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Rapid Assessment of Priority Coastal Area and Lagoon of Muri Catchment, Rarotonga, Cook Islands

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Rapid Assessment of Priority Coastal Area and Lagoon of Muri Catchment, Rarotonga, Cook Islands

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CONTENTS

ABBREVIATIONS

EGS	Ecosystem goods and services
ICI	Infrastructure Cook Islands
IW	International Waters
LIT	Line Intercept Transect
MMR	Ministry of Marine Resources
MTVKTV	Mei Te Vai Ki Te Vai
NES	National Environment Services
NGO	Non-governmental organisation
PVC	Polyvinyl chloride
R2R	Ridge to Reef
RapCA	Rapid Assessment of Priority Coastal Areas
UVC	Universal Visual Census
SPC	Pacific Community
TTV	To Tatou Vai

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

This is the first rapid assessment of a priority coastal area (RapCA) study conducted for the Muri lagoon. Issues with water quality in the lagoon date back to at least 1992 (Holden 1992) when high dissolved oxygen levels were noted, and further investigation was recommended. The Infrastructure Cook Islands commissioned the RapCA study to carry out an ecological assessment of the Muri lagoon and adjacent reef. The assessment also extends to conducting a community fishing survey, all aiming to establish baselines for the relevant biological/ecological indicators related to the marine habitats and resources, environmental indicators on water quality, as well as the socio-economic indicators on resource use and governance.

Much research has been done to evaluate the current flows and physical properties of the Muri lagoon[1]. In contrast, very little research or monitoring has been done on the ecological environment however Muri has been part of wider studies to investigate specific elements of the environment (Scoffin et al. 1985, N'Yeurt 1999, Džeroski and Drumm 2003, Drumm 2005, McCue et al. 2018)

There is no previous data specific to the state of habitats and resources to compare and to inform policy decisions. It is therefore difficult to assess positive or negative trends temporally and spatially as well as ascertaining environmental quality. However, spatial comparison is possible and there are globally acceptable standards established as guidelines to assist in assessing status of biodiversity and water quality. For instance, estimates of abundance generated from reef surveys in the Muri lagoon are consistent with surveys on similar environments elsewhere in the country.

The RapCA study carried out marine surveys in 34 sites inside the lagoon and 8 sites on the reef slope adjacent to the Avana passage. The surveys and data collection conform to the sampling design and protocols established for purposes of this study, and align with what is used by SPC in other R2R project participating countries. There are 22 indicators agreed by R2R projects covering ecological/ biological, environment, socio-economic and traditional ecological knowledge, governance, and administrations. This study focuses on collecting baselines for indicators relevant to establishing the current state of the marine environment (pollution, coliforms, nutrient offloads), habitats (current state and cover for corals, algae, sand/rubble, etc.), resources (fish/ invertebrates), and resource use (fishing pressure, consumption, etc.).

Below are the highlights and key results on the current state of the marine environment, habitats, resources, and exploitation.

i. 148 species were identified by the survey;

ii. Benthic data for the lagoon is dominated by either algae or sand. These could be used as an empirical measure of lagoon health but would require further correlation and investigation (McCue et al. 2018).

iii. Normal to high levels of coral cover (33% to 62%) indicate a healthy reef. While coral was not identified to the species level growth form, data indicates diversity of corals at genus level including *Acropora* sp*, Pocillopora* sp. *Porites* sp. and others.

iv. Holothurians (sea cucumbers) dominate the lagoon, while juvenile corals dominate the reef. Juvenile coral abundance in the lagoon is relatively high.

v. On the basis of ten community fishing survey respondents, most fish caught are pelagic, though about half the respondents still engage in fishing for invertebrates on the reef,

[1] These include the following studies: (Carter 1984, Holden 1992, Collins 1995, McCue et al. 2018)

although only for personal consumption. Fishing is a regular activity and supports the partial dietary requirements of their family and friends' network as well as buyers. The study found that men were more involved in fishing within the Muri lagoon and deep-sea area than women. Women were minimally engaged in fishing activities and were more engaged in post-harvest activities.

vi. The literature review found that Muri is a highly studied area for currents and physical parameters but understudied for ecological and environmental monitoring.

vii. Despite several recent reports, there remains no overall coordination for research and reporting conducted in this or other environments of the Cook Islands.

This report recommends the following:

i. The establishment of a research coordination unit for Muri and possibly other sites of national interest to ensure coordination of work, centralisation of reporting and commissioning of the appropriate work required to inform decision making.

ii. Considering the sensitivity of the ecology of the lagoon to changes in physical and chemical parameters, a long-term monitoring programme would be considered a standard way to assess change over time.

SECTION 1.

COASTAL AND FISHERIES HABITAT HEALTH SURVEYS – INDICATOR E3 HABITAT QUALITY

Introduction

Description of pilot site

Rarotonga is a volcanic island with a maximum elevation of 640 m where a fringing reef lies between 100 m and 600 m offshore. Coral reef cover is seen over the reef flats. In the southeast of Rarotonga there are three islands known as Koromiri, Motutapu and Oneroa, which are subject to the direct effects of the Southeast Trade Winds. Muri lagoon lies within these islands where two streams drain into the lagoon: Avana stream and Parengaru stream. Due to the variations in the flow of these streams, salinity varies, which may affect the biodiversity and is a crucial part of the ridge to reef continuum in Rarotonga.

Policies and legislation

The study site is predominantly a raui, a type of traditional marine protected area. Limited local harvesting does take place, particularly of traditional delicacies such as the patito, a small sea hare that has an annual season. However, there is no regular harvesting in the area for sustenance.

National plans

With the growing realities of climate change, sea level rise, the vulnerability to cyclones and other hosts of environmental impacts, the Cook Islands has put much effort into resilience. The formulation of disaster risk management plans and climate change adaptation strategies are now becoming synonymous agendas when it comes to national planning.

The government has also provided incentives for businesses in the private sector for employing renewable energy schemes. However, there is no incentive now for disaster risk management (Carlson 2012).

Lastly, there has not been significant moves by the government to show commitment towards its Disaster Emergency Trust Fund. This fund had a goal of NZD500,000 in 2010 and may have increased to date. In addition to this, there is a need for more accountability regarding government's expenditure toward disaster risk reduction. This would ensure that donor agencies know how funds are being used and for the desired purpose.

Purpose

The regional Ridge to Reef (R2R) International Waters (IW) programme aims to conduct fieldwork, collect relevant baseline data on the 22 indicators representing ecosystems goods and services (EGS) across land-sea continuum. The baselines and related information serve to establish a clear picture of the current state of Muri lagoon and better understanding of the broader Muri Catchment land-sea connectivity regarding EGS.

This study also reports on the various ecological and environmental parameters required to inform policy discussion and decisions for these areas. The Rapid Coastal Assessment toolbox is being implemented at all IW R2R demonstration project sites regionally, including the Cook Islands.

Within the Cook Islands context, this work is focused on the Muri Catchments and the adjacent coastal and lagoon/marine areas. The Muri lagoon has been a site of particularly high interest because of the chronic environmental degradation due to agriculture, tourism related activities and poor infrastructure drainage being observed in the lagoon. The adjacent coast has undergone significant development over the past 30 years to become a key resort and tourism location.

This study is specifically aimed at examining the ecological state of the lagoon and the reef adjacent to the main drainage passage.

All R2R work and studies undertaken under this regional programme has a Gender and Social Inclusion strategy, which ensures the inclusion of men, women, youth, and all other vulnerable members of communities. This allows for a gender analysis of work undertaken and the collection of sex-disaggregated data and the inclusion of men, women, youth, and other community members in all stages of the projects. Gendered information help in planning management to be implemented and the potential roles of men, women, youth, and other vulnerable members of communities in any such R2R management interventions.

Methodology

The Study Area

The rapid coastal assessment methods have been adapted from the regional guidelines of the Pacific Regional Ridge to Reef project, Rapid Assessment of Priority Coastal Areas (RapCA) (Secretariat of the Pacific Community) to fit the specific criteria for the Muri coastal lagoon. Several constraints led to the focus of this study on the marine environment, eliminating the terrestrial and stream surveys detailed in the regional guidelines. This occurred in part because of recent in-depth studies of surface water quality including freshwater surface and groundwater flow in the Muri lagoon catchment areas (Fig. 1).

The study area as defined in the tender document was the Muri lagoon from Avana stream to Parengaru stream. After further consultation with the Regional Project Office scientists, the methods and scope were changed somewhat to include sites on the outer reef proximate to the study location.

Forty-two (42) sites were identified, and the same methodology applied at each site to provide the data necessary to both fulfil the local research needs and to feed into the regional model being developed. The sites have been selected to represent a gradient working away from the stream outflows out to the back-reef environment. Of the 42 sites, only 34 were selected within the Muri lagoon catchment area extending from Parengaru stream in the south, to Avana stream in the north, and 8 sites on the outer reef slope immediately east of the study area on either side of Avana passage (Fig. 2).

Sites A1 to A5 are adjacent to Parengaru stream and sites G1 to G5 are adjacent to Avana stream. Sites from H1 to K2 are located on the outer reef slope, on either side of the Avana passage outflow. Four (4) sites are near the outer passage, and 4 sites (2 either side) are located about 1 km away from the centre of the passage. All other sites are generally placed to give even coverage of the lagoon study environment and to provide controls for the stream sites.

When selecting sites in the lagoon, benthic composition was not a consideration. For this study, given most of the lagoon floor is sandy with patch reef and intermittent coral bommies, wide coverage of the area was the preferred method for site dispersal. Previous regional RapCA studies have focused on hard reef substrate only and used specific indicators from these environments to assess watershed impacts. The Muri lagoon is a much smaller and shallower area than the other regional sites and therefore a different methodology for site selection had to be considered.

Eight (8) target sites on the outer reef fall outside the strict boundaries of the study area but were selected as reference or control to the target sites as well as to give some comparable data for hard reef sites surveyed in other areas. This is applicable directly to the Muri lagoon as the Avana passage drains 100% of the flow from all streams in the study area. Therefore, impacts by freshwater discharge and sediment on the outer reef from the study site will occur in the vicinity of the Avana passage.

