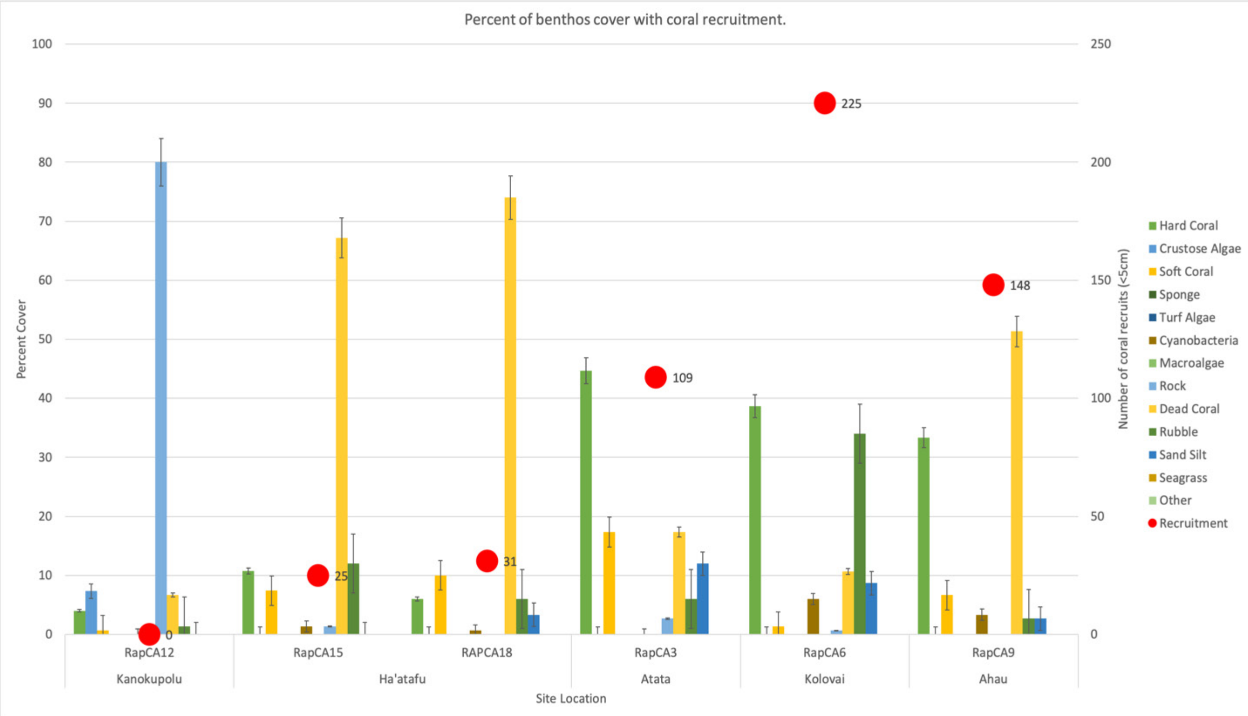

Figure 23: Chart showing the percentage of benthos habitat at with the number of coral recruits recorded across the transects. Error bars represent standard error (±SE).

3.5.2 Marine invertebrates

Marine invertebrates were in low abundance and diversity across all sites in the coral reef habitats under the RapCA (Figure 24) with 10 species across 7 families.

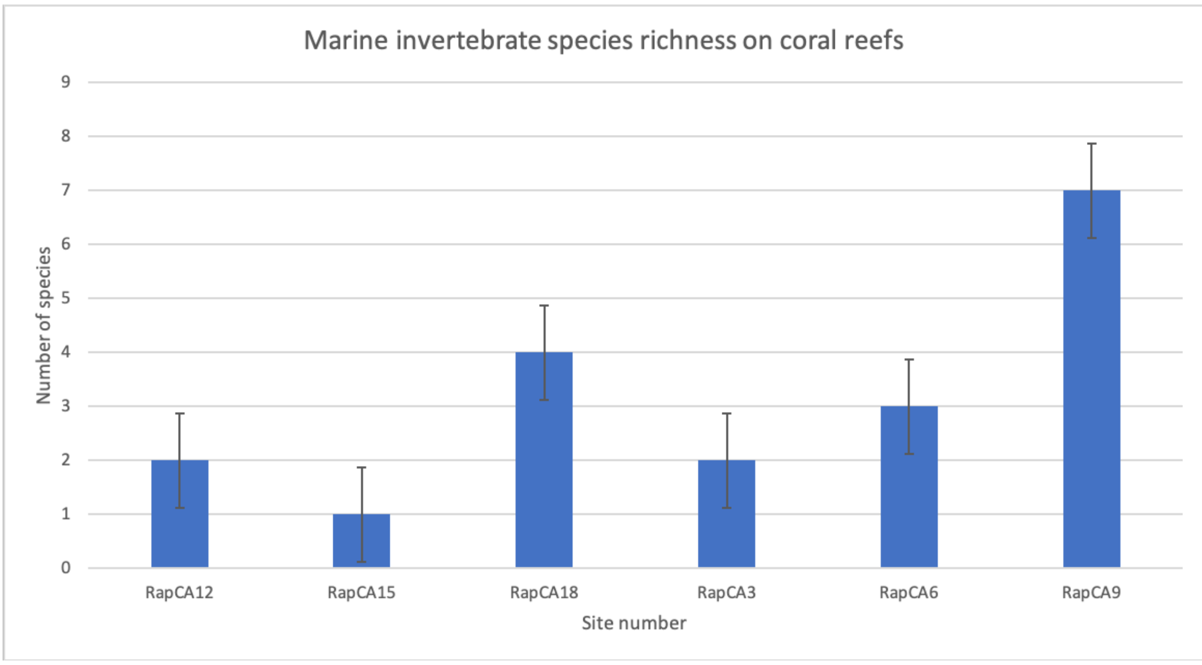

Figure 24: Chart showing the species richness of marine invertebrates within the coral reef habitats. Error bars represent standard error (±SE).

Table 7: Marine invertebrate abundance at family level across the 6 coral reef sites.

Family	RapCA12	RapCA15	RapCA18	RapCA3	RapCA6	RapCA9
Cardiidae	2				1	1
Diadematidae	717		16			
Echinometridae						1
Holothuridae		1	2	1	7	6
Synaptidae						1
Tegulidae			5	9		5
Ovulidae						1

Low diversity and very low abundance of Holothuridae (sea cucumbers) were observed within the reef habitats under the RapCA surveys. Species observed are listed in Table 8 with a single observation of *Holothuria nobilis* (black teat fish) being outside of transect (OT). *Holothuria edulis* (pinkfish) was in higher abundance (8) across the survey sites. Site 12 had no observations of *Holothuria* species, and this may be due to the difference in habitat primarily being scoured rock (<5% coral cover) (Figure 22).

Table 8: Species diversity and abundance of Holothuridae sea cucumbers across the 6 RapCA coral reef survey sites.

