Integrated Island Biodiversity

Technical Series

Marine Ecosystem Health Monitoring Program

Kingdom of Tonga 2016

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Our vision: A resilient Pacific environment sustaining our livelihoods and natural heritage in harmony with our cultures.

Integrated Island Biodiversity Project Marine Ecosystem Health Monitoring Program

2016

Ministry of Lands, Environment, Climate Change and Natural Resources (MLECCNR)

INDEX

ACRONYMS

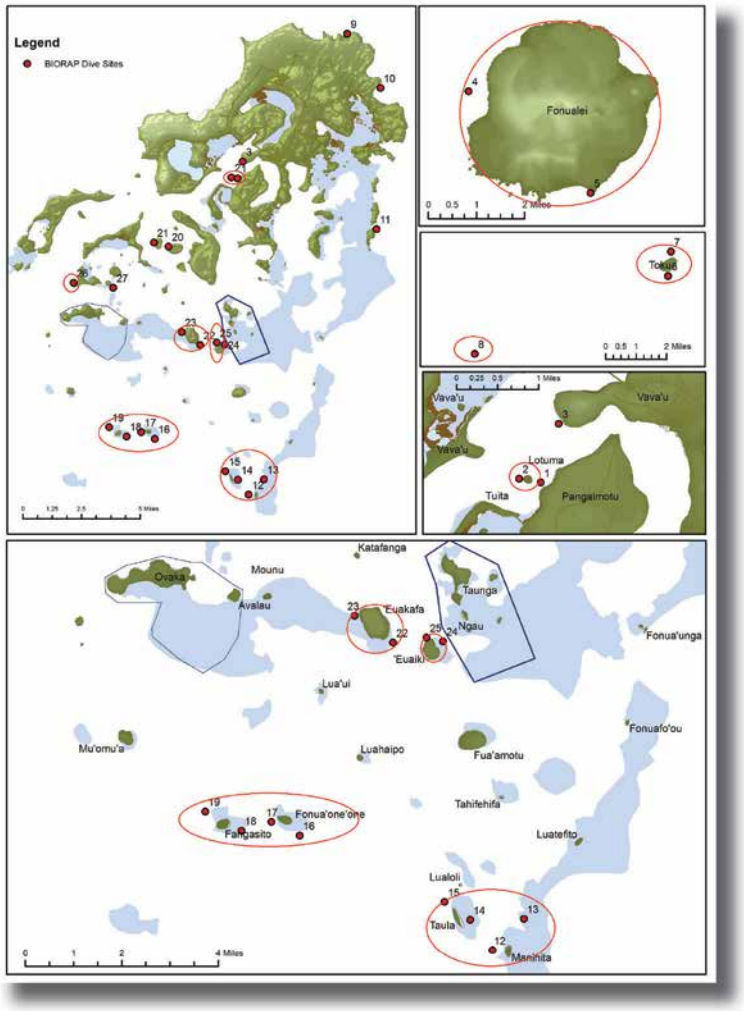
BioRAP	Rapid Assessment of Biodiversity
CRSP	Climate Resilience Sector Programme
GEF	Global Environment Fund
IIB	Integrated Island Biodiversity
IUCN	International Union of Conservation Networks
MAFFF	Ministry of Agriculture, Forests, Foods and Fisheries
MEIDECC	Ministry of Meteorology, Energy, Information, Disaster Risk, Environment and Climate Change and Communication
NBSAP	National Biodiversity Strategic Action Plan
PADI	Professional Association of Diving Instructors
R2R	Ridge to Reef programme
SPREP	Secretariat of the Pacific Regional Environmental Programme
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
VEPA	Vava'u Environmental Protection Association

1.0 Introduction

In 2014, a rapid assessment of the marine and terrestrial biodiversity of Vava'u (BioRAP) funded through Secretariat of the Pacific Regional Environmental Programme (SPREP) was conducted under the Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communication (MEIDECC).

The BioRAP included 27 marine sites as shown in Figure 1 below. Sites were chosen in order to assess the biodiversity of marine species and the health of the ecosystems for environmental management plans as outline in the National Biodiversity Strategic Action Plan (NBSAP, 2014)

Figure 1.
Map Showing the 27 Dive Sites from The Rapid Assessment of Biodiversity in February 2014



Coral reef ecosystems and marine habitats in Vava'u are widely utilized for both subsistence and commercial fisheries, tourism and recreational activities and are important both culturally and economically for the Kingdom of Tonga.

Human and climate change impacts threaten the resilience and sustainability of marine ecosystems and as recorded in the BioRap, management programs need to be introduced to ensure and improve upon the current status of marine resources in Vava'u.

Fishing activities are conducted during both the daytime and nighttime through spear fishing, placement of Gil nets along coastal areas, line and pole fishing. Commercial species such as groupers, parrotfish, emperors and snappers have been heavily targeted and abundance and biomass of targeted species were recorded as low on a number of the sites.

Marine invertebrate species such as clams (vasuva) and sea cucumber (mokohuna) were also observed as critically low in abundance during the BioRAP, which lead to the ban of sea cucumber harvesting for a minimum of five years by the Ministry of Agriculture, Forests, Foods and Fisheries.

Climate change threats to marine ecosystems include sea level rise and sea temperature increases over an extended period of time causing coral bleaching. Coral bleaching was recorded during the BioRap in 2014. Corals that have bleached and in instances of mortality where macro algae has overtaken; the corals are no longer providing the essential services of food, habitat and shelter for marine fishes.

Ecosystem health monitoring includes identifying threats and impacts that are occurring to the marine ecosystems, this is conducted through systematic collection of data that includes coral health and coral cover, reef fish families and invertebrate species. The recording of fish families is further transposed to dietary functions which can give an overview of the resilience of the coral reef ecosystem to human impacts and climate change threats.

Ecosystem resilience relates to the ecosystems ability to rebound and respond to threats by resisting damage and recovering quickly. Coral reefs that have been weakened and show signs of low resilience do not provide the ecological or socio-economical benefits to both fisheries and tourism and are unable to withstand ocean impacts such as increased storm surges and cyclones.

By conducting regular bi-annual monitoring surveys of coral reef areas and adjacent habitats, the ability for management responses and support of community programs to reduce potential impacts and to improve resilience will be of large benefit to the Vava'u archipelago.