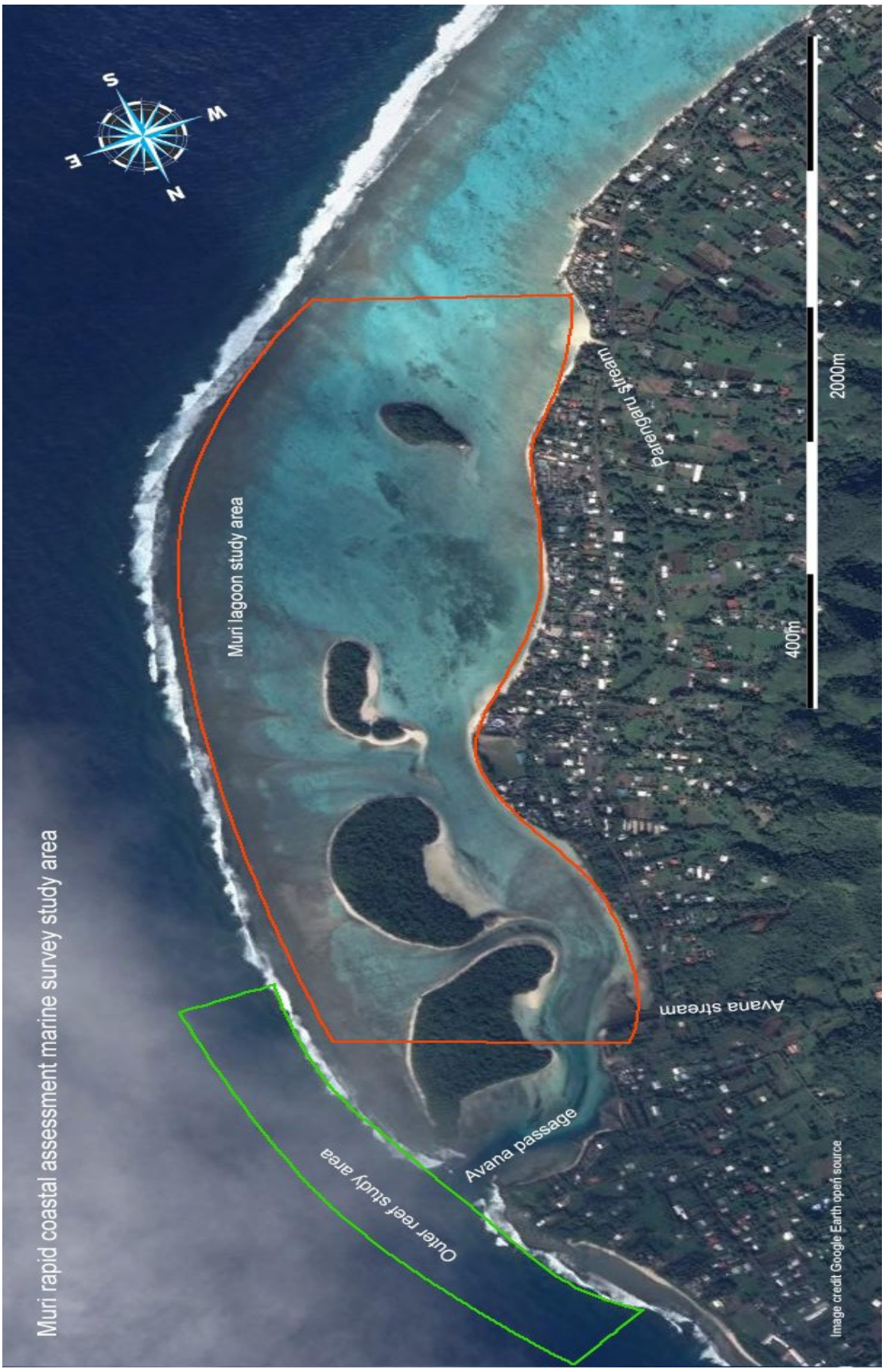

Figure 1: General layout of the Muri RapCA study areas

Figure 2: Specific survey locations and labels

Study Site

Muri lagoon is generally shallow with patchy hard bottom substrates. Taking this into consideration, the sampling design called for more sites than replicate transects to strengthen comparability between study sites and habitat types. The methods employed were taken from the survey protocols developed and targeted in reef dominated habitats in depth ranges down to 25 m.

The Muri lagoon environment differs from the usual areas of study in that it is not a predominantly coral reef environment. Rather, it is a shallow (<1.5 m) fringing lagoon typically representative of sandy flats with intermittent coral bommie formations known as patch reefs. The back reef area is predominantly coral and is very shallow (<1 m). While the dataset generated is an accurate snapshot of the current ecology of the Muri lagoon, it is less applicable for comparison between other RapCA sites where reef slopes have been surveyed at depth. For that purpose, the sites on the outer reef have been included to provide a dataset like those of other sites.

Each site had a single 25 m transect run parallel to the shore and reef crest, following an approximate depth contour. Sets of data were collected at each site along with a photographic record of a typical quadrat and a sediment sample (where appropriate).

The metrics gathered at each site align with the regional protocols developed (R2R) and published by the Pacific Community (SPC) (Labrosse et al. 2002). These methods are common methods derived from the Survey Manual for Tropical Marine Resources. For the purposes of this research the reference for the field methodology is the Survey Manual for Tropical Marine Resources (English et al. 1997).

General site data

Each survey began with the recording of general data for the site. This data is collected as a standard procedure in the event information needs to be correlated against any environmental factors. The general data collected, and the methods of those collections are given in Table 1.

Table 1: General site data and methods

Site number	Allocated at the time of survey, in numerical order of the sites surveyed.
Date/time	Recorded.
Depth	Measured using a tape measure for all lagoon sites, and with a dive computer for outer reef sites.
Bearing	The bearing of the transect taken using a compass.
Latitude and Longitude	Recorded off GPS app.
Cloud cover	Visual estimate.
Wind	Estimate correlated to weather reports.
Sea state	Visually assessed.
Temperature	Handheld field thermometer.
Salinity	Handheld field salinity refractor.
Visibility	Secchi disc run horizontally on or near the surface.

Ecological Indicators: E1 Diversity and E2 Abundance Fish diversity

Fish diversity and abundance was measured using the Universal Visual Census (UVC) method as prescribed in the Survey Manual for Tropical Marine Resources, and in accordance with the method presented by the Secretariat of the Pacific Community – Underwater Visual Fish Census Surveys (Labrosse et al. 2002).

The 25 m transect was laid out at the beginning of the site setup. Following that, the other observational data was recorded, and time was given for fish behaviour to normalise following the swimming out of the transect line. The time taken was about 20 min. The transect was then swum by one dedicated observer. The observer paused every 3 m to 4 m and identified and counted the fish 2 m on either side of the transect, and to a height of 1 m above the transect. Where the depth was shallower than 1 m, the observations were taken from the surface to the floor.

The total area surveyed was 100 m^2 (25 m x 4 m x 1 m). To derive fish density in biomass per m^2 of the total area surveyed, the total assessed biomass per species is divided by 100.

Where a site had a shallow depth of more than 1 m the corresponding unique total area was calculated using the formula 25 m x 4 m x depth (m). The fish biomass was then divided by that number to give the biomass per m^2.

E3 Habitat Quality Benthic cover including Coral cover and Algal cover - Line Intercept Transect

A dedicated observer swam the 25 m transect following on from the UVC so as not to disturb the fish count, employing the Line Intercept Transect (LIT) method. Observations were made of the benthic coverage of corals, algae, and other material such as sand and rock. The observer noted each substrate under the tape, and the distance at each point the substrate changes. Coral growth form type, algae growth form type and inert substrate was noted for a continuous sequence.

Information and raw data was recorded into a waterproof notebook and later validated and cleaned before entering new datasets to the database or Excel data repository. The classifications and methodology followed the methodology as described in Survey for Tropical Marine Resources (English et al. 1997). These are:

Table 2: Benthic categories for the Line Intercept Transect methodology

Hard corals	
Dead coral	DC
Dead coral with algae	DCA
Acropora (AC) branching	ACB
AC encrusting	ACE
AC submassive	ACS
AC digitate	ACD
AC tabular	ACT
Coral branching	CB
Coral encrusting	CE

Coral foliose	CF
Coral massive	CM
Coral submassive	CS
Coral mushroom	CMR
Coral heliopore	CHL
Coral *Millepora*	CME
Coral *Tubipora*	CTU
Other fauna	
Soft coral	SC
Sponges	SP
Zoanthids	ZO
Others (ascidians, anemones, Paua etc…)	OT
Algae	
Algal assemblage	AA
Coraline algae	CA
Halimeda	HA
Macroalgae	MA
Turf algae	TA
Abiotic	
Sand	S
Rubble	R
Silt	SI
Water	WA
Rock	RCK

Juvenile corals, invertebrate and other organisms for habitat quality assessment – quadrat method

To measure invertebrate communities the quadrat count method was used. A dedicated observer deployed a 1 m^2 quadrat on each side of the transect line at 4 m intervals, giving a total of 12 quadrats per transect.

Within each quadrat all invertebrates were counted and identified to the highest order possible. Juvenile corals were identified as any coral less than 10 cm in diameter. Other organisms included holothurians, urchins, starfish, molluscs, bivalves, worms, soft corals, and nudibranchs.

Photographic record of survey sites

To gain a photographic record of the survey sites, selective quadrats visually representative of the site were photographed. Where water depth did not allow for an image from vertically above the quadrat, the image was taken at an angle to include the full quadrat in the image.

The camera used was a GoPro Hero 5. On the outer reef sites a red filter was attached. There is some distortion in the photographs due to the nature of the lens of the camera.

Sediment core sampling

A sediment core was taken at each site where sediment made up part of the benthic substrate. A PVC (polyvinyl chloride) pipe was used to penetrate the sediment deposit on top of the basement lagoon limestone and extract a sample. The core was then extracted onto a tray and photographed to record the sediment structure and stratification. The sample was then bagged and labelled in the event further analysis is requested. Details of sites where core samples were taken can be requested from the Infrastructure Cook Islands.

General observations of study site for degraded areas

Throughout the survey of the study area, the consultants observed any specific areas that demonstrate below average environmental health or seem to be particularly vulnerable to degradation. These identified areas could then be included in the specific catchment management plan to be developed for the area.

Community engagement for enhanced management

The local counterparts were advised of a three-day period suitable for an open day to be held and members the local community were encouraged to come out and view the data collection and learn about the methods being employed. Interviews were held with fishermen and women to understand more about their engagement in resource use and potential role in any planned management in the study area. Local engagement was also achieved using two sub-contracted surveyors from the local community who were taught the methods to be employed and then executed their task throughout the survey.

Results[2]

Summary of Universal Fish Census

Over the 42 sites surveyed, 148 different species of reef fish were identified, with several wrasse, usually juvenile, remaining unidentified and one other species not identified. The list of species is provided in Appendix A.

In the survey there were 35 common family groupings represented. Figure 3 shows their relative abundance with the most common family being wrasse, with 8 family groupings having a single individual counted during the survey. There was a range in fish density from 0 fish per square metre (Fm^{-2}) to 2.48 Fm^{-2}, with an average count of 0.661 Fm^{-2}.

The reef habitats had overall higher fish counts than the lagoon. The range for the reef sites is 0.89 Fm^{-2} to 2.48 Fm^{-2} with an average of 1.38 Fm^{-2} and a median of 1.115 Fm^{-2}. The range for the lagoon sites was 0 Fm^{-2} to 1.02 Fm^{-2} with an average of 0.487 Fm^{-2} and a median of 0.462 Fm^{-2}.

The distribution of fish population in Muri lagoon and the outer reef system is largely dominated by herbivorous feeders like wrasse, damsels, and surgeons. This suggests presence and relative dominance of algae in the lagoon that could be triggered by nutrient offloads from land-based activities. A lot of target fish species for consumption appear low, which also suggest elevated levels of fishing pressure. The trend of fishing beyond the reef systems into the open ocean partly explains the relatively low abundance of target fish species in Muri lagoon and associated reef structures.

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[2] Ecological assessments: The raw data for the ecological assessments are available as an excel workbook and are provided along with this report.