Holothuridae	RapCA12	RapCA15	RapCA18	RapCA3	RapCA6	RapCA9
Holothuria atra					2	3
Holothuria edulis			1		5	3
Holothuria nobilis		1 (OT)				
Stichopus chloronatus			1	1		

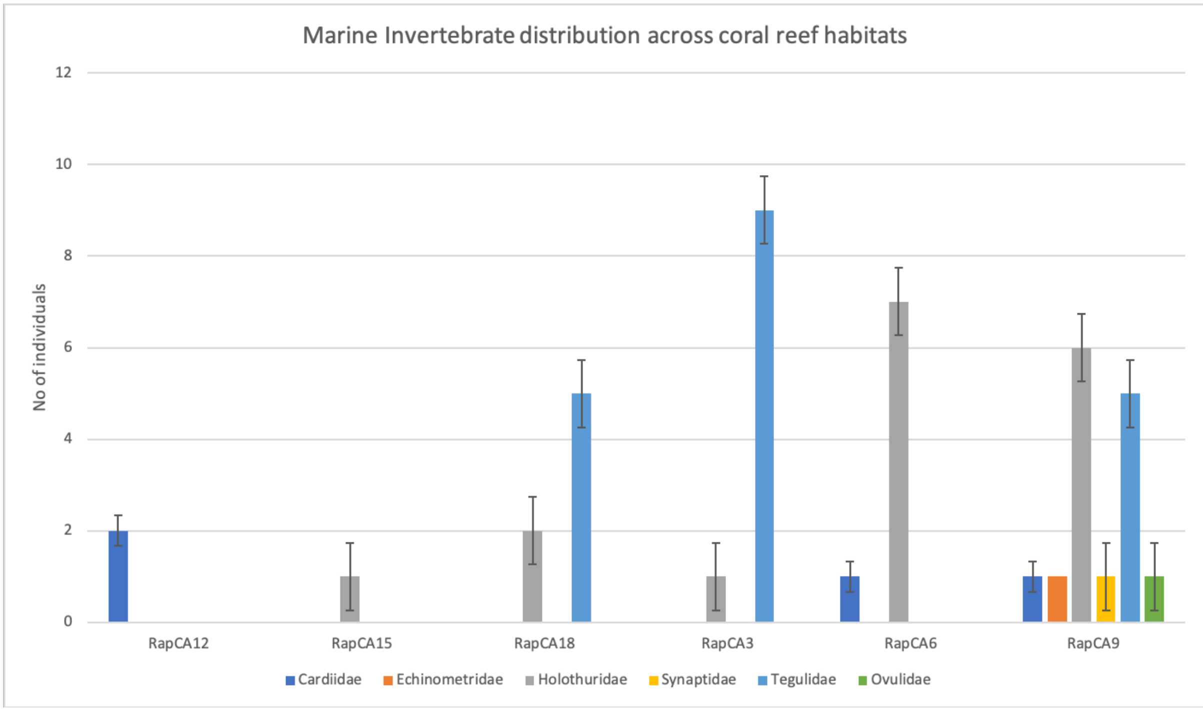

Figure 25: Bar chart showing the abundance of targeted marine invertebrate families across the 6 coral reef habitats. Error bars represent standard error (±SE)

Giant clam (Cardiidae) abundance was also low across the transects, with *Tridacna maxima* the only species observed at 3 sites: RapCA12 (2 individuals), RapCA6 (1 individual) and Rapca9 (1 individual) (Figure 25).

There was no observation of crown-of-thorns starfish (COTs) *Acanthaster plancii,* ('Alamea) or scarring (removal of zooxanthellae, symbiotic algae) of corals across the 6 sites and no observations of starfish (Ophidiasteridae or Oreasteridae) families or lobster (*Palinuridae* sp) across all sites.

Sea urchins (Diadematidae) were observed in high abundance at RapCA12 (Table 7).

3.5.3 Near-shore Reef Fish Species

A total of 141 near-shore reef fish species across 25 families was recorded during the assessment on coral reef habitats, of which 85 species are considered non-targeted (species that are not consumed) and 56 species targeted (species that are consumed for subsistence and domestic fisheries) resources (Figure 26).

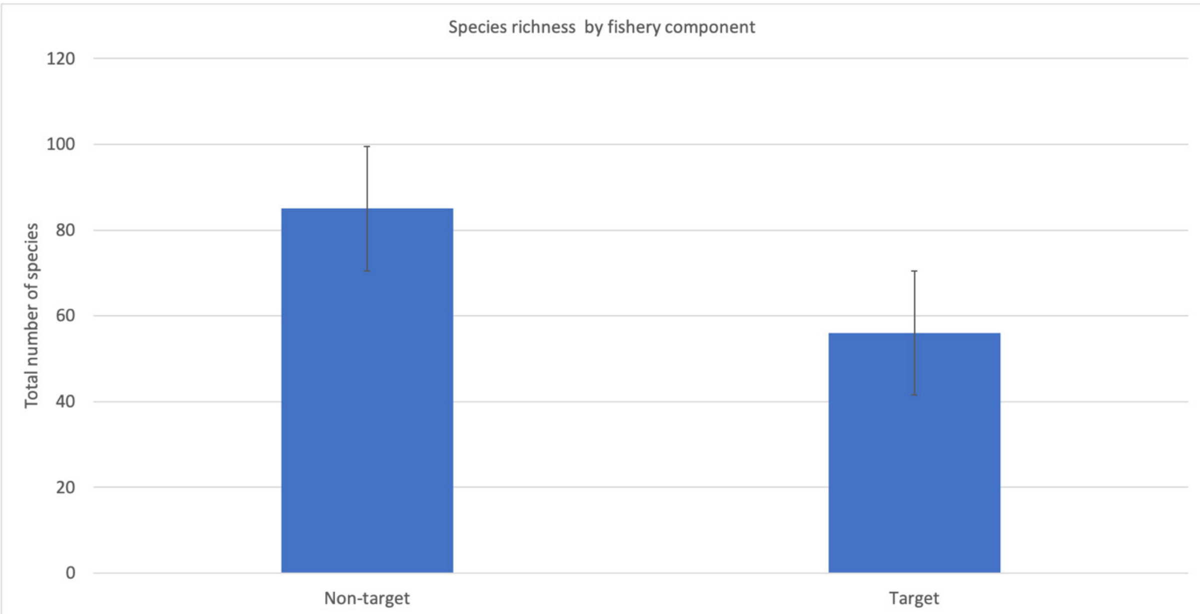

Figure 26: Species richness of near-shore populations across all sites under the RapCA surveys. Error bars represent standard error (±SE)

Non-target species accounted for 60% of the total species richness; these species are ones considered not valuable for a food source and are not commonly targeted though may be caught as unselected catch (Figure 26).

Species diversity was higher in the non-targeted families (Pomacentridae, Labridae, Blennidae, Gobiidae, Pomacanthidae and other fish species not beneficial for food consumption) across all sites (Figure 27).

Reef fish species diversity in comparison with live coral cover is represented in Figure 28, which shows that areas with higher coral cover had slightly higher diversity of reef fish species (RapCA15, 3, 6, 9), however, RapCa18 also had higher species diversity despite coral cover at 10%. RapCA12 had the lowest fish species diversity and the lowest coral cover across all sites. RapCA 6 was the only site with higher diversity observed in targeted species.