This follow up monitoring programme was conducted under the Integrated Island Biodiversity Programme (IIB) and in partnership with participants from the UNDP Programme (R2R) in Tongatapu and the Vava'u Environmental Protection Association (VEPA) .

2.0 Methodology

The first week of the two week program was spent training 6 participants to Professional Association of Dive Instructors (PADI) Open Water Scuba Diver certification. This portion of the program was to professionally train the environment monitoring team participants to be able to conduct safe marine surveys under their program.

The second portion of the program was to survey ten of the BioRAP sites and to include 4 locations within the Port of Refuge Harbour. Table 2 below shows the list of marine surveyors during the ecosystem health monitoring. Water quality monitoring was also conducted to assess the sediment, nitrate and phosphate levels of the Harbour waters. PH levels, temperature and electrical conductivity were recorded at the Harbour sites and Lotuma island located on the channel entrance to the Harbour.

The monitoring methods used were those standardised through the Department of Environment, that are based on global coral reef ecosystems monitoring programs. For each of the selected scuba diving sites 3 replicate transects of 20 meters were placed at depths of between 12 and 14 meters for the reef crest areas and the shallower reef transects were placed between four and six meters. Snorkel sites were also monitored at depths between two and four meters at selected sites in the Port of Refuge Harbour and Vaipua Bridge.

Table 1. Below Shows The List Of The Monitoring Team Personnel And Their Relative Government Ministries And Organisations

Name	Organisation	Survey Area
Lupe Matoto	MEIDECC	Fish
Siosina Katoa	MEIDECC	Coral
Sulieti Hufanga	MEIDECC	Invertebrates
Penikoni Aleamotu'a	MEIDECC	Coral /Water Quality Technician
Senituli Finau	MEIDECC	Fish and invertebrates
Ta'hirih Hokafonu	MEIDECC	Snorkel
Mataitini Tupou	MEIDECC	Invertebrate
Tu'amelie Fusimalohi	MEIDECC	Invertebrate
Uikelotu Valu	MEIDECC	Corals and fish
Karen Stone	VEPA	Corals, fish and invertebrate

2.1 Coral health and coral cover

The method used for coral health and coral cover is the standardised Point Intercept Transect (PIT) method, where the surveyor record the benthos directly under the survey tape at each half meter intervals along the 20 meter transect tape. Records were marked onto underwater survey paper using a mechanical pencil.

Table 2 below shows the codes set by the Department of Environment, 2016 were used for the identification of benthos. Internal training of coral survey methods were conducted for the R2R participants prior to the monitoring Programme including benthos.

Table 2. Displays The Codes Used To For The Bentos Surveys During The Ecosystem Monitoring Program

Code	Category	Code	Category
CT	Coral Tabulate	AA	Algal Assemblage
OT	Others	HA	Halimeda
CD	Coral Digitate	MA	Macroalgae
CS	Coral Submassive	SC	Soft Coral
CB	Coral Branching	DC	Dead Coral
CM	Coral Massive	DCA	Dead Coral with Algae
CE	Coral Encrusting	TA	Turf Algae
CF	Coral Foliose	CR	Coral Rubble
CMU	Mushroom Coral	SD	Sand
CME	Fire Coral	R (RK)	Rubble
CTU	Organ Pipe Coral	CYB	Cyano Bacteria
CHL	Blue Coral	RKC	Recently Killed Coral
SP	Sponge	SI	Silt
ZO	Zoanthid	RK	Rock
CA	Coraline Algae		

Observations were also made at each site on the impacts of pollution and waste, coral damage, siltation and sedimentation, indications of bleaching and diseases or discarded fishing gear.

Coral reef areas were also categorised as to how much impacts the area was susceptible from wind driven waves and ocean swells and currents as well as to drop off versus fringing reefs as shown in Table 3 below

Table 3. Defines The Reef Categories That Determine The Impacts That The Survey Sites Are Susceptible To Swells As Included In The Biorap 2014.

Category	Description
SR	Sheltered reef
ME	Moderately exposed
LD	Limestone dropoff
ER	Exposed reef

2.2 Marine Reef Fishes

For recording marine fishes, belt transects of five meters either side of the transects tape are included and only fishes that are directly in front or to the side are included, fishes that swim or enter from the area behind the surveyor are not recorded. Only fish over 5 cm in length were recorded and only those that were swimming above the corals.

For marine reef fishes, fishes were identified along the transects lines to family level unless genus and species were known. Fish families identified in either English or Tongan were recorded on underwater paper and slate with a pencil, the recorder also noted the abundance of the family along the transects.

2.3 Marine Invertebrates

Marine invertebrate species were identified through the use of the invertebrate identification charts from Pacific Communities in Fiji as shown in Appendix 2.

Marine invertebrates included within in this survey were Gastropoda, Holothuridae (sea cucumbers), Arcidae (giant clams), Crinoidae (sea stars and feather stars) and Crustacea (lobster and crabs).

Species such as the sea urchin from the genus Diadema sp. are indicators of coral reef health and abundance was noted on all transects. Echinoderms, star fish, the Crown of Thorns (COTS) starfish is a predatory starfish that can also be an indicator of ecosystem stress and observations were noted during the survey.

2.4 Water Quality Monitoring

Water quality monitoring of coastal marine waters has been implemented under the Integrated Water Resource Management and Integrated Water and Coastal Management programs for Vava'u and is deemed an insightful data repository to monitor land based erosion and infiltration of sediments and excessive nitrates and phosphates to coastal waters.

Under this monitoring program, replicate water quality collections were conducted and analysed for the harbour areas around the Port of Refuge and "Old Harbour" as well as the coastal waters adjacent to the landfill "kalaka".

3.0 Results

The following results are based upon the data collected and provided by surveyors and each section clarifies the findings in relation to the data. Further analysis is offered in the discussion section found on page 17.

3.1.1 Reef Categories

As with the initial 27 sites from the BioRap, 2014, the reefs were categorised for the reef type and exposure. Sheltered reefs (SR) are located within the refuge of the limestone islands of Vava'u and have little to no impacts from surge, two sites previously categorised are site seven and eight, A'a and 'Oto which are limestone drop offs located in the centre of the Vava'u Archipelago. Outer sites such as 'Eueiki, Euakafa and the further islands are considered as moderately exposed to swell and wind driven waves. Fonua'one'one and Fangasito are exposed to the south where the predominant trade winds and swells come from.