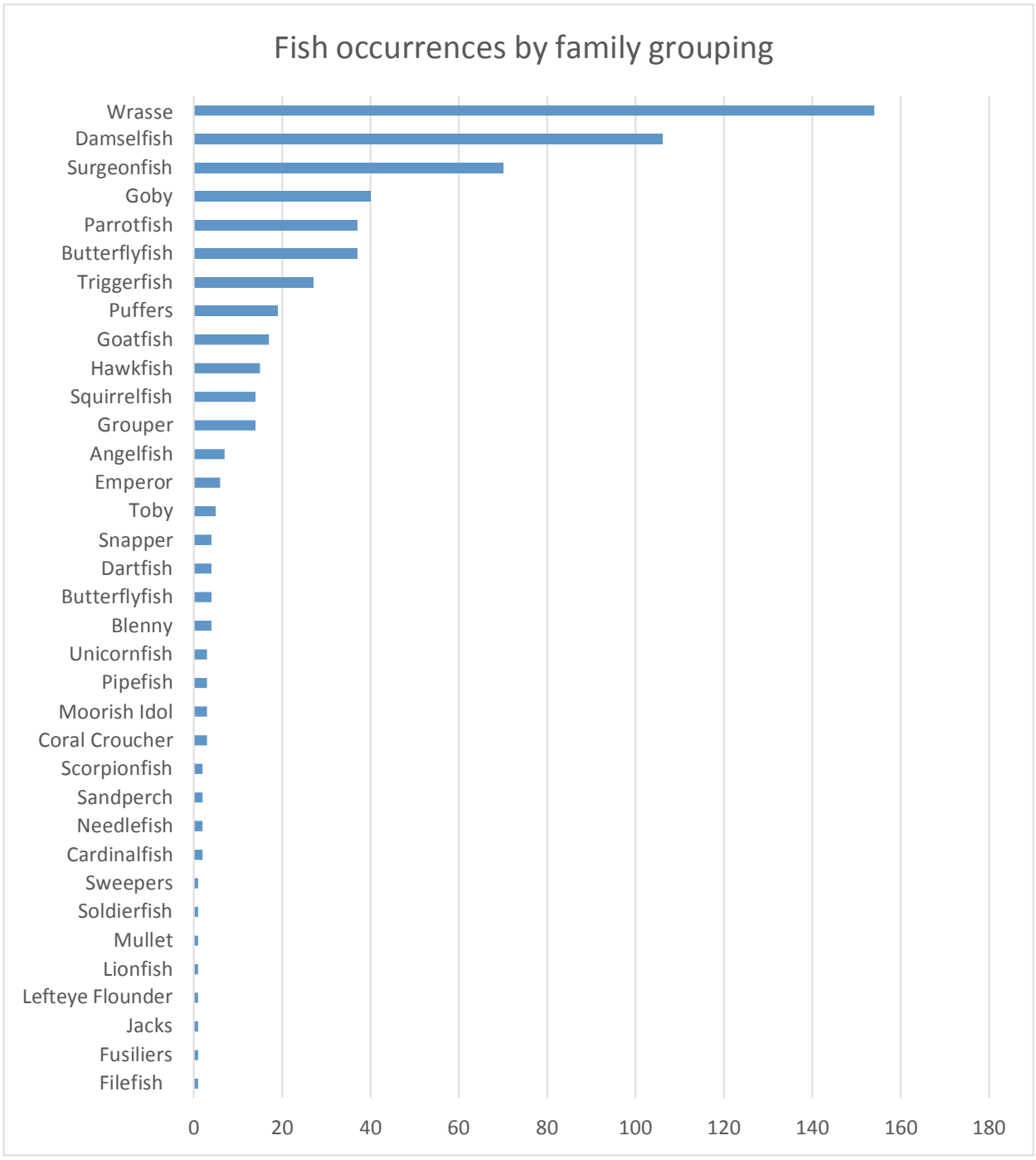

Figure 3: Fish occurrences by family grouping

Summary of Invertebrate Counts

Of the 42 sites surveyed, 10 classification groups of invertebrates were identified, with 37 higher classification groupings. Juvenile corals presented the greatest diversity, while holothurians (sea cucumbers) presented the greatest count as presented in Table 3. When broken into the two subsets, the reef is dominated by corals, while the lagoon is dominated by holothurians. This shows a clear correlation in the data with the observations of the differing environments with regards to the numbers of holothurians and juvenile coral.

Table 3: Benthic categories for the Line Intercept Transect methodology

	Totals	Lagoon	Reef
Holothurians	1301	1300	1
Urchins	1	1	0
Bivalves	9	7	2
Other echinoderms	5	3	2
Juvenile corals	1262	329	795
Mollusca	14	7	6
Worms	46	11	35
Nudibranch	5	1	3
Sponges	1	0	1
Soft Corals	7	0	7

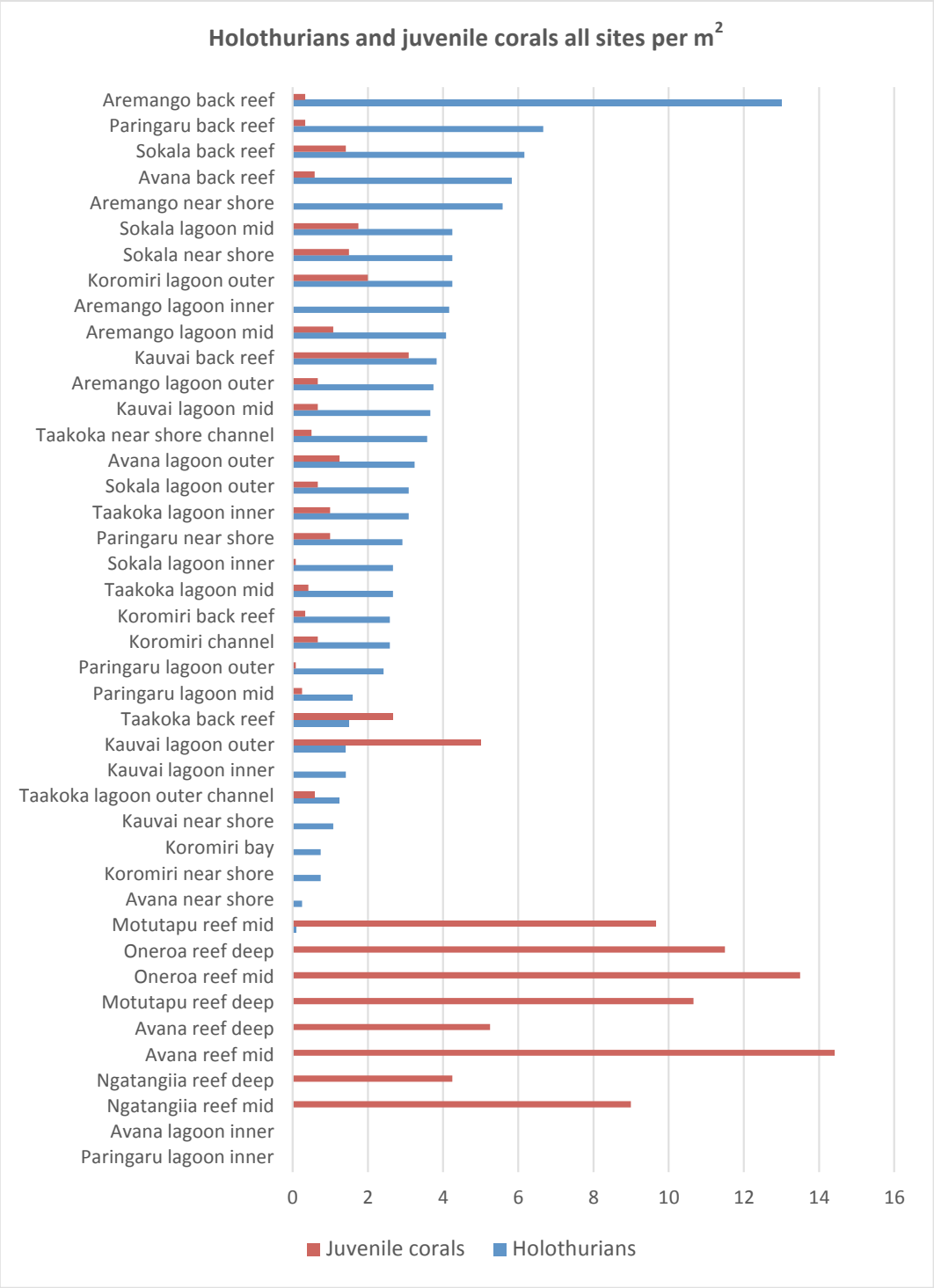

Figure 4: Holothurians and juvenile corals at all sites

Summary of benthic cover (Line Intercept Transect method)

The benthic environments differed significantly between the lagoon and reef slope sites. Interestingly, when the data is analysed, the dominant benthic cover is an algal assemblage for both environments as shown in Figures 5a and 5b. In the prescribed methods an algal assemblage is noted where there is an environment of more than one type of algae growth form dominating the area under the transect for that section. In reviewing the complete dataset and revisiting the methodology, it is clear the algal assemblage noted for the lagoon is considerably different than that noted for the reef.

The algal assemblage of the reef is characterised by a complex of coralline algae and turf algae, with some other small brown and purple algae present as well. With regards to the lagoon, algal assemblage is characterised as a mix of several macro algae species usually growing off one or more *Caulerpa* species that form vines on the lagoon floor.

The key outstanding difference is the amount of sand and rock found in the lagoon, and in contrast, the amount of coral found on the reef. The lagoon has 44% as either sand or rock (38% and 6% respectively) while the reef has about 3%. The reef has 41% coverage of corals, which is an indication of a healthy reef, while the lagoon has 4% coral cover.

These differences indicate that the data agrees with observations, that these are considerably different habitats and should not be compared directly. Because of this the discussion will investigate each separately as unique dataset.

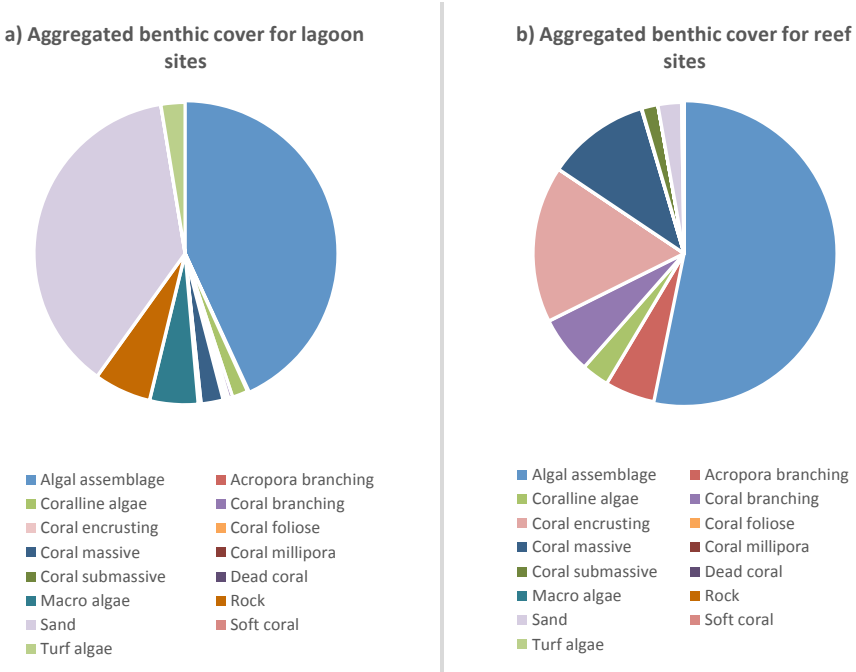

Figure 5: a) Aggregated benthic cover for reef sites. b) Aggregated benthic cover for lagoon sites

The biomass (kg/m^2) of fish appears to fluctuate from locations A to K (Figure 6). Highest numbers are found in B and D (Taakoka and Kauvai respectively) then a reduction of biomass trend from locations E to G, where G has the lowest biomass in the entire RapCA study. Marine surveys H to K are outside the reef, noting that the numbers in the outer reef are not different and there seems to be no obvious trend at locations H to K.

The biomass (kg/m^2) of fish in the three habitats within the lagoon are lowest (70 kg/m^2) at the coastal fringing reefs, greatest (just over 200 kg/m^2) at the lagoon patch and reduces to a biomass of 80 kg/m^2 at the back reef. The biomass count is highest outside the lagoon at almost 250 kg/m^2 (Figure 7).