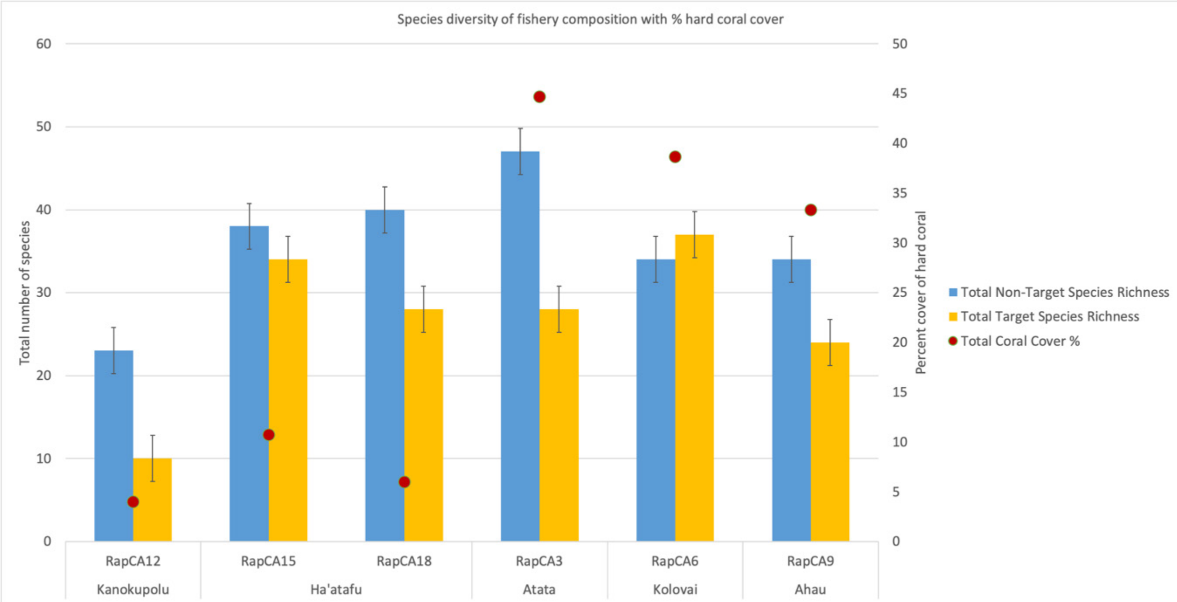

Figure 27: Chart showing the species richness for coral reef fishes and percent of live coral cover for the RapCA coral reef areas. Error bars represent standard error (±SE).

Figure 28 shows the biomass of targeted fish families across the 6 sites surveyed and extrapolated to kg/1000 m^2. Scaridae (parrotfish) had higher biomass at sites RapCa12, RapCa18 and RapCA9, whereas Acanthuridae (surgeonfish) showed the highest biomass at RapCA12. Serranidae (groupers) were in low biomass across all sites. Figure 29 shows the biomass ratings per site across the RapCA surveyed areas.

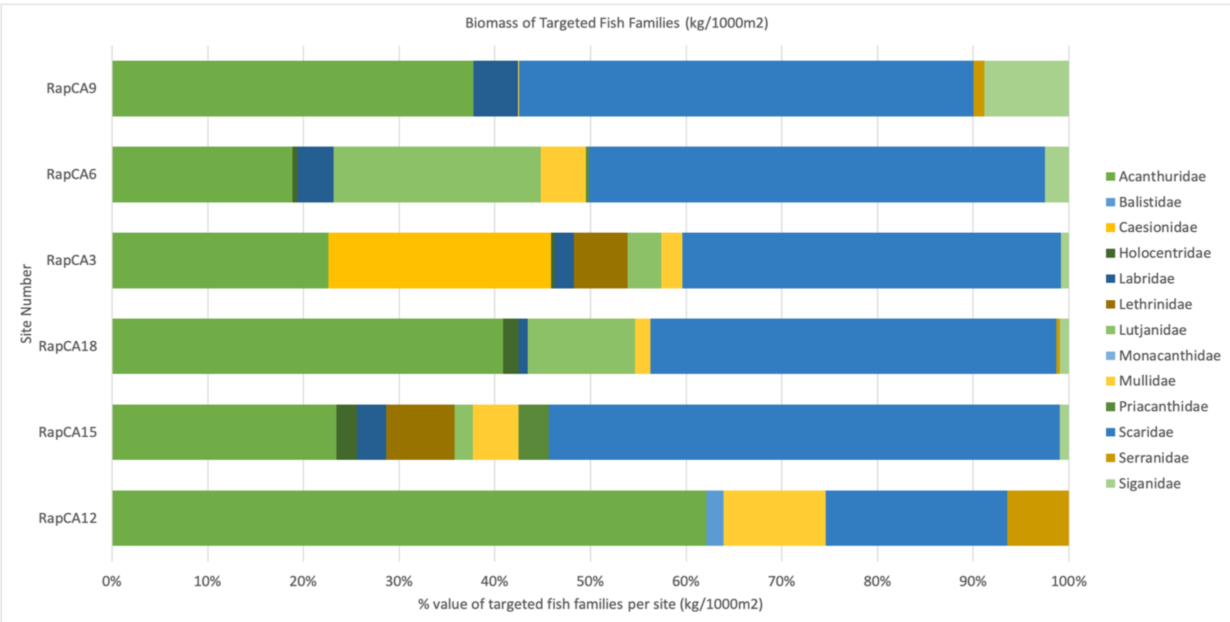

Figure 28: Chart showing the stacked percentage of biomass for targeted fish families across the RapCA coral reef habitats.

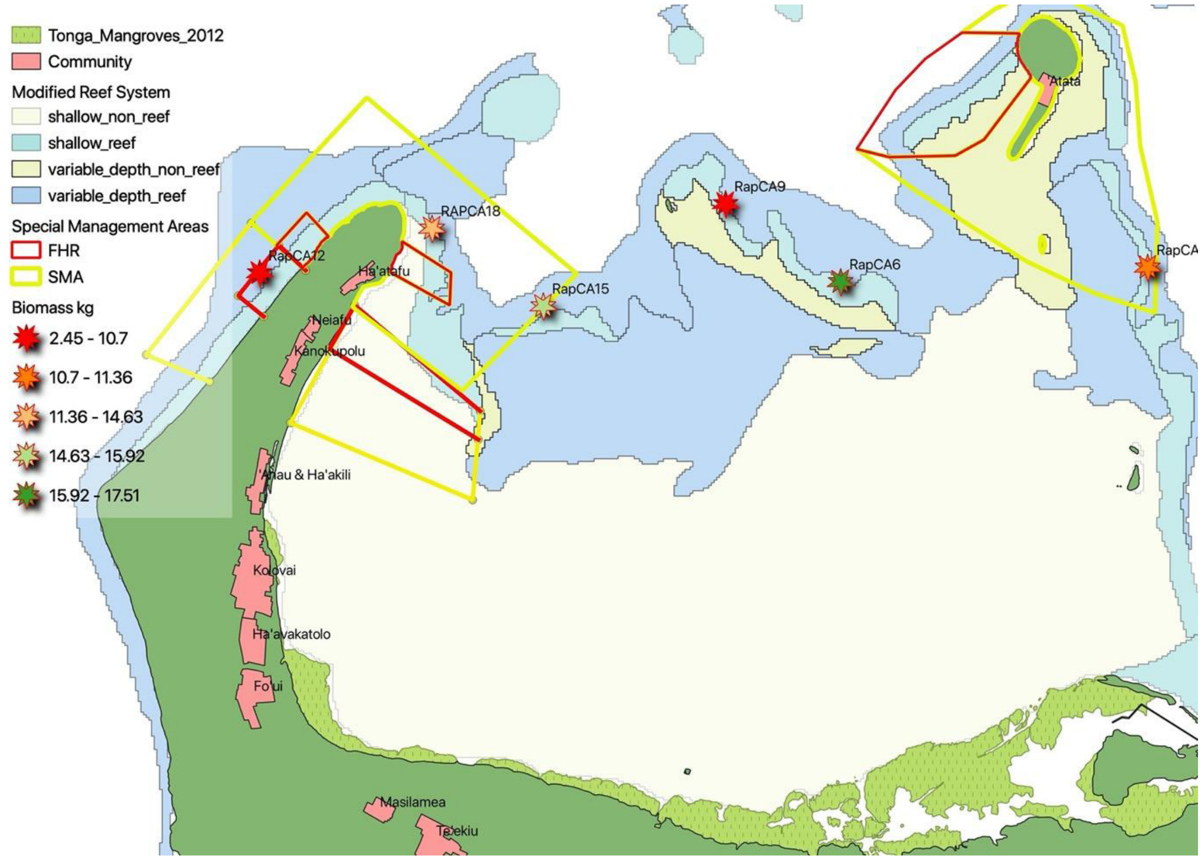

Figure 29: Map showing the coral reef survey sites undertaken during the RapCA assessments with analysis of total biomass (kg/per site) of targeted fish families.