In addition to the ten resampled BioRap sites, four Port of Refuge Harbour sites were incorporated into the monitoring. These sites are all extremely sheltered with little to no exposure. Snorkel sites that were conducted by team members are indicated with an S before the site number. The complete list of sites is shown in Table 4 below.

Table 4. List of survey sites conducted under the ecosystems health monitoring program 2016

Site Number	Site Name	GPS Locations	Category
1	Muikilekila	-18.65189°S -173.98535°W	SR
2	Toula	-18.66948°S -173.98799°W	SR
3	Utulei	-18.66930°S -173.98799°W	SR
4	Ava-lahi Talau	-18.65860°S -173.98267°W	SR
5	Lotuma	-18.649375°S -173.98267°W	SR
6	Vaka'eitu	-18.722934°S -174.105502°W	ME
7	A'a	-18.73097°S -173.98267°W	LD
8	Oto	-18.70158°S -173.98267°W	LD
9	Euakafa	-18.64087°S -173.00514°W	ME
10	Eueiki	-18.763506°S -174.020096°W	ME
11	Maninita	-18.855649°S -173.999091°W	ME

12	Taula	-18.844994°S -174.009434°W	ME
13	Fonua'one'one	-18.816105°S -174.063093°W	ER
14	Fangasito	-18.817140°S -174.078459°W	ER
S1	Fangapoa	-18.657914°S -173.981067°W	SR
S2	Palataisi	-15.661604°S -173.981018°W	SR
S3	Main Uafu	-18.651597°S -173.986468°W	SR
S4	Puataukanave	-18.654034°S -173.982645°W	SR
S5	Vaipua 1	-18.643844°S -173.994664°W	SR
S6	Vaipua 2	-18.644860°S -173.996535°W	SR

3.1.2 Coral Health and Coral Cover

Coral health and the benthos of the coral reef, creates habitats suitable for a range in fish species and sizes. Figure 1 below shows the percentage of hard coral cover at each site surveyed.

Site six at Vaka'eitu had the highest percentage of hard coral cover at 92% as well as site four at the entrance to the Port of Refuge harbour with 78% hard coral cover.

Figure 1 Graph showing the percentage of hard coral cover at each survey site

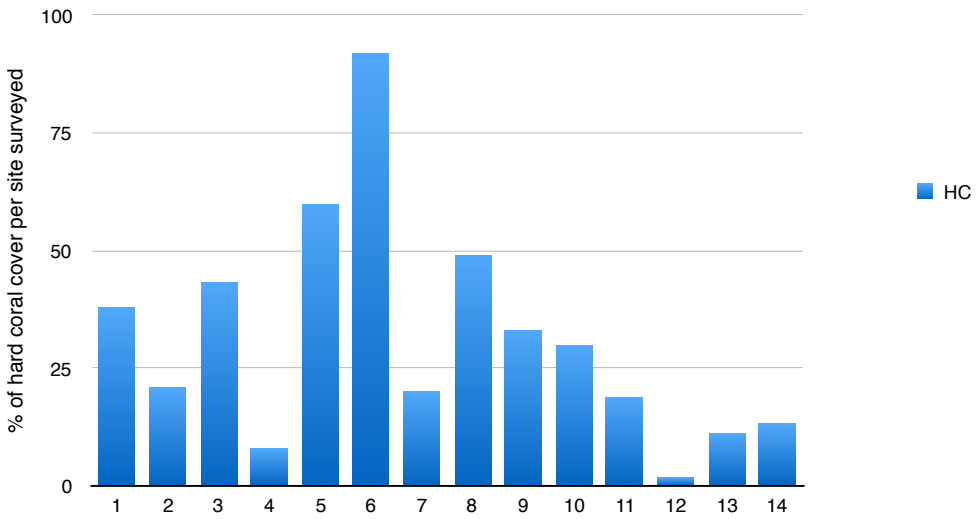


Figure 2 and 3 below below shows the percentages for benthos. over the fourteen sites surveyed on scuba diving. The first figure represents data at represents coral cover at depths of between twelve and eighteen meters and Figure 2 represents the coral cover and benthos at shallower depths of between four and six meters and represents coral cover at depths of between twelve and eighteen meters. Four outer island surveys were only conducted at the depth of twelve meters due to large south-westerly swells prohibiting surveys conducted in shallower waters of six meters.

Sites seven and eight are limestone drop off's which generally have less coral cover than flat and fringing reefs, site eight was recorded as 50% rubble (RB) and 50% dead coral (DC) at the shallower depth of 5 meters.

Site nine at 'Eueiki, had high levels of turf algae, with cover at 61% at the 12 meter depth. During the BioRAP, 'Eueiki suffered a severe bleaching episode and coral mortality was recorded.

Site six at Vaka'eitu had the highest hard coral cover with 92% and as well as site four at the entrance to the harbour which presented with 78% hard coral cover at six meters.