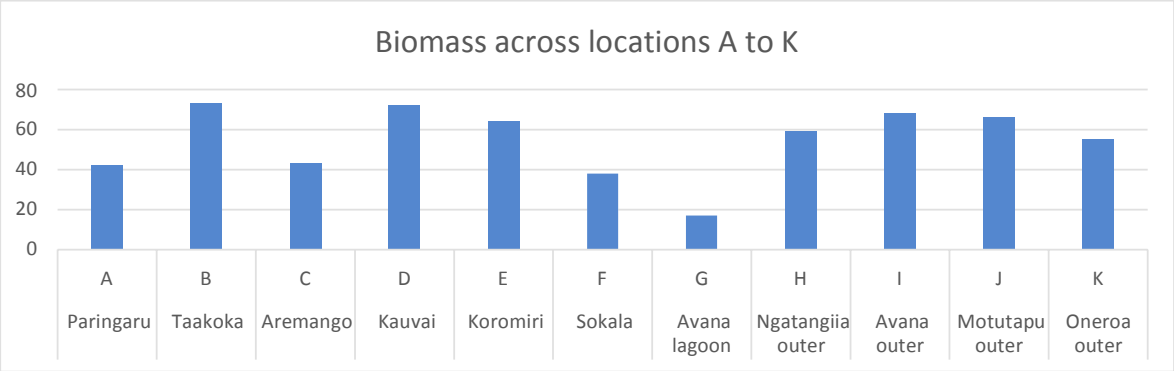

Figure 6: Biomass of fish across locations A to K

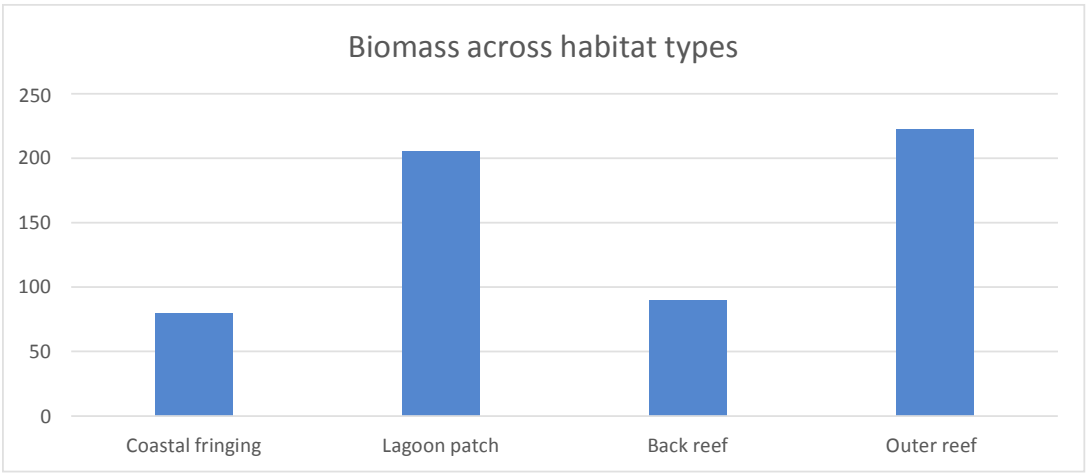

Figure 7: Biomass across habitat types

The abundance (number of fish/m^2) of fish from locations A to K (Figure 8) follows a very similar trend to that seen in the biomass (Figure 6). The only apparent difference is that locations D and E (Kauvai and Koromiri, respectively) have lower abundance counts than their biomass, which suggests that the fish in these two sites are lesser in numbers but heavier in weight.

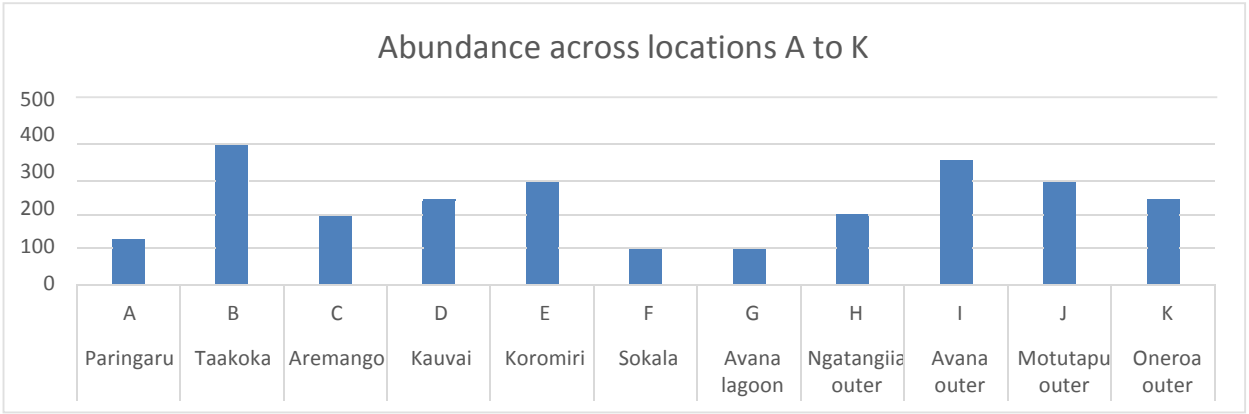

Figure 8: Abundance of fish across locations A to K

The abundance (number of fish/m^2) across habitat types follow a similar trend in the biomass seen in Figure 7 where the highest numbers are at sites B and D and lowest is seen at site G (Figure 9).

Generally, outer reef abundance and biomass are expected to be significantly higher than other habitats such as lagoon patch reefs. It did not appear to be the case in Muri lagoon, suggesting fishing pressures having similar effects on targeted species in preferred fish habitats.

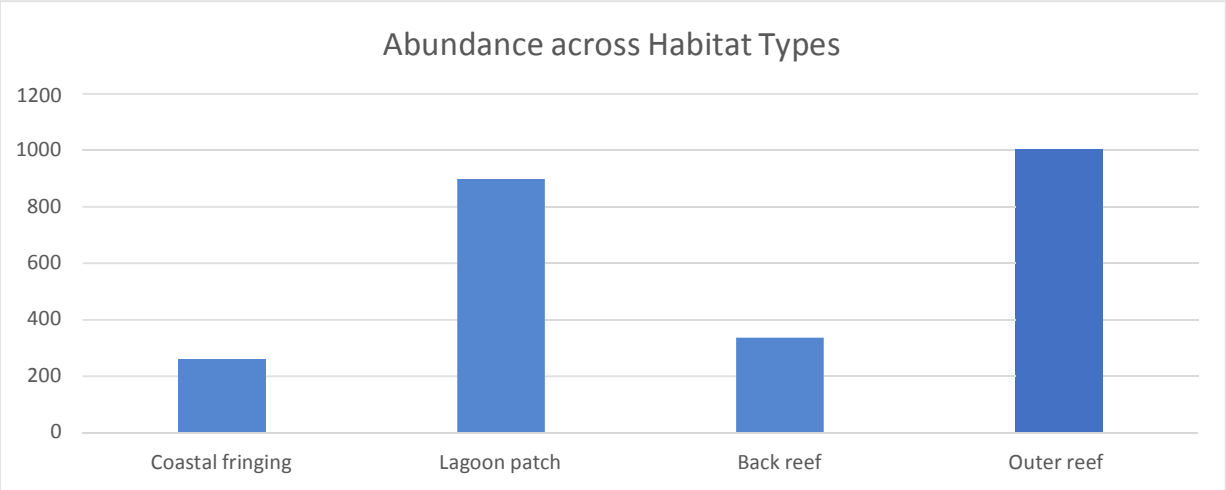

Figure 9: Abundance of fish across habitat types

The species distribution in the different habitats (Figures 10 and 11) shows that damselfish are the most common species except in the coastal fringing reefs (closest to the coast). The lagoon patch (middle section of the lagoon) shows almost an equal distribution of damselfish and wrasse, whereas in the back reef, damselfish are seen to be in greater amount than wrasse species. Surgeonfish are seen to be in greater numbers in the outer reef compared to the lagoon sections where surgeonfish are 3rd or 4th highest. The most obvious difference is seen in the coastal fringing reef, which has a relatively high number of goby species, not seen in any other habitat types.

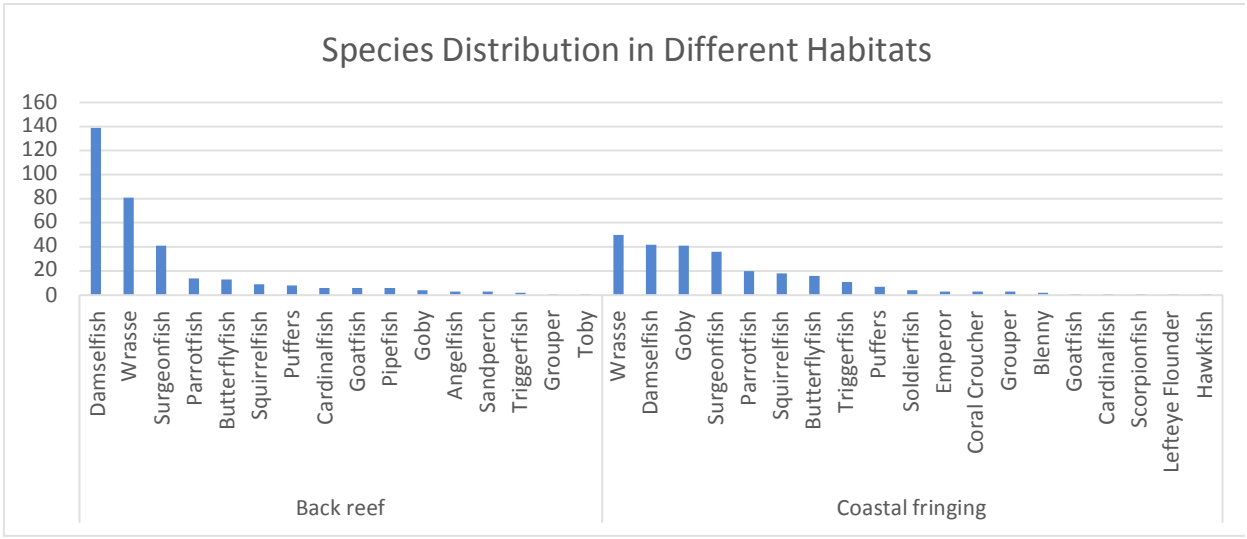

Figure 10: Species distribution in the back reef and coastal fringing reef

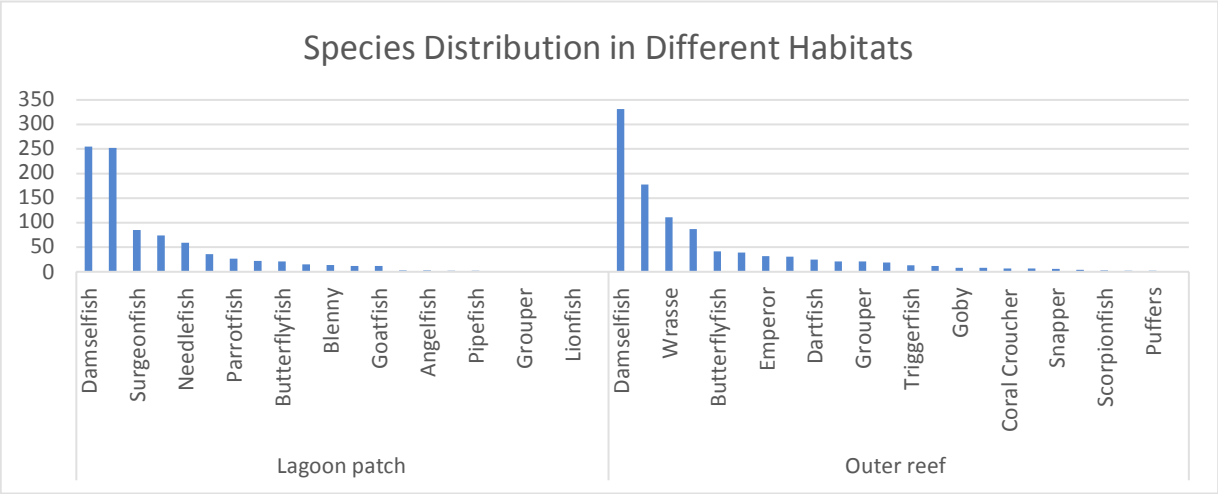

Figure 11: Species distribution in the lagoon patch and outer reef

Upon examination of data from Figures 12 to 14, it is apparent that the lowest species distribution and overall numbers per species is in Paringaru (A), Sokala (F) and Avana (lagoon area) (G). Locations B, C, D and E all have higher numbers within the lagoon, but these numbers are much lower compared to locations H, I, J and K, which are the outer reef numbers. Damselfish and wrasse fish are the most common species despite location except for Avana (outer reef), which has a much higher species count of fusiliers.