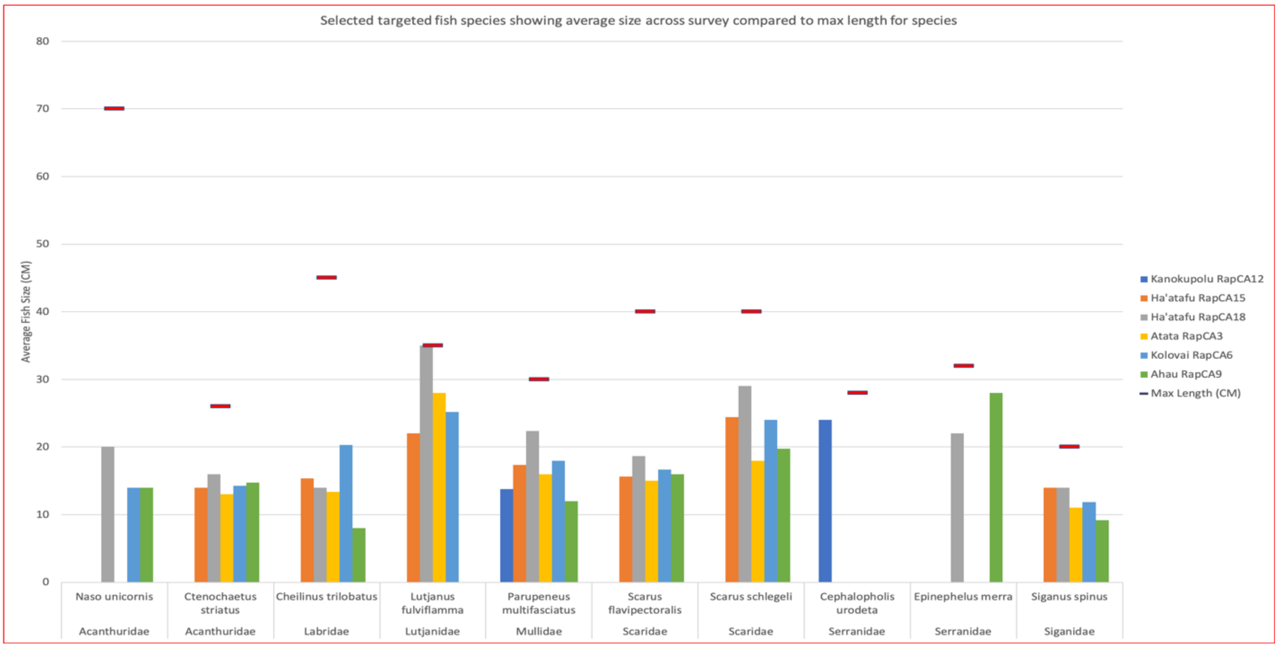

Figure 30: Bar chart showing the average length in centimetres of targeted fish species from selected species observed over the 6 coral reef habitats under the RapCA biological and ecological surveys.

Average fish lengths in centimetres for selected targeted (consumed) species were analysed from the survey sites (Figure 30) and compared across sites with the total maximum length for the species. Maximum fork lengths were taken from the Identification Guide to Common Coastal Food Fishes of the Pacific Island Region (Moore and Colas 2016).

The Dory snapper (*Lutjanus fulviflamma*) was the only species selected that was observed at the maximum length (35 cm), hence indicating it had reached the adult stage.

Scaridae juvenile *Chlorurus spilurus* and *Scarus flavipectoralis* were in high abundance with size ranging between 6 cm and 10 cm with very few species at 31 cm to 35 cm. Lethrindae and Lutjanidae families were comprised between 16 cm and 20 cm and 21 cm to 25 cm range with lower abundance at 26 cm and above (Figure 30).

Primary trophic function of reef fish families can be attributed and beneficial to the overall health of ecosystems, however, through resource use and fishing pressure, trophic functions can shift causing imbalances on the overall reef health. An example is the intensive algal turf farmer fish, *Stegastes nigricans* and *Amblyglyphidodon melanopterus,* an endemic species of damselfish. These fish increase turf algae cover over hard corals and were observed in high abundance at all sites except RapCA12 (Figure 31). This shift is caused by overfishing and harvesting of predatory species and trophic function such as carnivores and piscivores.

Carnivores and piscivores were in very low abundance over all sites. These families (groupers, snappers, and emperor fish) are important predatory species for keeping smaller fish and invertebrate species from dominating reefs and changing ecological balance such as increasing macro algae dominance (Figure 31), however, are targeted by fishers for subsistence and domestic income activities.