Figure 2. Percentage of coral reef benthos at a depth of 12m

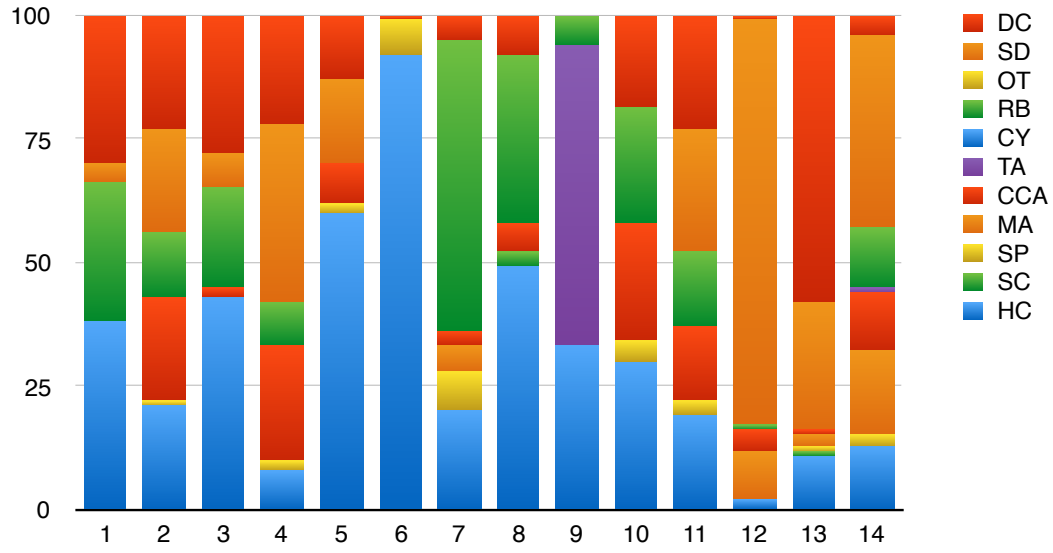
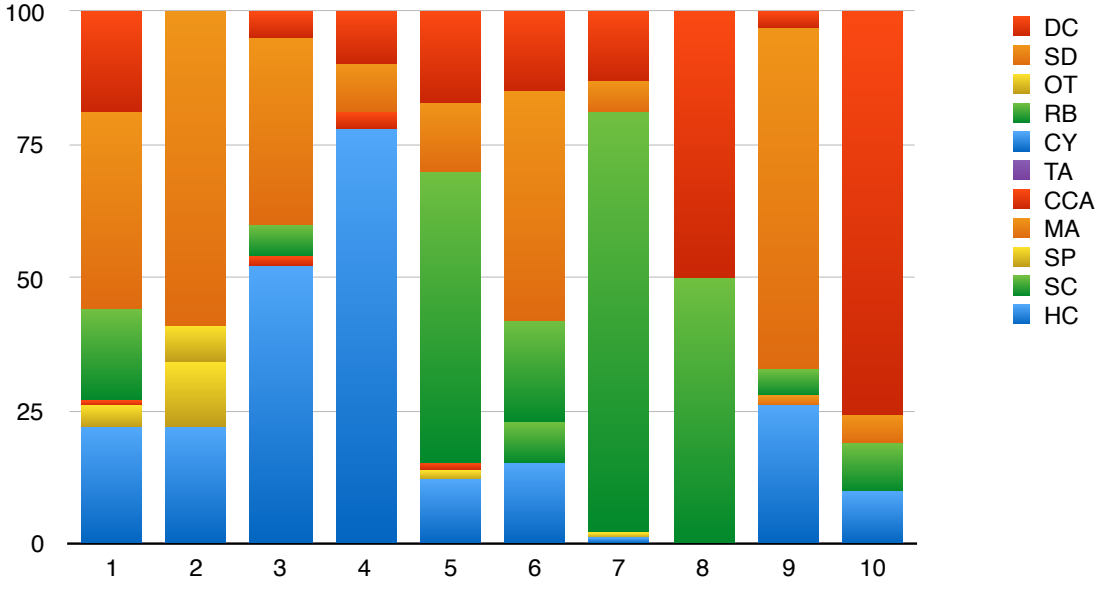


Figure 3. Percentage of coral reef benthos at a depth of 6m



3.1.3 Reef Health

During the surveys, there was no evidence of bleaching events, this was a concern prior to the surveys where coastal water temperatures had peaked at 31°C, 3°C over the threshold for zooxanthellae, the symbiotic algae. When stressed zooxanthellae is released from the corals, leaving behind a white skeleton. Bleaching had been recorded previously in 2014 and 2015. However due to Tropical Cyclone Winston in February 2016, marine water temperatures dropped by 4°C to 27°C, which is within the corals temperature threshold.

Crown-of-Thorns (COTS), are a destructive predatory starfish that is able to decimate coral reef areas by feeding on coral polyps. COTS individuals were recorded on three sites namely Utulei, 'Oto and Fonua'one'one. Despite only a few individuals being recorded, COTS scars were recorded on seven of the sites, with fewer scarring being noticed on the sites located outside of enclosed waters, apart from the site 13 on Fonua'one'one where large damage from a single COTS was recorded and is shown in Figure 4 below.

Figure 4. Displays a Single Crown of Thorns Found on Fonua'one'one (Site 13)

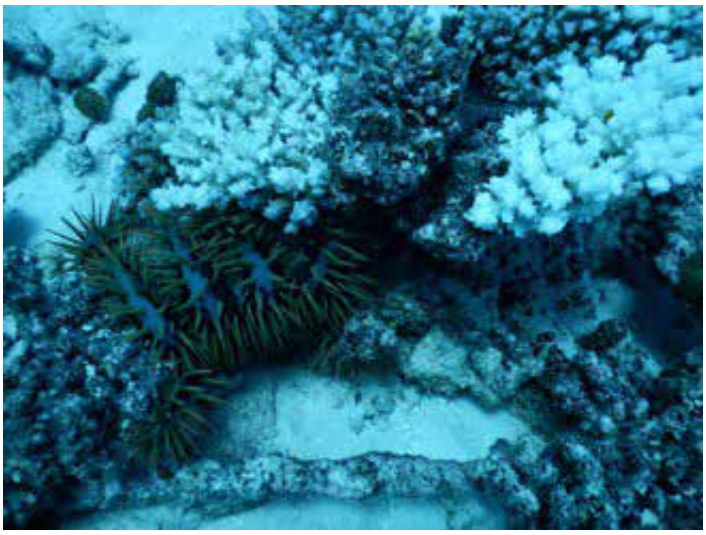
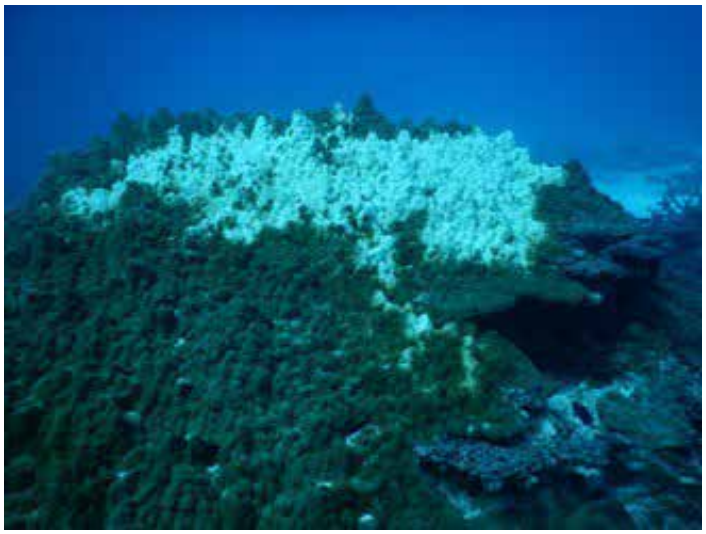


Figure 5. Damage to Porites Sp. from Crown Of Thorns



Within the harbour areas, rubbish such as bottles, cans and plastic bottles were noted as well as a few lost fishing nets that were lying over corals. The urchin Diadema sp. can indicate reef disturbance (BioRAP,

2014), in the four sites located within the Neiafu harbour, there was large abundance of Diadema urchins, suggesting that the reefs are in poorer condition. Coral cover results also indicated on sites one and two, with low coral cover percentages at both depths of 12m and 4m.