Fish not included in the graphs are angelfish, filefish, goby, grouper, jacks, lefteye flounder, lionfish, scorpionfish, toby, unicorn fish as numbers were too low to be effectively represented in Figures 10 to 14.

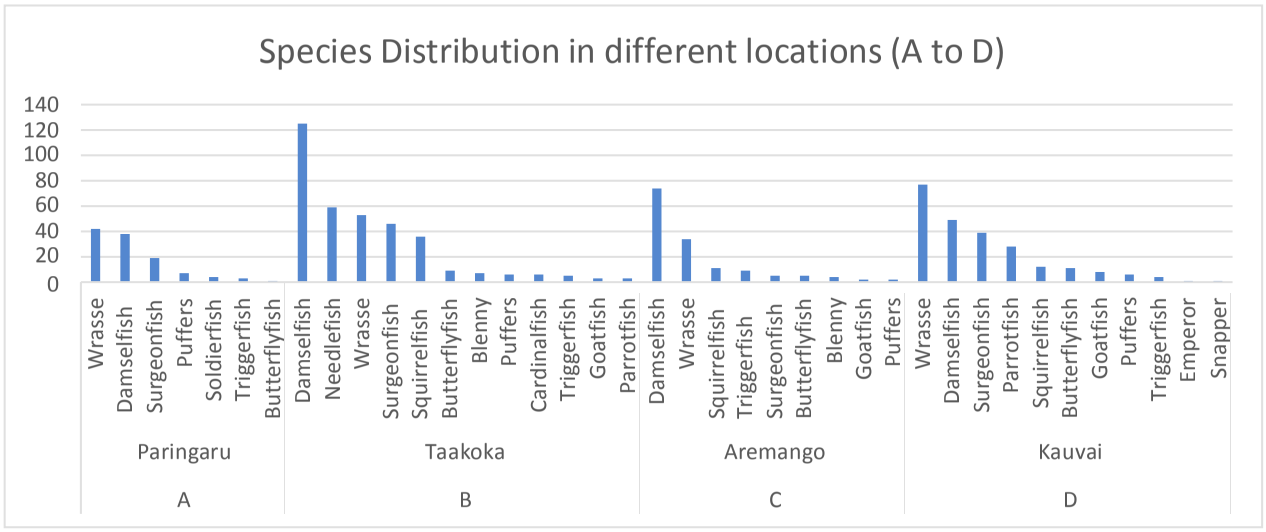

Figure 12: Species distribution in different locations (A to D)

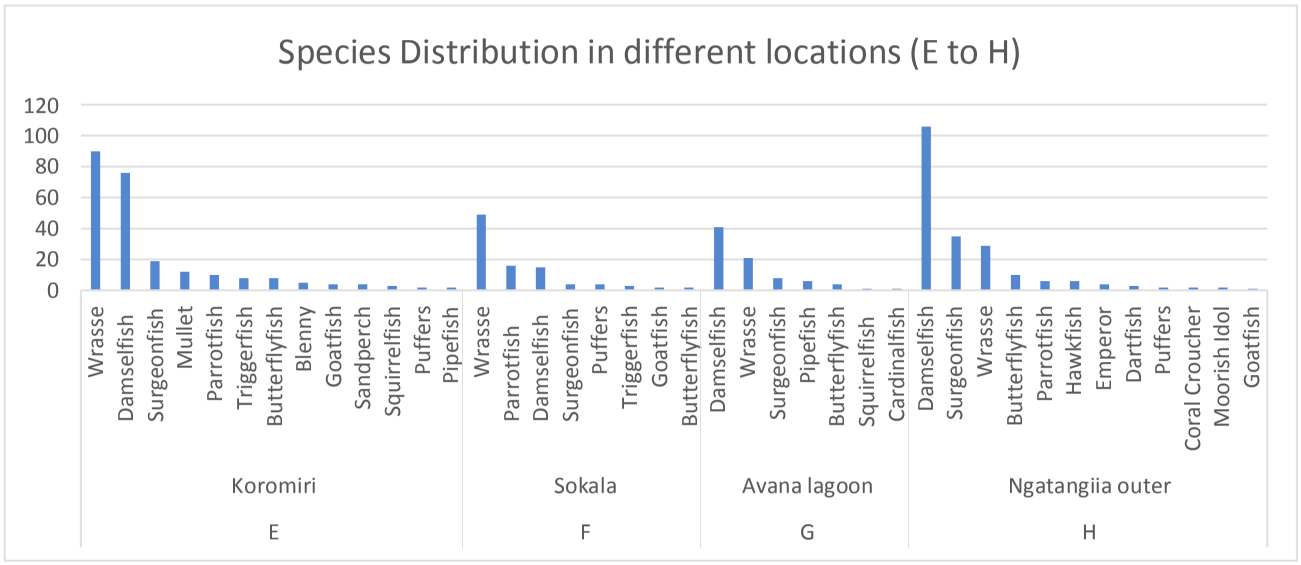

Figure 13: Species distribution in different locations (E to H)

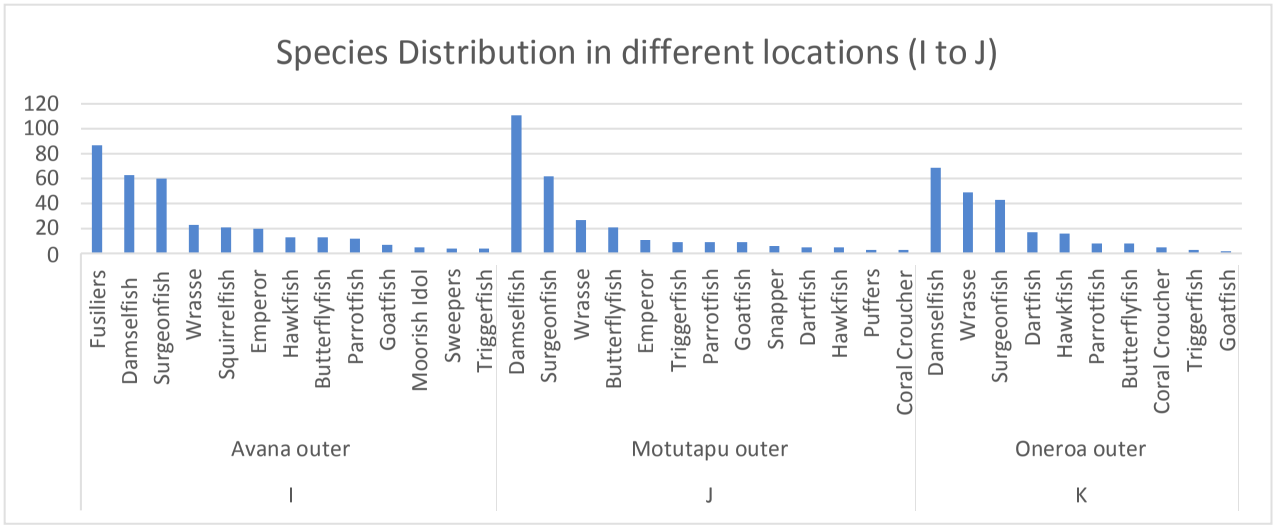

Figure 14: Species distribution in different locations (I to J)

Figure 15 shows a clear correlation between the composition of sand/rubble (abiotic) and algae in the lagoon, however depicting no clear pattern of dominance in specific habitats. Another clear trend is that coral cover is relatively low everywhere; exceeds 20% cover only in one site and others averaged cover below 10%. If this study is repeated, it will show how the lagoon benthos changes over time. When used in conjunction with remote sensing such as aerial imagery, we will be able to assess how our actions are impacting this environment for the better or for the worse.

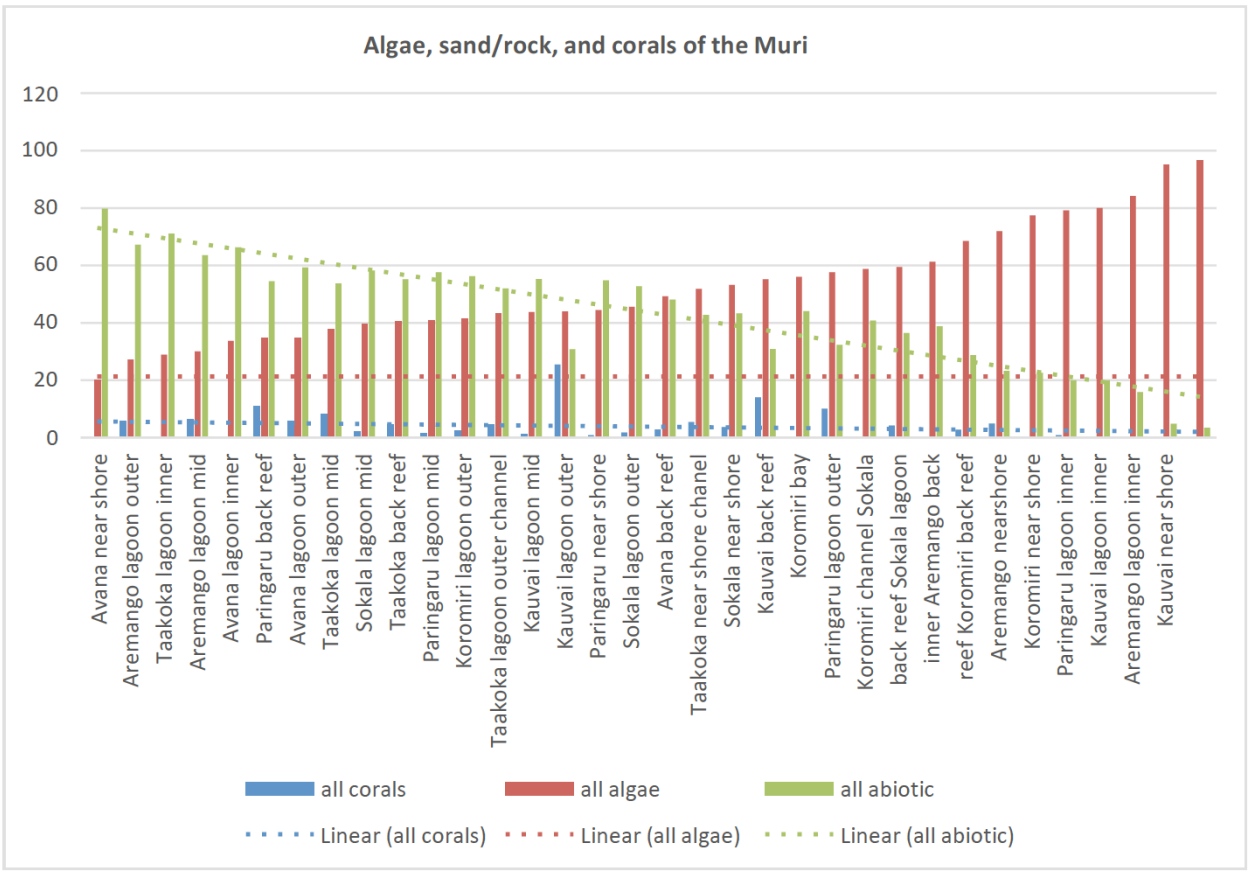

Figure 15: Algae sand/rock and corals of the Muri lagoon.

Discussion

General

The rapid assessment of Muri lagoon provides the opportunity to collect baselines needed to establish relevant R2R indicators that can be used for monitoring into the future to assess full impact of the range of stresses from land-use activities, particularly sediment export from up streams and ascertain levels of pollution. The study did not fully assess the ridge to reef ecosystems to comprehend and understand better the flora and fauna biodiversity and these been impacted by both natural and man- made stresses.

The study concentrated on Muri lagoon ecosystems with sites selected as good representation of the coastal, lagoon, back reef, and outer reef systems. Due to the nature of the two environments being so different, this discussion focuses on the lagoon study and the reef study as separate pieces of work to report on.