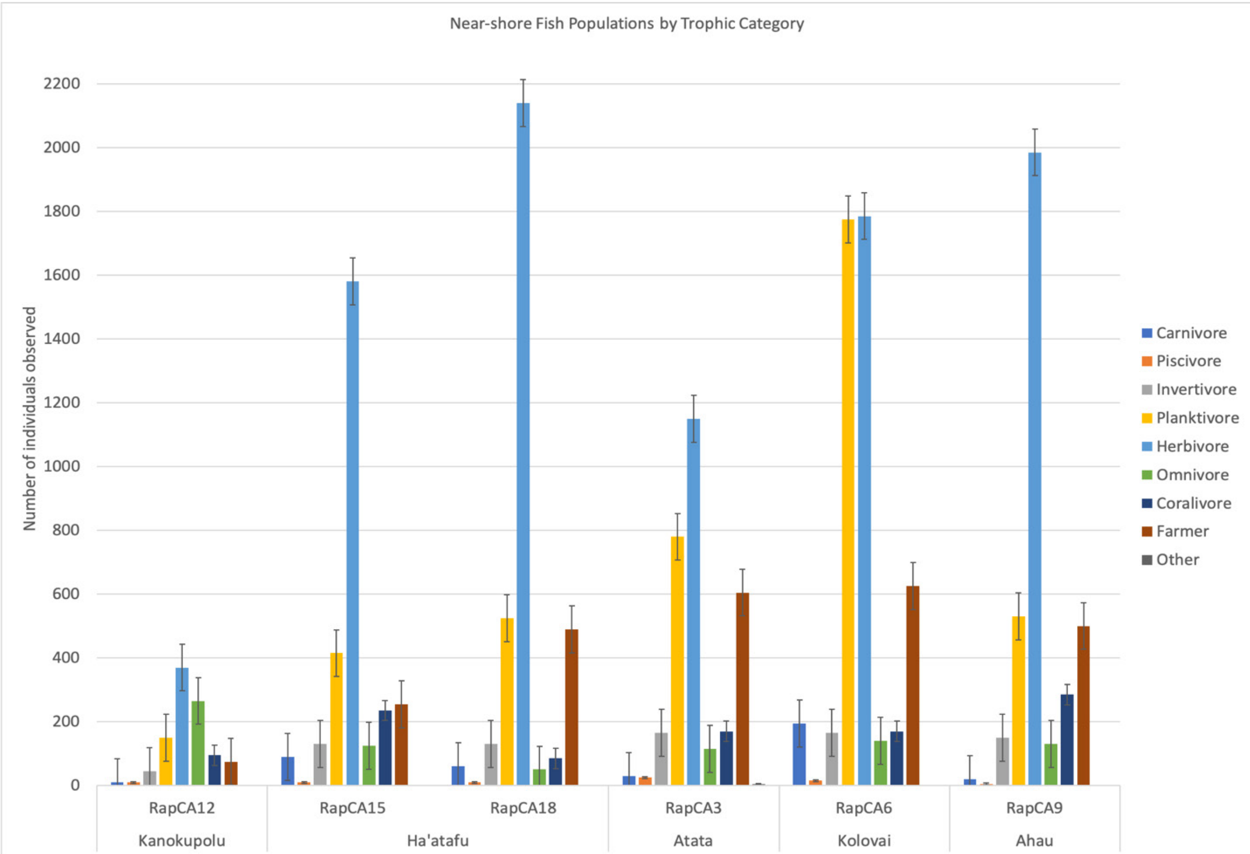

Figure 31: Chart showing the fish abundance per overarching trophic function category across the 6 coral reef habitats surveyed. Error bars represent standard error (±SE).

3.6 Endangered, Threatened and Endemic Species Observations

Species observations were recorded both within the transects and in general observations outside of the transect for endemic, and endangered or threatened species.

3.6.1 Endemic

Fish species that are listed as endemic under the National Biodiversity and Strategic Action Plan (NBSAP) were observed during the RapCA assessments.

Pomacentridae – *Amblyglyphidodon melanopterus* was observed in abundance across all sites and *Pomacentrus spilotoceps* at two sites in low occurrence. *Meiacanthus tonganus*, Blennidae was observed at four sites.

3.6.2 Endangered or Threatened Species

A single juvenile Napoleon wrasse (*Cheilinus undulates*) of 45 cm length was observed outside of the transect on RapCA15. The Napoleon wrasse, which can reach over 2 m in length when adult, is listed as endangered[4] under the International Union for the Conservation of Nature RedList of Threatened and Endangered species. *Cheilinus undulatus* are a species targeted for consumption by communities despite the low abundance. There is currently no fishing regulations or species protection for *Cheilinus undulatus* or other fish species that are identified as threatened or endangered, including sharks. There were no observations of sharks throughout the 6 sites.

4 DISCUSSION

Through the RapCA ecological and biological assessments, varying environmental and anthropogenic activities have been identified that are impacting the coastal habitats, biodiversity, and ecosystem services, with further impacts from natural disasters apparent through upturned plate/table corals on the reefs. These impacts have clear links to the proximity to communities and the movements of the watershed between the ridge to the reef.

The Hihifo district coastal area is low lying and flat with shallow elevation of 2 m above sea level towards the community areas and a slow rise to approximately 15 m above sea level towards the middle of the peninsula. The water lenses are located within this rise and are connected directly to the nearby community areas. Streams continue to the coastal habitats and mangroves.

The terrestrial biodiversity located between the communities and the coastal waters has been fragmented and dispersed between houses, agriculture, and infrastructure development, including roads and climate resilient foreshores.

The mangrove habitats within Fo'ui, Kolovai and 'Ahau areas all show ongoing and long-term environmental impacts from land-based pollution and run off to impoverished mud habitats, with little natural regeneration or growth shown through historical analysis taken from Google Earth.

The shallow elevation of the coastal marine area to land increases the ability for mud and sediment deposits within mangrove areas, which may be contributing to poor natural regrowth and loss of mangrove areas (Krauss et al. 2010). Wastewater impacts are indicated in the ecological surveys with evidence from streams in the mangrove habitats (Figure 10). Phosphate and ammonia were

4 Listing for Cheilinus undulatus on the IUCN Redlist https://www.iucnredlist.org/species/4592/11023949

identified in water quality surveys, however, the coastal waters showed anomalies in nitrate levels, with 8 sites showing 0 mg/L (refer Water Quality Assessment component of the RapCA) and this could be due to technical difficulties in the detection of nitrate in seawater (Ghassemzadeh et al. 1997). Heavy metals were indicated in the sediment testing with copper, nickel, iron, and hexavalent chromium found in all sites and exceeding guidelines for species conservation and recreational uses. Their presence indicates impacts from land use and human settlement. These heavy metals can contaminate marine species and impact human health when the food species are consumed. Further studies are recommended to identify the changes in sedimentation and what the impacts may be attributed to, including monitoring coastal water movement with current meters to assess if sediment deposition is localised or from a wider distribution through water movement.

Mangrove rehabilitation programmes along the coastal area of Hihifo may be at risk if land-based pollution and increasing sedimentation issues are not addressed. Mangroves are essential for coastal control, including the uptake of heavy metal and wastewater pollutants, however high levels of sedimentation can cause burial of the seedlings, limiting growth and development. If the land-side issues, including wastewater and inorganic waste are not reduced, efforts for rehabilitation and the provision of ecosystem services will be impacted.

The future design and implementation of infrastructure needs to be carefully addressed to minimise further fragmentation of the coastal flora and ecosystems which were indicated in the 2014 diagnostic study (McCue 2014). Though infrastructure may be necessary for coastal protection, there are ways to reduce the environmental impacts through maintaining tidal flow with culverts or openings within the design and similarly to reduce restrictions on natural springs and water flow that can be critical for mangrove habitats and habitat drainage.

Intertidal mudflats are an important habitat, and this survey was the first to analyse the benthic habitat and marine invertebrate species within the intertidal areas in Hihifo. The analysis showed that seagrass and macroalgae are primary contributors to providing habitat for invertebrate species that are utilised for community activities such as gleaning, however, are susceptible to environmental impacts such as increasing sedimentation, pollution, and habitat destruction.

Seagrass not only provide habitats for juvenile and transient marine species but is also a major attribute as a carbon sink with the ability to uptake carbon dioxide (CO_2) as well as provide further stabilisation to sediments from the coastal areas (Brodie et al. 2020). Furthermore, they can protect corals and other organisms from ocean acidification through their buffering effect (Bergstrom et al. 2019).

Excess sedimentation from land runoff and increasing land-based impacts including land clearance for settlements and developments, reduce the ability of seagrass to photosynthesise and provide nutrients and other benefits to the habitat. Monitoring areas of coastal erosion and increasing protection through landside and coastal flora would improve seagrass areas and placing them within FHRs would be beneficial to the recovery of marine invertebrates. Monitoring can be conducted through the percentage cover area of land erosion areas and through per cent cover and epiphytes on seagrass and secondarily through water quality such as turbidity studies.