3.2 Reef Fish Composition

Reef fish were recorded by family groups to give an overview of the composition of reef fishes within each survey area. Thirty one fish families were identified during the monitoring program. The most common families of fish recorded were damselfish (Pomacentridae) and wrasses (Labridae), with sightings in higher abundance of damselfish than any other family. These smaller fish species can become dominant on coral reef habitats when there is a lack of predatory species such as groupers (Serranidae), snappers (Lutjanidae) and emperor fish (Lethrinidae).

The pie chart below in Figure 6 shows the overall primary dietary composition of all fish families identified during the survey. Fish dietary groups were extracted from Fishbase (FishBase 2016). Figure 7 shows the primary dietary composition of fish families at the depth of 12 meters for over the 14 sites.

Figure 6. Shows the Primary Dietary Composition of the Fish Families Identified During the Ecosystem Health Monitoring

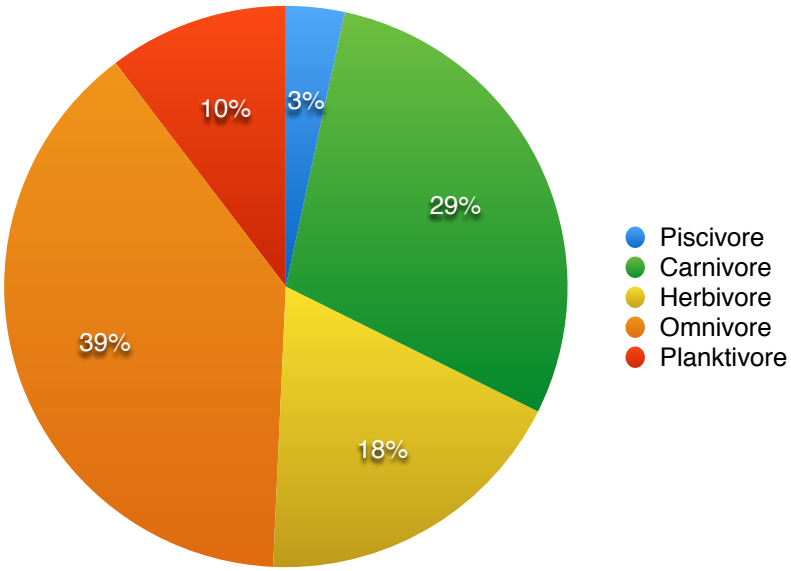
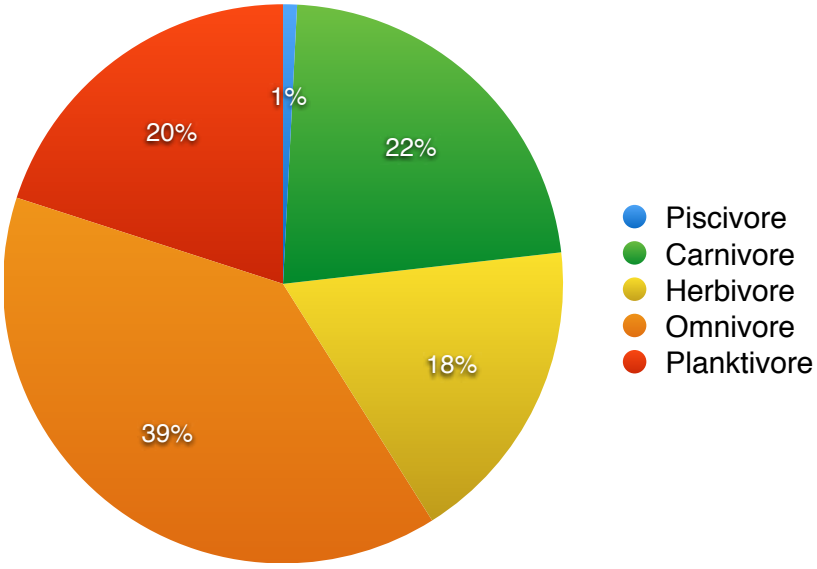


Figure 7Shows An Overview Of The Fin Fish Dietary Composition For All Sites Surveyed At The Depth Of 12 Meters



3.3 Marine Invertebrates

Marine invertebrates are a wide ranging taxonomic group covering a wide range of species that play essential roles in ecosystem health and resilience. Under this survey, Gastropoda (snails and slugs), Holothuridae (sea cucumbers), Arcidae (giant clams), Crinoidae (sea stars and feather stars) and Crustacea (lobster and crabs).

During the surveys, low numbers of sea cucumbers were identified on the transects, with the highest abundances being of the species *Holothuria edulis* (Pinkfish) and *Holothuria atra* (Lollyfish), both of these species were seen on 5 out of the 14 dive sites but in low numbers with the average of 2 per site except site 1 and site 8, where the *Holothuria edelis* was recorded as abundance of 22 per site.

The sea cucumber species, *Stichopus chloronotus*, Greefish, was not seen on any of the transects conducted during the 14 sites. A single, *Holothuria fuscogilva* (White Teatfish) and *Holothuria fuscopunctata* (Elephant Trunkfish) and *Thelenota ananas*, (Pineapple sea cucumber) were recorded during the transects, showing low abundance of these species.

The Diadema spp. urchin was recorded in high abundance on sites 1 and 2 within the Neiafu harbour, Diadema spp. are an indicator of reef health. The presence of urchin species aids the reef in managing algae growth as they are herbivorous by dietary group, however if the predatory species of omnivores are overfished and increased nutrient pollution occurs, urchin species such as Diadema spp. take over coral reef areas and lead to unsustainable bio erosion. (IUCN 2006)

Three individual Crown-of-Thorns (COTS) were identified during the survey on sites four, eight and thirteen. The predatory starfish feeds on healthy corals especially Accropora sp, however will also feed upon large massive corals such as Porites spp. when other healthy corals are not present. There were no records of the main predator species to COTS of Triton Trumpet shells (*Charonia tritonis*).