Lagoon

The lagoon study is a comprehensive ecological baseline analysis of the Muri lagoon covering 34 sites from Avana stream to Parengaru stream. Survey sites cover all habitats in the lagoon and were placed strategically to include channels where flow is concentrated, gradients of sites away from the streams both seaward and laterally and spatially dispersed through the study area.

The study methodology was prescribed by the regional R2R programme within the ecological indicators for marine ecosystems (E3). These methods were developed predominantly for the study of reef habitats, particularly the Line Intercept Transect method, and therefore may not have been the most appropriate method for studying a sandy lagoon environment. However, the data is robust and does give the information required to report on the ecological state of the lagoon in terms of both the health of its habitats and resources.

The benthic survey would usually be used to assess reef health by calculating the ratio of living reef to algae and abiotic benthos. The algae can be further analysed by type to identify potential impactors such as nutrification. That analysis is outside the scope and methodology of this study.

In the absence of a reef habitat, the LIT method becomes less useful as it can only describe the state of algae and other growth forms over the abiotic sandy lagoon. To make matters a little more complicated, the lagoon is not all sand, with patch reef, coral rubble and bommies making up some reef-like habitat.

The baselines of certain ecological characteristics of Muri lagoon can provide early indication of the health of the lagoon's habitats and resources.

The results show a clear correlation between the composition of sand/rubble (abiotic) and algae in the lagoon, however depicting no clear pattern of dominance in certain habitats. The algae dominant lagoon suggests relatively high level of perturbations from land use activities and sediment export downstream smothering and suffocating live coral colonies. There is the possibility of excessive fishing activities targeting specific fish species and corallivores. If it is to be assumed that a healthy environment is one that is free from algae (historical studies and aerial imagery confirms the macro algae mats to be a recent phenomenon) then the LIT study can assess in a gross empirical way, the health of a site by the level of algae present.

With regards to living organisms of the lagoon, both, the universal visual census (UVC) and the invertebrate quadrat count, directly assess these metrics. This holds most value over time so that changes can be monitored and evaluated. The data on its own creates a snapshot of the current situation, but does little to inform the state of the environment because it has no baseline to be compared to.

These studies have provided a comprehensive list of the species found in the lagoon and where they are currently distributed. The UVC shows that the lagoon is a significant nursery, particularly for wrasse, but for other species as well.

The invertebrate study found corals at almost every site. Certainly, every site that had an amount of rocky substrate also had juvenile corals (coral colonies less than 10 cm in diameter). This indicates that the lagoon, despite the prevalence of algae, is still capable of supporting coral life. This gives hope for recovery once water quality improves.

Outer reef

These sites were not initially included in the project design, but later added once the project began after a request to do so for purposes of determining the effect of pressures in Muri lagoon. Accordingly, eight sites were selected to represent mid and deep depth sites in proximity to the Avana passage on either side of the passage mouth, and away from the passage on either side, western and eastern direction. The Avana passage drains the Muri lagoon catchment. They were selected to provide information on the impact of the Muri catchment on the surrounding reef. This type of habitat is similar to that of the survey at the Tagabe RapCA study in Vanuatu.

All outer reef sites surveyed can be generally classified as healthy, with coral coverage ranging from 33% to 66%. No dead coral was identified in the survey, but the general area had patches of crown-of-thorns damage with two mature crown-of-thorns spotted.

The algae present was thin filamentous algae, coralline algae, and turfing algae typical of a reef ecosystem. There were no macro algae identified in the survey.

The invertebrate study found juvenile corals and urchins to be most dominant, with occasionally other organisms such as feather stars and nudibranchs being recorded.

The data for the outer reef is directly comparable to other studies using the same methodologies elsewhere on coral reef ecosystems. The methodology is robust and repeatable, used by SPC and researchers across the Pacific.

The algal assemblage on the outer reef slope is characterised by a completely different matrix of species and growth forms than that found in the lagoon. The processes of dilution, dispersion and mixing over much of the exposed environment in the outer reef ecosystem is far more pronounced. In contrast, the Muri lagoon has limited and restricted shallow environment and is exposed directly to point and non-point discharges from coastline and river mouth. Therefore, they are not necessarily an indicator of the same environmental issues.

However, the study found similarities in abundance and biomass of targeted fish species in both the outer reef and lagoon. More biomass would be expected in the outer reef habitats, given the suitable habitats and environment. These results are alarming and suggest that excessive and possibly indiscriminate exploitation of resources in these habitats have reached unsustainable levels and need effective management.

SECTION 2.

INDICATOR SE4 EXPLOITATION OF LIVING RESOURCES

Introduction

Daily observations were conducted throughout the study site during surveying. Surveying took place throughout the day for a period of 10 days.

During the field surveys only one person was observed cast netting on the shoreline south of the study area. The consultants were unable to locate that individual once we had returned to shore following our surveys.

The study site is predominantly a raui, a type of traditional marine protected area. Limited local harvesting does take place, particularly of traditional delicacies such as the patito, a small sea hare that has an annual season. However, there is no regular harvesting in the area for sustenance.

Fishing happens from the area through the Avana passage. The passage and associated natural harbour are the local launching and exit points for fishermen fishing outside the reef in the open sea.

The study interviewed 10 local fishermen who are regular users of the harbour and reside in the Muri or surrounding area.

Method

The community fishing survey was conducted by way of a personal interview with fishermen as they returned from fishing back to the Avana harbour. The questionnaire was based on the community fin fish survey developed by the Secretariat of the Pacific Community and published in the socio-economic fisheries surveys for Pacific Islands: A manual for the collection of a minimum dataset (Kronen et al. 2007).

The questionnaire was adapted and created in a digital format using Google Forms. It was then conducted in the field by a dedicated interviewer, recording responses onto the form.

The questionnaire is attached as Appendix C.

Results

The respondents were dominantly male (90%) with age range 25–60 years and representing Muri communities. The high number of male respondents is because fishing by Muri Communities is dominantly by men. There is relatively equal representation of men and women in a household across the Muri communities. Some relevant demographic features of the individuals being consulted:

- Of the 10 respondents, 2 surveys took place at the Avana wharf, 8 in the Muri community.
- 9 respondents live in the district of Ngatangiia – 8 live in Muri and 1 life in Arorangi district.
- Out of all the respondents, 9 respondents were male and 1 was female. The age range of respondents was 25 to 60 years with the median age of 40.5 years. The female respondent was one of the few women that still fished, as men dominantly fished for pelagic species in the area.

- Average number of females per household was 1.9 with a range of 1 to 5; average number of males per household was 1.8 with a range of 1 to 4.

Regarding preferred choice of fishing grounds, most chose fishing in the open sea, and closely followed by a combination of fishing in the lagoon, passages, and reef areas. Multiple fishing grounds targeted at each fishing trip is also preferred. Key results from the consultations and interviews include:

- 3 fishing grounds and environments that could be fished − lagoon, passages/reef and pelagic open seas.
- 5 respondents fished all in all environments, 4 fished pelagic open seas only and 1 fished the passage/reef and pelagic open seas.
- 4 respondents fished only in 1 fishing area at a time, 5 fished lagoon and passages/ reef, and 1 fished passage, reef, and pelagic open seas.

In terms of ranking the most important and preferred habitats, the results varied between respondents. Three respondents felt that lagoon/passage/open sea habitats are all equally important. 3 felt pelagic open seas were the most important, 2 felt passages, reef and open seas were most important, 1 felt passage and reef was, and 1 felt lagoon, passages and reef was most important. Overall pelagic open seas ranked most important (8), passages and reef next most (7) and lagoon least (4). The preference for open sea fishing can also indicate the high use of coastal areas for tourism purposes, thus the focus on fishing for pelagic fish.

The frequency of fishing trips a week is predominantly 2−3 times targeting open sea fishing for pelagic species. Many respondents target fishing in the passage and the reef habitats only once a week. Results of the interviews are summarised below:

- 5 respondents fished 1 day per week in the lagoon; 5 did not fish the lagoon.
- 7 respondents fished 1 day per week in the passages and reef; 3 respondents did not fish this environment.
- 3 respondents fished 3 days per week in the open seas; 4 respondents fished twice a week, one respondent fished once a week and 2 do not fish in the open seas.

Regarding mode of fishing, most people in Muri communities generally use a boat all the time, but there is a certain proportion of the population that use a boat less frequently, and others never use a boat. This information is useful to determine the level of fishing pressures exerted on the Muri lagoon. The results from the surveys confirm these trends:

- 2 respondents always use a boat, 5 respondents use the boat most of the time, 1 respondent uses the boat sometimes and 2 respondents never use the boat. 5 respondents fish only during the day, and 5 fish day and night.

Fishing methods are predominantly to do with surface trolling for pelagic fish species mainly in the passage and open sea, handlining targeting shallow lagoon patch reefs and outer reef. Spear fishing and deep water down lining, and gillnetting are also common fishing methods. The results show prevalence of fishing methods (spearfishing, gillnetting, handlining, cast netting), followed by trolling.

This suggests large level of fishing pressures targeting fish species associated with reef habitats, and causing tremendous impacts on damaging reef habitats. A high number of respondents indicate using multiple fishing methods in any given fishing trip, noting several others do not necessarily use

multiple fishing methods, which is commonly associated with short fishing trips. Key results of the survey on fishing methods are as follows:

- 2 respondents chose trolling only, 1 speared from the boat and trolled.
- 2 used hand lining, spearfishing, trolling, spearing while walking and deep water down lining.
- 1 hand lined, spearfished, trolled and deep water down lining.
- 1 used spearfishing, trolling, gill netting and deep water down lining.
- 1 used cast netting, gill netting and spearing while walking.
- 1 used hand lining, spearfishing and cast netting and 1 just spearfished.
- Overall, only 3 used any type of net, 6 spearfished and 7 trolled.

The pelagic fish species commonly targeted by fishermen in the Muri lagoon are yellowfin tuna, mahimahi and wahoo. Other pelagic species less common are skipjack tuna, blue marlin sailfish, short- billed spearfish, paramarau, striped marlin, rainbow runner, A'a manga, ruby snapper, and red snapper. The most common reef fish targeted are unicorn and parrotfish, which are commonly caught by spear fishing at night. There is gleaning, snorkelling, and walking search for invertebrates such as octopus, sea urchins, lobsters, shellfish and vermetid worms. Fishing activities highlighted mostly target pelagic fishing and night fishing, which target specific reef fish. Fishing appears to be mostly carried out by men. The methods indicate men fishing activities, thus women fishing activities is minimal.

- 7 respondents targeted pelagic fish with the most common being yellowfin tuna, mahimahi and wahoo. Other pelagic fish targeted include skipjack tuna, blue marlin and sailfish.
- 7 respondents caught reef fish, the most common being both unicorn and parrotfish. Other fish include pipi, ku, goatfish, rabbitfish, bream, and grouper. The average size of reef fish for all respondents was 16 cm − 24 cm.
- 5 respondents harvest invertebrates, with 2 harvesting octopus, 4 harvesting urchins, 2 harvesting lobster, 2 harvesting shellfish and one harvesting vermetid worms. The woman interviewed engaged in harvesting shellfish, octopus, sea urchins. Fishing activities appear to be dominated by male fishers.

The majority of people engaged in fishing in Muri communities are not fishing for sale but mainly for home consumption or sharing with friends and families. This is a positive sign, given the current state of resources in the Muri lagoon is already at unsustainable levels. Aspects of post-harvest development to keep fish fresh and of good quality is recognised from the survey.

- 5 respondents do not sell any catch.
- 1 sell to wholesalers, 2 to commercial customers and 3 in the community.
- All respondents give fish away, 9 to family, and 8 to friends.
- 7 respondents preserve their catch at sea with ice, while 3 do not use anything.
- Once landed, 1 respondent smokes the catch, 7 refrigerate, 1 keeps on ice and one eats it fresh the day fish is caught.

As indicated above, various post-harvest activities are used and both men and women engage in these activities.