The brown alga *Hormophysa cuneiformis* (Figure 14), will need further analysis and field observations to indicate if its abundance is due to a recent cyclone or seasonal changes. The genus *Hormophysa* is a normal component of the Tongan benthic algal flora (N'Yeurt and Tsuda 2014), however, not in over-abundance as seen during our survey, where it was seen across all sites and was being discussed in Tongan social media[5] with questions being asked on what it is and where it has come from. It is

[5] Details were in communication between VEPA and Ministry of Fisheries after posts in an online Facebook group

known that nutrient inputs into coastal areas from agriculture and anthropogenic sources can have a direct impact on algal blooms in island lagoon habitats (Fujita et al. 2013; N'Yeurt and Iese 2015) and a similar scenario involving different opportunistic algal species could be occurring in Tongan coastal waters.

With the SMAs at Ha'atafu and Kanokupolu, the inclusion of the intertidal habitat within the SMAs and FHRs could provide important areas for restocking of marine invertebrates such as sea cucumbers. However, priority actions within SMAs should include reducing land-based activity impacts such as pollution and strengthening coastal flora and waste management practices. Selecting protected areas with higher benthic cover of macroalgae and seagrass over areas with higher cover of silt, would have the potential to increase species abundance. However, this would be secondary to increasing the support for FHRs to be compliant to no-fishing or extraction activities to increase the ability for marine resource stocks to replenish.

Reef fish composition was higher in non-target species diversity than target fish species, which is consistent with other marine surveys completed within the Kingdom of Tonga. Fish length composition highlights that juvenile and intermediary fish (10–20 cm) of targeted fish species were in higher abundance than adult fish, indicating that fishing pressure is occurring on adult species within the coastal areas. Juvenile and intermediary size fish populations can be in relation to the shallow fringing reef and dependent on coral species diversity (Komyakova et al. 2013).

Intertidal and mangrove areas should be placed under habitat management programmes that identify, develop, and mitigate environmental and human use impacts. These habitat management areas could help restore and improve the functionality and ecosystem benefits while allowing for sustainable harvesting of marine resources. Sites ideal for this would be Fo'ui (RapCA1), due to the larger mangrove area to the east of this survey, and 'Ahau (RapCA7).

Coral reef habitats benefit from the protection and management activities either placed within FHRs inside of SMAs or through other beneficial conservation programmes. These sites would include RapCA6, RapCA9 and RapCa15, which are currently outside of the SMA programme and undesignated.

The outer and exposed coral reef habitat at RapCA12 will need to have further monitoring under the SMA programme which would be recommended to be conducted annually to record changes due to the placement of the FHR in 2020 and needs to be included in further water quality analysis with the development of resorts and tourism-based activities. Regeneration of natural coral habitat, including the analysis of available crustose coralline algae (7% cover), and lack of available coral recruitment and growth within this location is lower due to the scoured nature of the reef from high exposure to waves and swells.

5. CONCLUSION AND RECOMMENDATIONS

The RapCA surveys and assessments at the Hihifo demonstration site provided a snapshot status of ecological and biological processes of the coastal and near-shore habitats and biodiversity. The additional data collected on watershed and community knowledge and perceptions through the socio-economic surveys was useful to understand emerging trends. Ridge to reef indicators have been identified as a critical to the habitats and are further discussed below with recommendations and further monitoring and research activities to be included under Coastal Management Plans and Special Management Areas.

Priority should be given to land-based activities within the water lens and habitats that are impacting on the health and biodiversity of shoreline flora and fauna and the coastal ecosystems. The following provide a guide to activities that may be undertaken in the development of the Coastal Management Plan:

Awareness

1. The local communities need to have open dialogue and knowledge exchange programmes that involve meaningful participation of men and women to look at and identify the ecosystem services that the natural habitats are providing and/or are not providing. This would be a critical step in ensuring that management programmes are inclusive and based on community interaction and management such as the SMA programme. The current state of resources and habitat needs to be established and monitored into the future; the results of which should inform community dialogue and resource planning.

Terrestrial and Coastal Biodiversity

2. Further watershed analysis and water quality testing should be a priority for addressing the wastewater and pollution issues and to enhance the benefits that mangroves can bring to coastal habitats and shoreline protection.
3. Further research is needed on the terrestrial flora and fauna biodiversity, including updated mapping of native forest areas located within the Hihifo district, since these native forest areas would be beneficial for implementing protected areas between the terrestrial and coastal vegetation. Native forests are extremely beneficial to the health of coastal habitats and fauna through reducing run off and sedimentation to the fragile coastal areas. Invasive species management would be an essential component in maintaining the forest areas and need to be identified and addressed, both environmentally and through agriculture programmes.
4. Strong emphasis for management and further analysis needs to be placed on the coastal habitats and communities at Fo'ui, Kolovai and Ahau with nature based and improved infrastructure coordination and collaboration on environmental impact assessments conducted by Department of Environment (MEIDECC).
5. A coast-wide waste removal programme for the dumping areas would remove potentially harmful pollutants and reduce the leaching of waste into the coastal habitats and watershed areas. This would require commitments and engagement through multiple sectors and community members. Planting of species such as vetiver grass can increase bioremediation measures increasing the breakdown of pollutants and assisting in the clean-up of habitats.
6. The mangrove habitats in Fo'ui and 'Ahau need to be monitored for sedimentation increases and changes over a 3-year period to identify where the main sources of

sediment increase and settling are located. A sediment gauge or trap could be developed for this purpose.

7. Monitoring of current flow across the basin of Fo'ui, 'Ahau and Kolovai would also provide insight into the movement and flow of water and sediments. Data indicators show that these areas are experiencing reduced water flow due to the natural topography of the land. Monitoring in-shore currents would help identify improved management actions for coastal rehabilitation and/or beneficial infrastructure.
8. Coastal replanting activities within shoreline areas as secondary, and associate species around the mangroves would be beneficial in some areas, but there is a need to ensure that species diversity is represented in native plants and trees. For best outcomes, community engagement and design would be paramount to the success of these programmes.
9. Protection of endangered species listed in the NBSAP and IUCN Red List such as *Cheilinus undulatus (Napoleon wrasse) must be undertaken through the Fisheries Management (Conservation) Regulations, to reduce or periodically ban the harvesting of these species and to ensure recovery and sustainability.*

Special Management Areas and Coastal Management Programmes

10. Special Management Areas and Coastal Management Programmes are an integrated approach to community management and governance to manage, monitor and reduce impacts to ecosystem services. SMAs currently focus primarily on the near-shore coastal habitats and marine species, however the information provided by the community in the Coastal Community Management Plan (CCMP) shows strong linkages to incorporating ridge to reef activities that would reduce impacts from watershed and land-based human activities. All SMAs and Coastal Management Programmes should be gender inclusive, using approaches that include men and women and consider gendered benefits and impacts of these projects.
11. Biodiversity and habitats including the outer intertidal and reef edge need to be protected within the FHR of new SMAs alternative activities for communities need to be increased to assist in resource stocking and habitat management. These need to be strongly supported through coastal landside management within the SMA.
12. Complementary livelihood programmes would be beneficial for communities while the ecosystems are not providing the ecosystem services especially in Fo'ui, Kanokupolu and 'Ahau. These activities could include pilot aquaculture programmes that support environmental repair and subsistence food sources, including edible macroalgae programmes for limu (*Caulerpa racemosa).* All programmes should have a gender inclusive approach, also assessing benefits of the programme to men, women, and other marginalised groups in communities.
13. Secondary programmes such as the sea cucumber aquaculture programme under the Ministry of Fisheries should utilise the natural intertidal habitats of seagrass and macroalgae for release of juveniles over predominantly silty areas.