Giant clams from the family Arcidae, were also in low abundance with only 10 individuals seen during the 14 surveyed sites.

The Blue starfish (*Linckia laevigata*) was recorded on eight out of the 14 sites with higher abundance of individuals on sites three and four in the Neiafu harbour.

There were no sightings of any lobsters during the surveys, however lobsters are a cryptic species that are more commonly observed at night.

3.4 Water Quality Analysis

Water quality measurements can be used to assist in the observations of potential coral reef ecosystem issues through land based activities. Nitrates and phosphates commonly enter the coastal waters after heavy rain periods with the increased sedimentation. Water quality tests were not conducted on the outer island survey sites, due to less occurrence of farming and run off of land based activities and less sedimentation in the water column.

The following results show both the levels of nitrates and phosphates as well as the results of electrical conductivity and pH, which is used to assess the acidity of the oceans.

Sites one through four are based at the landfill and have leachate ponds designed to reduce nitrates and phosphates from entering the mangroves and coastal waters adjacent to the landfill.

Number	Site Name	Date & Time on-site tests & Sample collection	G.P.S Locations Longitude - Latitude -		Electrical conductivity (µS/cm)		Temperature (°C)		pH	Turbidity tube (cm)	Secchi Disk (m)
					ECTestr11	Solinst TLC	ECTestr11	Solinst TLC			
1	Kalaka Lagoon 1	24/02/2016 1:05	Nil.	Nil.	0	47.4	29.5	29.5	8.2	Nil.	Nil.
2	Pond 1	24/02/2016 1:15	Nil.	Nil.	8.40	14.3	30.2	30.1	8.90	Nil.	Nil.
3	Pond 2	24/02/2016 1:25	Nil.	Nil.	18.70	29.7	30.0	30.0	9.01	Nil.	Nil.
4	Pond 3	24/02/2016 1:36	Nil.	Nil.	13.10	20.3	30.1	30.0	8.66	Nil.	Nil.
5	Neiafu tahi wharf	25/02/2016 10:45	18.60729	173.93977	0	52.6	27.0	27.0	8.36	Nil.	Nil.
6	Neiafu tahi Government Primary School	25/02/2016 10:55	18.60729	173.93977	0	57.7	28.2	28.0	8.50	Nil.	Nil.
7	Beluga doc	26/02/2016 12:00	18.60729	173.93977	0	54.4	28.4	28.2	8.29	Nil.	Nil.
8	Pafilio doc	26/02/2016 11:45	18.60729	173.93977	0	53.6	28.2	28.2	8.25	Nil.	Nil.
9	Vepa outlet	26/02/2016 12:25	18.65340	173.98254	0	50.7	28.7	28.7	8.17	Nil.	Nil.
10	Public toilet outlet		Nil.	Nil.	Nil.	Nil.	Nil.	Nil.	Nil.	Nil.	Nil.
11	Fisheries outlet		Nil.	Nil.	Nil.	Nil.	Nil.	Nil.	Nil.	Nil.	Nil.
12	Leluma	3/3/2016 10:29	18.649375	173.99579	0	58.9	27.1	27.1	8.37	100+	7+
13	Avalahi	2/3/2016 11:29	18.65880	173.98257	0	58.7	58.7	27.2	8.33	100+	7+
14	Ululei	2/3/2016 12:12	18.98830	173.98257	0	46.7	27.5	27.5	8.31	100+	3+
15	Mukilakila	1/3/2016 11:29	18.65189	173.98535	0	58.5	27.5	27.5	8.35	100+	3+
16	Toula	1/3/2016 1:20	18.98948	173.98799	0	58.6	27.4	27.4	8.35	100+	3+
17	Ata	4/3/2016 12:12	18.70387	173.04102	0	59.0	27.0	27.0	8.38	100+	10+
18	Oto	4/3/2016 10:20	18.70158	173.05888	0	59.0	27.0	27.0	8.35	100+	10+
19	Ata	1/3/2016 12:12	18.98830	173.98257	0	56.7	27.7	27.7	8.40	100+	10+
20	Tuakata	5/3/2016 10:11	18.64087	173.00514	0	59.0	27.0	27.0	8.34	100+	10+
21	Tuaiki	5/3/2016 11:00	Nil.	Nil.	0	58.8	27.2	27.2	8.36	100+	10+
22	Vaipua	3/3/2016 4:30	Nil.	Nil.	0	57.6	28.8	28.6	8.49	100+	3+
23	Uni tap water	5/3/2016 6:00	Nil.	Nil.	3.40	4787	27.0	27.0	7.21	Nil.	Nil.
24	Uni Filter water	5/3/2016 6:00	Nil.	Nil.	40.0	23	27.4	27.4	6.40	Nil.	Nil.

Site Number	Description	Date & Time	Amonia (mg/L NH4)	Nitrate (mg/L NO3)	Phosphate (mg/L PO4)	Comments
1	Kalaka Lagoon 1	24/02/2016 7pm	0.00	0.000	0.10	
2	Pond 1	24/02/2016 7pm	0.36	0.000	0.31	
3	Pond 2	24/02/2016 7pm	0.20	0.000	0.07	
4	Pond 3	24/02/2016 7pm	0.00	0.046	0.16	
5	Neiafu tahi wharf	25/02/2016 6.55pm	0.01	0.013	0.05	
6	Neiafu tahi Government	25/02/2016 6.55pm	0.02	0.072	0.12	
7	Beluga doc	26/02/2016 7.30pm	0.01	0.124	0.14	
8	Pafilio doc	26/02/2016 7.30pm	0.02	0.107	0.08	
9	Vepa outlet	26/02/2016 7.30pm	0.02	0.313	0.06	

10	Public toilet outlet	25/2/2016 6.55pm	0.167	0.000	0.12	
11	Fisheries outlet	25/2/2016 6.55pm	0.168	0.000	0.49	
12	Lotuma	3/3/2016, 10.29pm	0.01	0.360	0.06	
13	Avalahi	2/3/2016, 11.29pm	0.01	0.043	0.00	
14	Utulei	2/3/2016, 12.12am	0.02	0.090	0.17	
15	Muikilekila	1/3/2016, 11.29pm	0.01	0.008	0.06	
16	Toula	1/3/2016, 1.20am	0.02	0.016	0.06	
17	A'a	4/3/2016, 12.12pm	NIL	NIL	NIL	No Sample
18	'Oto	4/3/2016, 10.20pm	NIL	NIL	NIL	No Sample
19	A'a	1/3/2016, 12.12pm	NIL	NIL	NIL	No Sample
20	'Euakafa	5/3/2016, 10.11pm	NIL	NIL	NIL	No Sample
21	'Euaiki	5/3/2016, 11.00pm	NIL	NIL	NIL	No Sample
22	Vaipua	3/3/2016, 4.30pm	0.00	0.000	0.06	

4.0 Discussion

Data collection of marine resources can be strongly supportive of marine management activitie ncluding assessing the need for larger scale protected areas and species protection. The following discusses an overview from the results found during this survey.