Discussion

Currently, due to COVID-19, there is an increase in fishing activity for sustenance, and less fishing for commercial sales. The local price of fish has dropped from over NZD20 per kilo (filleted) to NZD8 or less. The survey reflects the times in that regard, particularly with regards to how many people are selling their catch.

All fishers catch for more than just their immediate families. They all share their catch with their wider family and friends. The majority of fishers access the fishing grounds by boat, and this is related to the environment they fish in, being the pelagic seas. However, there are still some that access the fishing grounds by walking or swimming. Three of the youngest respondents were also the ones that did not use boats. This may be because they don't yet own a boat due to costs or that young people do not consider it is worth the investment to buy a boat and fish further offshore.

Five fishermen still have some connection to the lagoon and shallow reef crest. Fishing of invertebrates happens almost exclusively in this environment. All invertebrate harvesting seemed to be for personal consumption. It is a good time out for the family to enjoy snorkelling and swimming in Muri lagoon and at the same search for edible fish and invertebrate resources. Women and men are involved in invertebrate collection with women targeting species within the immediate coastal zone.

Fishing forms a key part of the diet for many local people and from the sample taken, one fisher is responsible for feeding a group of up to ten or more people once sales and gifting is considered. The regularity of fishing, with seven respondents fishing two to three days a week on average, is a fairly high rate of fishing considering there is little to no commercial market and most people can store their catch. This shows that there is a high reliance on sea food for family consumption.

Fishing is an important subsistence, recreational and cultural activity in the Muri area, supporting many families by way of the provision of protein and giving the predominantly male set of respondents, time out of the water to enjoy the peace of the sea.

SECTION 3.

LIST OF LITERATURE FOR THE MURI AREA

The Muri lagoon is a well-studied environment, with most work having focused on the physical properties and characteristics of the lagoon. These include sedimentation and current flow. The earliest study by (Kirk 1980) set a baseline for subsequent studies and indicates that over the past 40 years the physical properties of the lagoon, with regards to flow, have not changed much.

As Muri became a point of interest in 2016 due to the build-up of an algal bed which persists, studies shifted focus to investigate nutrient flows. This included some very detailed work investigating ground water flow of the Muri catchment. Physical properties of the lagoon have remained the major point of research.

Sporadic work exists on the ecology of the lagoon. Scoffin et al. (1985) investigated rhodoliths and coralliths of Muri lagoon and how they might attribute to larger sedentary coral formation and growth. Drumm (2005) conducted detailed habitat and ecological assessments of Rarotonga lagoon including Muri lagoon. McCue et al. (2018) conducted an ecological assessment of Muri lagoon.

There has not been a long term and comprehensive monitoring plan for the ecology of the lagoon despite early recognition by (Holden 1992) that dissolved oxygen levels were high. These early signs show that issues were already occurring, and we have lost the opportunity to understand the impacts over the past 40 years of development.

A list of references is provided below.

Table 4: List of literature for the Muri area

Author	Year	Title
Kirk	1980	Sedimentation in Ngatangiia Harbour and Muri Lagoon, Rarotonga, Cook Islands
Carter	1984	Baseline Study for Coastal Management Coastal Engineering Study at Ngatangiia Harbour and Muri Bay, Rarotonga, Cook Islands
Scoffin	1985	Rhodoliths and Coralliths of Muri Lagoon, Rarotonga, Cook Islands
Holden	1991	Physical Oceanography of Ngatangiia Harbour-Muri Lagoon and Avarua Harbour, Rarotonga, Cook Islands
Holden	1992	Circulation and Flushing of Natangiia Harbour and Muri Lagoon.
Collins	1993	Bathymetry and Sediments of Ngatangiia Harbour and Muri Lagoon, Rarotonga, Cook Islands (Report)
Collins	1995	Bathymetry and Sediments of Ngatangiia Harbour and Muri Lagoon, Rarotonga, Cook Islands (Thesis)
Drumm	2003	Using regression trees to identify the habitat preference of the sea cucumber (Holothuria leucospilota) on Rarotonga, Cook Islands
Drumm	2005	Habitats and macroinvertebrate fauna of the reef-top of Rarotonga, Cook Islands: implications for fisheries and conservation management

NIWA	2006	Titikaveka Health Effects: Environmental Investigations, December 2004 to November 2005
Ministry of Works	2008	Integrated Water Resource Management (IWRM) Demonstration Project
Miller	2008	A Quantitative Assessment of Ra'ui (a Traditional Approach to Marine Protected Areas) on the Fishes and Invertebrates of Rarotonga, Cook Islands
Ministry of Marine Resources	2010	Muri Water and Sanitation Project
Consultant	2011	EU Muri Water & Sanitation Project
Consultant	2012	EU Soil Investigation Risk Assessment
Tait	2013	Estimating submarine groundwater discharge in a South Pacific coral reef lagoon using different radioisotope and geophysical approaches
Tait	2013	Nutrient processing in a novel on-site wastewater treatment system designed for permeable carbonate sand environments
Blue Barn	2013	Assessment of Commercial Properties Sanitation Systems Muri Beach
Blue Barn	2014	Re-Assessment Report
Erler & Shepherd	2014	Performance of Pilot On-site Wastewater Treatment Systems in Muri/ Avana district, Cook Islands, Report Prepared for WATSAN
SOPAC	2015	Muri Lagoon Desktop Survey
Tait	2015	Nutrient transport, modification, and fate in a carbonate sand coral reef lagoon
Tait	2015	Nutrient and greenhouse gas dynamics through a range of wastewater-loaded carbonate sand treatments
Calibre	2015	Review of Muri Waste Management Initiative Pilot -Rarotonga
Lyon	2016	Algae removal pilot study completion report
Climate Change Cook Islands	2016	A Brief Assessment of Physical and Biological Parameters around the Fishtrap Area in Muri Lagoon
Beetham and Turner	2016	Preliminary field observations of Muri shoreline and lagoon
GHD	2016	Muri Waste Management Initiative Pilot Review – Peer Review
Lyon	2016	EIA - Ecological and Aesthetic Restoration of Muri Lagoon
AECOM	2018	Interdisciplinary Assessment of the Muri Lagoon – Consolidating the Sanitation Development Upgrade for the Cook Islands Government
MMR, Ainley	2018	Muri Lagoon Ecological Assessment
Tonkin and Taylor	2019	Muri Catchment Feasibility Study for Stormwater Management
GHD	2019	Summary of Mei Te Vai Ki Te Vai Environmental Investigations
Tait	2019	Assessment of nutrients in the Muri Lagoon, Cook Islands
UNSW	2019	Hydrodynamic Investigation of Muri Lagoon and Avana Harbour

SECTION 4.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Material for presentation to the community

The Muri catchment RapCA study has produced a dataset of ecological data covering invertebrates, fish, and benthic communities. The data has been presented in this report and includes maps, graphs, tables, and images to communicate the findings. These materials are available for the development of a community communication regarding the state of the Muri lagoon as concluded by this report.

The lagoon is an environment geographically placed between two opposing influences. On the seaward side, the great Pacific Ocean drives fresh oceanic water into the lagoon on an almost constant basis, providing the mechanism for flushing the lagoon and holding the water quality at a level necessary to support a typical tropical Pacific coastal ecosystem of this sort.

On the other side, the lagoon is pressured by the influences of the land. These influences have changed over time because of the development of the Muri area firstly for agriculture, then later for tourism and an accommodation centre. These land uses undoubtedly impact on the quality of the ecology of the lagoon, and the data indicates this impact is greater closer to shore. Thus, the importance of considering social and gender factors on pressure exerted on resources within the Muri area. This will include considering other users and uses of the Muri coastal and shore areas including tourism and agricultural activities.

The materials produced by this study can be used to tell the story of the health of the lagoon, the parts that are healthy and the parts that are stressed. The abundance and biomass of resources in the lagoon provide an indication of its health. The results of this study suggest that Muri Lagoon is heavily over exploited, and habitats dominated by algae signal the need to reverse stresses from upland use activities, including sediment export and pollution from downstream rivers and other non-point sources discharging directly into the lagoon. Land based activities and impacts on the streams and river systems within the catchment areas can then be analysed and further advise the assessment of the health of the lagoon. Gender inclusive approaches and sex disaggregated analyses of activities will enable targeted management or regeneration activities that target men, women, and other sectors of the communities.

Options for ongoing monitoring of the Muri catchment and lagoon

Ongoing monitoring is a key consideration that will benefit all stakeholders. The Muri lagoon is often referred to as the crown jewel of Rarotonga's tourism industry and maintaining it is well-acknowledged as being of national importance.

The seriousness of the situation in Muri lagoon is recognised and steps are being taken to address it, as is evident from the previous waste management project and the current project.

Environmental changes are often chronic in nature and once damaging changes have occurred, they are hard to undo, and improvements are incremental.

To understand the changing environment, for the better or for the worse, we need to be monitoring it. Our anecdotal information – the stories we tell of the past – are often not enough to drive decision making. The Muri lagoon is a sandy lagoon with algae covering the lagoon floor for most of the shoreward extent and extending out 50 m to 150 m from the beach. It has been this way for several years now and for many, it is a normalised situation. Without the data we cannot express the changes that have happened. That data can come from many sources. Research, remote monitoring, third party sources. The data is the first step, and a cohesive plan to manage and report that data is the second. Monitoring work can be undertaken by men, women, youth, and other sectors of the community depending on their different use of resources.

Monitoring Methods

There are several options to consider for the ongoing monitoring of the Muri lagoon. These are dependent on time and funding, as well as the type of information authorities wish to receive. Methods can be overlapped to give greater variation in data to support decision making.

The key to successful monitoring is commitment to the long-term and consistency. If these two variables are duly provided for, then the work will take care of itself.

It is also worth noting that currently the Cook Islands Government is working in silos with regards to environmental monitoring in our coastal environment. This is a weakness that should be addressed to enable improved coordination and efficient application of resources.

Key activities that can contribute to long term monitoring include:

1. Conducting an annual survey of environmental indicators similar to the work completed for this RapCA study.
2. Conducting remote sensing of physical and chemical water attributes over the long term.
3. Conducting regular aerial observations for changes in the benthic environment.
4. Conducting water quality testing.

All these activities have occurred haphazardly and without coordination in the past and continue to do so.

Logistics

To ensure monitoring activities for the Muri catchment are coordinated and reported in a manner that adds value, it is recommended that an environmental monitoring unit be established within an appropriate agency. This would be a coordinating agency responsible initially for the study of the Muri catchment and potentially extended to cover other areas of national environmental interest.

The key output of the unit would be an annual report on the state of the Muri catchment.

The proposed unit would:

- ensure water quality data and aerial surveys by the Ministry of Marine Resources are reported and collated in the annual report;
- ensure any monitoring and evaluation work conducted by MTVKTV (Mei Te Vai Ki Te Vai)/TTV (To Tatou Vai) is reported and included in the annual report;

- coordinate and collate any work by external researchers such as SPC, universities and NGOs; and
- assess the research gaps and find ways to fill these using existing government resources or external resourcing where appropriate.

The unit itself may or may not have the capacity to undertake studies itself. It is suggested here that ample capacity and adequate resourcing exists within the current agencies of Infrastructure Cook Islands (ICI), Ministry of Marine Resources (MMR), National Environment Services (NES) and To Tatou Vai (TTV) to support the work required to provide sustainable long-term environmental monitoring.

Scheduling

Ideally, annual reports should be used to inform decision making and report on the state of the Muri catchment. The scheduling of work should be in alignment with providers and partners.

Chemical water quality monitoring should be consistent and regular – at least monthly, but far better if done weekly.

Remote monitoring is continuous. There are affordable sensors available that can measure temperature and other parameters continuously and be downloaded easily in the field. These should be deployed as a basic first step of any long-term monitoring.

Aerial surveying is a key element of environmental monitoring for Muri. A key indicator of the health of the lagoon is the amount of algae growth occurring. Regular aerial surveys can provide short-term and long-term datasets to inform decision making and provide an alert of any trends before more formal in water surveys can take place. The more frequent the better, for these. If regular satellite imagery is available, that would be ideal as it can be provided regularly and reliably, and the only barrier is cloud cover. Depending on what is acquired, it can also provide other datasets such as sea surface temperatures.