Further research and monitoring

14. The RapCA ecological and biological surveys provide a snapshot view of the status of the coastal and marine habitats and biodiversity and strengthened the approach for evaluating the ridge to reef processes. Monitoring and research activities should be led by Tongan researchers with input from community to establish internal protocols

and reduce resource costs. Data should be utilised across multi-ministry activities and it would be beneficial to include multi-partner research teams with the support of NGOs and regional organisations for capacity building and systems development. Both women and men should be included in this research and monitoring activities.15. Increasing current monitoring to include rapid assessment methodologies should be inclusive of community and governance approaches with increased gender considerations. Water quality and biological assessments should be conducted simultaneously on an annual basis at selected locations with quarterly water quality assessments establishing longer baselines for effective actions and monitoring of coastal pollution mitigation activities.

15. Sediment quality and flow is of increasing importance to shallow water habitats and biodiversity. Establishing permanent sites for monitoring near-shore current and seasonal wave and surge patterns would be beneficial to future conservation and infrastructure development. These should be conducted with an environmental impact assessment approach looking at key indicators for adaptation and mitigation of impacts to sensitive habitats.

16. Community-based evaluations through changes in catch and availability of resources would be a secondary component to analysing management impacts. These can be conducted on a more frequent basis (monthly or quarterly) than full technical field analysis but can increase flexibility in the adaptation and mitigation of environmental changes. These community-based evaluations will include regular assessment of gender inclusion in projects implemented.

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6 APPENDICES

Appendix 1: List of reef fish species and abundance as observed over the 6 coral reef habitats within the transects, categorised in non-target and target fishery components.

Fish Species	RapCA12	RapCA15	RapCA18	RapCA3	RapCA6	RapCA9	Grand Total
Non-target	**121**	**211**	**251**	**312**	**557**	**314**	**1766**
Amblyglyphidodon melanopterus		61	29	14	76	9	189
Anampses caeruleopunctatus			1	2		5	8
Anampses neoguinaicus			1			1	2
Anampses twistii			1				1
Arothron nigropunctatus			1	1			2
Aulostomus chinensis		1		1	2		4
Cantherhines dumerilii			1				1
Canthigaster valentini			3	2			5
Centropyge bicolor		11		3	1	4	19
Centropyge bispinosa		2	3	5			10
Centropyge flavissima			2				2
Chaetodon auriga	2			2	3		7
Chaetodon bennetti		1		2			3
Chaetodon citrinellus	10	3	1		2	1	17
Chaetodon ephippium				5	4		9
Chaetodon flavirostris				2			2
Chaetodon lunula				1	1		2
Chaetodon lunulatus	2	11	6	4	4	8	35
Chaetodon melannotus		3	3	4		3	13
Chaetodon mertensii		2			1		3
Chaetodon pelewensis	3	4	2		5	4	18
Chaetodon plebeius	2	8		2	1	2	15
Chaetodon trifascialis		1		6	1	2	10
Chaetodon ulietensis	2	2	2	1	4	2	13
Chaetodon unimaculatus					1		1
Chaetodon vagabundus	1	2		1			4
Chromis acares	7	2					9

Fish Species	RapCA12	RapCA15	RapCA18	RapCA3	RapCA6	RapCA9	Grand Total
Chromis atripectoralis			3	4	1		8
Chromis bami		1					1
Chromis chrysura				1			1
Chromis iomelas			14				14
Chromis lepidolepis		1					1
Chromis margaritifer	1						1
Chromis viridis		3		14	162	15	194
Chrysiptera brownriggi	7					4	11
Chrysiptera taupou	22	1	48	39	108	79	297
Cirrhilabrus punctatus			1	13			14
Cirripectes stigmaticus			1				1
Coris batuensis				1			1
Dascyllus aruanus		4		15			19
Dascyllus reticulatus				3			3
Dascyllus trimaculatus				3			3
Epibulus insidiator		1	1			3	5
Exallias brevis				1	1	1	3
Fusigobius signipinnis				1			1
Gobiodon brochus				1			1
Gomphosus varius		1	1		5	13	20
Halichoeres hortulanus			1	1			2
Halichoeres marginatus			1				1
Halichoeres trimaculatus			1				1
Heniochus chrysostomus				2			2
Heniochus monoceros				2			2
Heniochus varius				2	1	1	4
Labrichthys unilineatus		1	1		2	14	18
Labroides dimidiatus	2		2		4	1	9
Labropsis australis		2			2		4
Meiacanthus tonganus		2	2	6		1	11
Neoglyphidodon carlsoni				2			2
Oxycheilinus digramma		1	2	5		1	9
Oxymonacanthus longirostris		11	1	10	10	20	52
Parapercis clathrata	2			1	1		4

Fish Species	RapCA12	RapCA15	RapCA18	RapCA3	RapCA6	RapCA9	Grand Total
Pempheris adusta						1	1
Plectroglyphidodon johnstonianus	1					1	2
Plectroglyphidodon lacrymatus		3	26	34		2	65
Pomacentrus adelus	1	4	3	12	6	2	28
Pomacentrus bankanensis	6						6
Pomacentrus maafu		3		1		1	5
Pomacentrus philippinus		6	3	2	7	1	19
Pomacentrus spilotoceps	1	1				5	7
Pomacentrus vaiuli	14	1	2		4		21
Pseudocheilinus hexataenia			2			1	3
Pteragogus cryptus			1				1
Pteragogus enneacanthus				1			1
Stegastes fasciolatus				1			1
Stegastes nigricans		44	69	74	119	91	397
Stethojulis bandanensis			3		1		4
Stethojulis strigiventer			1				1
Synodus binotatus		1					1
Thalassoma amblycephalum	23						23
Thalassoma hardwicke		1	4	2	10	14	31
Thalassoma lunare	1				2		3
Thalassoma lutescens	5	2			4		11
Thalassoma nigrofasciatum	4						4
Valenciennea strigata	2						2
Zanclus cornutus		2	1		1	1	5
Target	**83**	**357**	**447**	**297**	**417**	**405**	**2006**
Acanthurus blochii					3	2	5
Acanthurus nigricauda	1	5		24	7		37
Acanthurus nigrofuscus	59	58	9	4	39	17	186
Acanthurus olivaceus	1				1		2
Acanthurus pyroferus		1					1

Fish Species	RapCA12	RapCA15	RapCA18	RapCA3	RapCA6	RapCA9	Grand Total
Acanthurus thompsoni		2		1			3
Balistapus undulatus	1						1
Calotomus spinidens			1	1		1	3
Cephalopholis urodeta	1						1
Cheilinus chlorourus				1	1		2
Cheilinus fasciatus		1					1
Cheilinus trilobatus		4	2	3	3	1	13
Chlorurus bleekeri	1	18		17	3	1	40
Chlorurus microrhinus		1		1			2
Chlorurus spilurus	7	87	84	77	156	94	505
Ctenochaetus binotatus		1	8		5	2	16
Ctenochaetus striatus		24	181	30	23	37	295
Epinephelus merra			1			1	2
Hemigymnus fasciatus					1		1
Hemigymnus melapterus		3	2	2	4	7	18
Hipposcarus longiceps		7	11	5	4		27
Lethrinus harak		8					8
Lutjanus fulviflamma		2	4	3	27		36
Lutjanus fulvus		1	4		6		11
Lutjanus gibbus			1		2		3
Lutjanus monostigma					1		1
Monotaxis heterodon				10			10
Myripristis berndti			4				4
Naso lituratus			1	2	2		5
Naso unicornis			1		1	1	3
Neoniphon sammara				1	2		3
Parupeneus barberinoides		3		2	3		8
Parupeneus barberinus		1					1
Parupeneus crassilabris			2		6		8
Parupeneus cyclostomus	2	1		4			7
Parupeneus indicus		1					1
Parupeneus multifasciatus	5	11	3	1	2	1	23
Pervagor alternans					1		1
Priacanthus hamrur		4			1		5