4.1 Reef Resilience

The reefs in Vava'u are under many pressures both through human activities such as pollution and overfishing and climate change based through increased ocean temperatures, ocean acidification and sea level rise. The term "resilience" applies to the habitats ability to "rebound or respond to pressures and to adapt to changes".

Resilience for coral reefs looks at the development of coral areas over a period of time to ensure that coral reefs are continuing to reestablish and rebound to change. This includes coral recruitment, which is the settlement of coral larvae onto substrate and develop into corals (IUCN 2009). Other factors for coral development include good water quality, conditioning by biological agents and a stable substratum for coral larval settlement. Negative influences such as land based run off and pollution, lack of coral larval supply rubble or unstable substratum and large areas of algal cover reduce the resilience of coral reefs. An area that is not currently included on marine monitoring for ecosystem health is coral recruitment, this is the ability to identify new corals <5cm in diameter developing on reef flats. On four survey sites of Maninita, Taula, Fonua'one'one and Fangasito, coral recruitment was included on the survey however on all transects on the sites, no coral recruitments were recorded.

Coral reefs need to continue to re-establish and regrow after natural disasters and climate events such as coral bleaching, where the ocean water temperatures have remained higher than the 28°C maximum threshold limit for coral development.

In order for coral areas to recover are grazers and herbivores from the families Acanthuridae (Surgeonfish) and Scaridae (Parrotfish). Overfishing pressure of herbivores, piscivores such as Lutjanidae (Snappers), Serranidae (Groupers) and Lethrinidae (Emperors) are also essential to balance out the trophic level and allow for predation of smaller fish species of Pomacentridae (Damselfish) and Labridae (Wrasses). If predation is not naturally occurring on coral reef areas, then the smaller fish species are able to take over the dynamics of the reef and this causes an increase in algae cover.

COTS have the ability to decimate large areas of healthy reef when there is a bloom or stressor such as pollution to the reef area. One of the natural predators of COTS is the Triton Trumpet Shell, *Charonia tritonis* have been heavily harvested due to their value as souvenir and decorative shell. There were no recordings of Triton Trumpets during this survey.

4.2 Reef Fish

As data was collected only to family level, assumptions on the trophic density and biomass of fish populations is not easy to determine. Instead dietary composition of fish species was analysed on the primary dietary function of the families.

As indicated in the results, the primary dietary group over all reefs was omnivoresat 39%, where as predatory piscivore species of Lutjanidae, Lethrinidae and Serranidae only constituted for 3% of the overall composition within the Vava'u sites. These results are in line with the low abundance and biomass of commercially targeted species recorded during the BioRAP, 2014.

4.3 Marine Invertebrates

Low abundances and species diversity of Holothuridae species, indicates a slow recovery from the pressures of the Bêchê-de-mer industry in Vava'u. Despite a five year ban on the collection of sea cucumbers for commercial exports in 2014, further surveys are needed annually to assess the stocks of sea cucumbers before the industry recommences.

The coral reefs of Vava'u, appear to be under a bloom of the predatory species of COTS, excessive damage to healthy coral reefs will continue to occur unless the COTS are managed by fishers, Government and NGO's. A reduction in eutrophication from land is necessary to reduce pollution based blooms.

4.4 Water Quality

Water quality is essential to many marine species especially photosynthesising species such as seagrass and corals and to filter feeders such as clams (vasuva) and other bivalve species.

Water quality monitoring parameters were taken from the Integrated Water and Coastal Management programme, water quality assessment as follows below (SOPAC, 2013):

Parameter	Instrument	Expected Results
EC	WPR-84 Water Quality Meter	
Depth to Water	Solinist	n/a
pH	WP-84 Water quality Meter	A ph range of 6.5 – 8 is optimal for freshwater. A range of 8 – 9 is optimal for estuarine and sea water.
Temp	DelAgua membrane filtration kit/Solinist	n/a
Dissolved Oxygen	Handhelp YSI Water Quality Meter	Estuaries 60 – 120 Marine 90 - 110
Turbidity	DelAgua membrane filtration kit	Excellent = 10 NTU's Fair 15-30 NTU's Poor > 30 NTU's
Bacteria (faecal coliforms)	DelAgua membrane filtration kit	Saltwater 104 CFUs per 100 ml Fresh water 61 CFUs per 100 ml
Ammonia	Palintest	– no guideline based on health; guideline based on odour and taste are 1.5 and 35mg/L respectively.
Phosphate	Palintest	As PO_4 Low < 0.06 Medium 0.06 – 0.15 High > 0.15 – 0.45 Very High > 0.45
Total Nitrogen /Nitrate	Hach Method/ Palintest	Total N Low < 0.5 (2.2) Medium 0.5 – 1.0 (4.4) High > 1.0 – 3.0 (13.2) Very High > 3
Co-ordinated and Mapping	Garmin GPS	n/a
Colour	Observation	n/a
Smell	Observation	n/a

The pH results indicated optimal values of between 8.0 and 9.0 for coastal marine waters, the use of the data from the pH range for coastal waters can be adapted as an indicator of ocean acidification, whereby, higher than normal acidic levels (i.e. lower pH numbers) are impacting upon calcium carbonate shells and corals.

The water quality results indicate that the main harbour of Neiafu (Sites 7 through 11) as having below normal levels for ammonia, nitrate and phosphate in accordance with international guidelines except for site 9, located near the VEPA office which had a nitrate level of 0.313mg/L and site 12 at Lotuma military island, which had a nitrate reading of 0.360mg/L. These may be due to run off and from fertiliser use.

Sample site number 11 at the Fisheries showed higher than optimal levels of phosphate with a reading of 0.49mg/L. Increased phosphate may be an indicator of leaching from septic systems.

High levels of phosphate and nitrate from eutrophication into coastal waters can trigger harmful algal blooms or "red tides", which can have long term impacts upon sessile marine species such as oysters, clams and other molluscs.

Ocean water temperatures recording during the survey were between 27.0°C and 28.7°C, the optimal ocean temperatures for coral reefs is between 18°C and 28°C, where sustained ocean temperature above 28°C can trigger coral bleaching. This is when the coral releases the symbiotic algae zooxanthellae and the coral is at risk of mortality which can cause considerable long term weakness and low resilience to coral reef habitats.

4.5 General

The use of indicator species can be broadened through both reef fish species and marine invertebrates, this data can be used to track issues and coral reef areas of low resilience to changes. Macro-algal shifts on coral reef areas are indicators of overfishing and nutrient overload and can be detrimental to coral reef recovery.

5.0 Conclusion

In an ever changing environment, consistent and effective monitoring plans and surveys are essential for management practices to be adapted and improved upon to increase marine resources and ecosystem resilience. Changes to connected habitats such as mangroves and sea grass areas are also vital to the overall health of corals. Increased sedimentation through land based run off and poorly executed and maintained coastal infrastructure are impacting upon coral reefs.

Programs for coastal planting need to be established to reduce the ability of nutrients to the coastal waters. This can be done through coastal management planning at district level and support community conservation programs such as the special managed areas under the Climate resilience Sector Programme (CRSP).

Attention needs to be furthered on long term sustainable infrastructure developments that adhere to coastal management planning recommendations including adequate drainage on road developments and improved connecting causeways and bridges that allow for critical tidal water flow exchanges.

The continual training of data collectors is essential for the refinement of data down to species and genus levels, this improves the ability to monitor the habitat health through dietary composition and species abundance and diversity to a much finer degree.

Marine temperature sensors could be researched and deployed for monitoring the ocean temperature changes more consistently and allowing for more consistent and widespread reporting of bleaching events.

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Appendices

Appendices 1: Reef Fish Families

Family	Tongan Name	Dietary Group	
Acanthuridae (Surgeonfish)	Ume/Pone/Manini	Herbivore	
Apogonidae (Cardinalfish)	Matapula	Planktivore	
Aulostomidae (Trumpetfish)		Carnivore	
Balistidae (Triggerfish)	Humu	Omnivore	
Belonidae (needlefish)	Haku	Piscivore	
Blennidae (Blennies)		Herbivore	
Caesionidae (Fusiliers)	Huli	Planktivore	
Caragnidae (Trevallies)	Lupo	Piscivore	
Carcharhinidae (Sharks)	Anga	Piscivore	
Chaetodontidae (Butterflyfish)	Sifisifi	Carnivore	
Clupeidae (Herrings)	Ava	Planktivore	
Echeneidae (Spadefish)		Omnivore	Benthic Inv. Feeder
Fistulariidae (Cornetfish)	Tota'o	Piscivore	
Gobiidae (Gobbies)		Carnivore	Benthic Inv. Feeder
Haemulidae (Sweetlips)		Carnivore	Benthic Inv. Feeder
Holocentridae (Squirrelfish)	Ta'a/Telekihi	Carnivore	Benthic Inv. Feeder
Labridae (Wrasse)	Ufu/Meai	Carnivore	Benthic Inv. Feeder
Lethrinidae (Emperor fish	Tanutanu	Carnivore	

Family	Tongan Name	Dietary Group	
Lutjanidae (Snapper)	Fate	Carnivore	
Muglidae (Mullets)	Unomoa	Herbivore	
Mullidae (Goatfish)	Vete	Carnivore	Benthic Inv. Feeder
Muraenidae (Moray)	Toke	Carnivore	
Pomacanthidae (Angelfish)	Angelo	Carnivore	
Pomacentridae (Damselfish)	Tukuku/Tikuku (hiku enga)	Omnivore	
Scarridae (Parrotfish)	Hohomo	Herbivore	
Serranidae (Grouper)	Ngatala	Piscivore	
Siganidae (Rabbitfish)	Ö/Ma'ava	Herbivore	
Synodontidae (lizzardfish)	Mohe'aho	Piscivore	
Tetradontidae (Pufferfish)		Carnivore	Benthic carnivore
Theraponidae (Grunters)			
Zanclidae (Moorish Idol)		Carnivore	

Appendices 2: Marine Invertebrates

Family	Species	Common Name	Tongan Name
Acanthasteridae	*Acanthaster planci*	COTS	Alamea
Arcidae	*Tridacna maxima*		Kukuku
Arcidae	*Tridacna sp.*	Giant Clam	Vasuva
Comasteridae	*Comaster nobilis*	Crinoids	
Cypraeidae	*Cypraea tigris*	Tiger Cowrie	Pule maka
Diadematidae	*Diademe setosum*		Vana'uli
Diogenidae	*Dardanus spp.*	Hermit Crab	
Holothuria	*Bohadschia argus*	Leopardfish	Matamata
Holothuria	*Holothuria fuscogilva*	White Teatfish	Huhuvalu hinehina
Holothuria	*Holothuria fuscopunctata*	Elephant trunkfish	Elefanite
Holothuria	*Holothuria atra*	Reef lollyfish	Loli
Holothuria	*Holothuria edulis*	Pinkfish	Loli pingiki
Holothuria	*Stichopus chloronotus*	Greenfish	Holomumu
Holothuria	*Stichopus hermani*	Brown curryfish	Lome
Muricidae	*Chicoreus ramosus*	Snail	Potupatu
Muricidae	*Drupella spp*		
Ophidiasteridae	*Linckia laevigata*	Blue starfish	
Oreasteridae	*Choriaster granulatus*	Pink starfish	
Oreasteridae	*Culcita novaeguineae*	Pin cushion starfish	
Parasaleniidae	*Parasalenia gratiosa*	Urchin	
Phyllidiidae	*Phyllidia sp.*	Nudibranch	
Spondylidae	*Spondyllus squamosus*	Thorny Oyster	Fai'ahu
Spondylidae	*Spondylus sp.*	Oyster clam	
Strombidae	*Lambis spp.*	Spider Conch	
Thelenota	*Thelenota ananas*	Prickly Redfish	Pulukalia
Thelenota	*Thelenota anax*	Carpet Cucumber	Mokohunu saianiti
Toxopneustidae	*Tripneustes grattilla*		Tukumisi
Trochidae	*Trochus niliticus*		Takaniko