Fish Species	RapCA12	RapCA15	RapCA18	RapCA3	RapCA6	RapCA9	Grand Total
Pterocaesio tile				43			43
Sargocentron spiniferum		1	1	1			3
Scarus altipinnis					1	2	3
Scarus flavipectoralis		57	18	2	5	17	99
Scarus frenatus					33		33
Scarus ghobban		2		1		6	9
Scarus niger			1	9	2	2	14
Scarus oviceps		1	3		3	11	18
Scarus psittacus		1			20	13	34
Scarus rivulatus		2					2
Scarus rubroviolaceus			1				1
Scarus schlegeli		6	3	3	2	10	24
Scarus spinus		6	9		1	10	26
Siganus argenteus		1	3		3	4	11
Siganus spinus		2	1	4	9	45	61
Zebrasoma scopas	5	28	86	38	21	118	296
Zebrasoma veliferum		6	2	7	13	2	30
Grand Total	204	568	698	609	974	719	3772

Appendix 2: Targeted and indicator marine invertebrate species including Tongan name, Family and Species. Compiled from survey assessments and Ministry of Fisheries.

Tongan Name	Family	Species
Alamea	Acanthasteridae	*Acanthaster solaris*
Mulione	Aplysiidae	*Dolabella auricularia*
Kaloa'a	Arcidae	*Anadara* sp.
Tuahi	Cardiidae	*Acrosterigma elongatum*
Lengango	Cardiidae	*Fragum unedo*
Tokanoa	Cardiidae	*Tridacna derasa*
Kukukuku	Cardiidae	*Tridacna maxima*
Matahele	Cardiidae	*Tridacna squamosa*
Tevolo	Cardiidae	*Tridacna tevoroa*
Jelly	Cassiopeidae	*Cassiopea* spp
Kele'a	Charoniidae	*Charonia tritonis*
Fuhu	Conidae	*Conus admiralis*
Fuhu	Conidae	*Conus striatus*
Hulihuli	Cryptoplacidae	*Cryptoplax* sp.
Pule	Cypraeidae	*Cypraea annulus L.*
Pule maka	Cypraeidae	*Cypraea tigris*
Vana huhu	Diadematidae	*Diadema setosum*
Vana	Diadematidae	*Echinothrix calamaris*
Vana	Echinometridae	*Echinometra mathaei*
Vana maka	Echinometridae	*Echinostrephus sp*
Ha'ape	Harpidae	*Harpa amoretta*
Ha'ape	Harpidae	*Harpa major*
Loli fulufulu	Holothuridae	*Actinopyga miliaris*
Matamata	Holothuridae	*Bohadschia argus*
Loli	Holothuridae	*Holothuria atra*
Tepupulu maka	Holothuridae	*Holothuria coluber*
Loli pingiki	Holothuridae	*Holothuria edulis*
Elefanite	Holothuridae	*Holothuria fuscopunclata*
Tepupulu	Holothuridae	*Holothuria leucospilata*
Mokohunu huhuvalu	Holothuridae	*Holothuria nobilis*
Huhuvalu 'uli'uli	Holothuridae	*Holothuria whitamei*
Mokohunu maka	Holothuridae	*Holothuria whitmaei*

Tongan Name	Family	Species
Holomumu	Holothuridae	*Stichopus chloronatus*
Lomu	Holothuridae	*Stichopus herrmanni*
Lomu*	Holothuridae	*Stichopus horrens*
Pulukalia	Holothuridae	*Thelenota ananas*
Mokohunu salaniti	Holothuridae	*Thelenota anax*
Tu'ulalo	Lucinoidea	*Codakia tigerina*
Tava'amanu	Lucinoidea	*Fimbria fimbriata*
Ohule	Mesodesmatidae	*Atactodea striata*
Fuhu	Mitridae	*Mitra mitra*
Fuhu	Mitridae	*Mitra* sp.
Potupatu	Muricidae	*Chicoreus ramosus*
Kuku	Mytilidae	*Modiolus* sp.
Hihi vai.	Neritidae	*Nerita polita*
Feke	Octopodidae	*Octopus cyanea*
Kelikeli	Olividae	*Oliva miniacea*
Fetu'u tahi (pulu)	Ophidiasteridae	*Linckia laevigata*
Fetu'u tahi (pingiki)	Oreasteridae	*Choriaster granulatus*
Fetu'u (pini)	Oreasteridae	*Culcita novaguineae*
Pulepule	Ovulidae	*Calpurnus verrucosus*
Pule'oto	Ovulidae	*Ovula ovum*
Hermit Crabs	Paguroidea	
Uo	Palinuridae	*Panulirus* sp
Ufi	Pinnidae	*Atrina vexillum*
Tofe	Pteriidae	*Pinctada margaritifera*
Tofeloa	Pteriidae	*Pteria penguinn*
Fai'ahu	Spondyllidae	*Spondylus* sp.
Angaanga	Strombidae	*Lambis lambis*
Angaanga	Strombidae	*Lambris crocata*
Fuhu	Strombidae	*Stombus lattisimus*
Kele'a	Strombidae	*Strombus gibberulus gibbosus*
Kele'a	Strombidae	*Strombus gibbus gibbus*
Kele'a matale'a	Strombidae	*Strombus luhuanus*
Angaanga	Strombidae	Strombus thersites
Peva	Synaptidae	*Euapta godeffroyi*
Takaniko	Tegulidae	*Trochus niliticus*
Mehingo Tonga	Tellinidae	*Pharaonella tongana*

Tongan Name	Family	Species
Mehingo	Tellinidae	*Quidnipagus palatum*
Mehingo	Tellinidae	*Tellinella staurella*
Kelitoke	Terebridae	*Terebra maculata*
Tukumisi	Toxopneustidae	*Tripneutee* spp.
Takaniko	Turbinidae	*Tectus pyramis*
Tengamae	Turbinidae	*Turbo agryostomus L.*
Topulangi	Turbinidae	*Turbo chrysostoms*
Elili	Turbinidae	*Turbo crassus*
Elili	Turbinidae	*Turbo marmolatus*
Elili	Turbinidae	*Turbo petholatus L.*
Elili	Turbinidae	*Turbo setosus*
Elili	Turbinidae	*Turbo* sp.
Winkle	Turbinillidae	*Vasum* sp
To'o tengange	Veneridae	*Gafrarium pectinatum*
To'o teka	Veneridae	*Gafrarium tumidum*
Tu'atea	Veneridae	*Lioconcha annettae*
Tu'atea	Veneridae	*Lioconcha castrensis*
Tava'amanu	Veneridae	*Periglypta puerpera*
Tava'amanu	Veneridae	*Periglypta reticulata*
Pipi	Veneridae	*Pitar prora*