In lieu of satellite, or in addition to it, regular drone surveys can be conducted.

In-water ecological surveys should be scheduled annually so that an empirical dataset is established that can be used to verify the remote sensing and imagery information and provide a consistent long-term set of information on which to base reporting and decision making.

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APPENDICES

List of appendices

Appendix A: Muri RapCA Report – List of Fish Species Recorded

Genus	Species
Abudefduf	*septemfasciatus*
Abudefduf	*sexfasciatus*
Acanthurus	*achilles*
Acanthurus	*nigrofuscus*
Acanthurus	*nigrosis*
Acanthurus	*olivaceus*
Acanthurus	*pyroferus*
Acanthurus	*thompsoni*
Acanthurus	*triostegus*
Apogon	*nigrofasciatus*
Asterropteryx	*semipunctatus*
Awaous	*ocellaris*
Blenniella	*periophthalmus*
Bothus	*mancus*
Cantherhines	*dumerili*
Canthigaster	*bennetti*
Canthigaster	*petersii*
Canthigaster	*solandri*
Caracanthus	*maculatus*
Caranx	*melampygus*
Centropyge	*flavissimus*
Centropyge	*heraldi*
Centropyge	*loricula*
Cephalopholis	*argus*
Cephalopholis	*urodeta*
Chaetodon	*auriga*
Chaetodon	*citrinellus*
Chaetodon	*ephippium*
Chaetodon	*lunula*
Chaetodon	*lunulatus*
Chaetodon	*ornatissimus*
Chaetodon	*pelewensis*
Chaetodon	*quadrimaculatus*
Chaetodon	*unimaculatus*

Genus	Species
Chaetodon	*vagabundus*
Cheilinus	*chlorourus*
Cheilinus	*oxycephalus*
Cheilinus	*trilobatus*
Chlorurus	*frontalis*
Chlorurus	*sordidus*
Chromis	*acares*
Chromis	*agilis*
Chromis	*Bami*
Chromis	*margaritifer*
Chromis	*vanderbilti*
Chrysiptera	*galba*
Chrysiptera	*glauca*
Coris	*aygula*
Coris	*gaimard*
Coris	*roseoviridis*
Corythoichthys	*flavofasciatus*
Ctenochaetus	*flavicauda*
Ctenochaetus	*striatus*
Ctenogobiops	*feroculus*
Dascyllus	*aruanus*
Dascyllus	*flavicaudus*
Dascyllus	*trimaculatus*
Doryhamphus	*excisus*
Epinephelus	*fasciatus*
Epinephelus	*hexagonatus*
Epinephelus	*tauvina*
Forcipiger	*flavissimus*
Gnathodentex	*aureolineatus*
Gnatholepis	*anjerensis*
Gomphosus	*varius*
Halichoeres	*hortulanus*
Halichoeres	*margaritaceus*
Halichoeres	*ornatissimus*
Halichoeres	*trimaculatus*
Haliechoeres	*hortulanus*

Genus	Species
Heniochus	*acuminatus*
Heniochus	*chrysostomus*
Hologymnosus	*annulatus*
Hologymnosus	*doliatus*
Hyporhamphus	*dussumieri*
Iniistius	*pavo*
Istigobius	*rigilius*
Labroides	*bicolor*
Labroides	*dimidiatus*
Labroides	*rubrolabiatus*
Lutjanus	*bohar*
Lutjanus	*fulvus*
Lutjanus	*monostigma*
Melichthys	*vidua*
Monotaxis	*grandolculis*
Myripristis	*berndti*
Myripristis	*woodsi*
Naso	*lituratus*
Naso	*unicornis*
Nemateleotris	*magnifica*
Neomyxus	*leuciscus*
Neoniphon	*argenteus*
Neoniphon	*sammara*
Paracirrhites	*arcatus*
Paracirrhites	*forsteri*
Paracirrhites	*hemistictus*
Paragobiodon	*echinocephalus*
Parapercis	*hexophtalma*
Parupeneus	*barberinus*
Parupeneus	*ciliatus*
Parupeneus	*insularis*
Parupeneus	*multifasciatus*
Parupeneus	*pleurostigma*
Pempheris	*oualensis*
Plectroglyphidodon	*dickii*
Plectroglyphidodon	*johnstonianus*

Genus	Species
Plectroglyphidodon	*lacrymatus*
Pomacentrus	*bankanensis*
Pomacentrus	*coelestis*
Pomacentrus	*pavo*
Pomacentrus	*vaiuli*
Pomachromis	*fuscidorsalis*
Pseudobalistes	*flavimarginatus*
Pterocaesio	*tile*
Pterois	*antennata*
Rhinecanthus	*aculeatus*
Rhinecanthus	*lunula*
Scarus	*forsteni*
scarus	*frenatus*
Scarus	*globiceps*
Scarus	*psittacus*
Scarus	*rubroviolaceus*
Scarus	*schlegeli*
Scorpaenopsis	*diabolus*
Sebastapistes	*tinkhami*
Stegastes	*albifasciatus*
Stegastes	*emeryi*
Stegastes	*fasciolatus*
Stegastes	*lividus*
Stegastes	*nigricans*
Stethojulis	*bandanensis*
Stethojulis	*interrupta*
Stethojulis	*strigiventer*
Sufflamen	*bursa*
Thalassoma	*hardwicke*
Thalassoma	*lunare*
Thalassoma	*lutescens*
Thalassoma	*quinquevittatum*
Valenciennea	*sexguttata*
Valenciennea	*strigata*
Zanclus	*cornutus*
Zebrasoma	*flavescens*

Genus	Species
Zebrasoma	*rostratum*
Zebrasoma	scopas

Appendix B: List of invertebrate species recorded

https://drive.google.com/drive/folders/1QDF-hztQLyvzpypSVxfSojxGJr_Xactm

Appendix C: Community fishing survey

FINFISHER SURVEY QUESTIONNAIRE FORM

Target group

- Fishers (men and women 15 years and older) from households surveyed

Objective: To gather detailed information on:

- average catch size and composition
- fishing techniques
- proportions of catch for subsistence, gift and sale
- methods of conserving and preserving seafood

Village / Place	
Household no.	
Date	
Name of surveyor	

Person interviewed (*confidential information, names will not be published*)			
Name	Age (years)	Gender	
		Male	Female

F.1 Which areas do you fish? (Tick √ boxes and use chart)	coastal reef ☐ lagoon ☐ mangrove ☐ outer reef (including passages) ☐ pelagic/ open ocean ☐		
F.2 Do you fish only one of the habitatsthat you target at a time—or do you usually visit several during one fishing trip? If so, which ones do youusually combine during one fishing trip? (please fill in)	Habitat	only targeted(tick √)	targeted together with habitat (fill in)
	Coastal reef		
	Lagoon		
	Mangrove		
	Outer reef (incl. passages)		
	Pelagic/open ocean		

Annex III: Fisheries survey questionnaire form

F.3 How often do you visit each habitatin a week, or a combination of habitats? How many hours does the averagefishing trip take to this habitat, orcombination of habitats? How many months in a year do youfish this habitat / combination of habitats?	Coastal reef ☐ Lagoon ☐ Outer reef ☐ Mangrove ☐ Times/week: _____ Hours/trip: _____ Months/year: _____
F.3 continue	Coastal reef ☐ Lagoon ☐ Outer reef ☐ Mangrove ☐ Times/week: _____ Hours/trip: _____ Months/year: _____
F.3 continue	Coastal reef ☐ Lagoon ☐ Outer reef ☐ Mangrove ☐ Times/week: _____ Hours/trip: _____ Months/year: _____
F.3 continue	Coastal reef ☐ Lagoon ☐ Outer reef ☐ Mangrove ☐ Times/week: _____ Hours/trip: _____ Months/year: _____
Please select your most important habitat(or combination of habitats mostly fished during one fishing trip) and answer the following questions:	Most important habitat (or habitat combination) (fill in): _____

Annex III: Fisheries survey questionnaire form

F.4 Do you use a boat for fishing?	Always ☐ Sometimes ☐ Never ☐
F.5 When do you go fishing?(Tick √ box)	Only during the day ☐ Only during the night ☐ Day and night ☐
F.6 Which fishing techniques do you use?(Tick √ boxes)	Handlining ☐ Spearfishing (diving) ☐ Castnetting ☐ Trolling ☐ Gillnetting: ☐ Mesh size (in inches or cm) __ Spearing while walking ☐ Spearing while canoeing ☐ Deep bottom handlining Other techniques (specify): _____
F.7 Do you use only one technique perfishing trip, or do you use several during one trip? (Tick √ box) If you use more than one, which techniques do you combine duringone trip? (List)	☐ One technique/trip ☐ More than one technique/trip Which ones? _____ + _____ + _____
F.8 How much do you catch during a normal fishing trip (your catch or share of catch only)? (Use size charts)	Size class: A B C D E E+ cm _____ No. offish: ☐ ☐ ☐ ☐ ☐ ☐ _____ Or kg:
F.9 On an average/normal fishing tripas above, what kinds of fish do you catch? (Fill in the names and numbers per size class) Figures are numbers? ☐ or kg? ☐	Technique used most often to get this catch? _____

Name of fish	Size class (use size chart)						
	A	B	C	D	E	E+	cm

F.10 Do you sell your fish? (Tick √ box)

Yes ☐ No ☐

If yes, where?

Within the community ☐

Outside the community,Which place? ☐

F.11 To whom do you sell? (Tick √ box)

☐ Individuals (door-to-door, along roadside)

☐ Shop ☐ Middleman/agent

☐ Market ☐ Restaurants

F.12 Which preservation method do youuse for your catch? (Tick √ box)

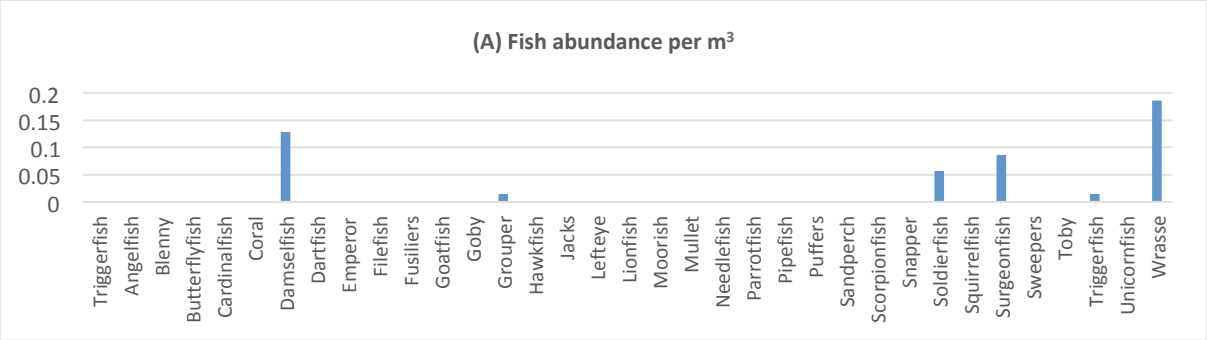
None ☐

Method	Always	Sometimes	Never
Ice (during fishing trips)	☐	☐	☐
Refrigeration	☐	☐	☐
Freezing	☐	☐	☐
Smoking	☐	☐	☐
Drying	☐	☐	☐

Other method—specify: _____

Appendix D: Ecological status of study sites in Muri Lagoon

A1 Parengaru Near Shore



The Parengaru near shore site was abundant with shallow rock and sand, with significantly thick macro algae growth. The algae assemblage consisted of fleshy green and brown algae. Holothurians, *Holothuria leucospilota,* and *H. atra* were the dominant species.

Juvenile corals were present on the rock with a density of 1m^2. There was also coral identified on the benthic transect making up 1% of the benthic cover.

Fish diversity was reasonable, with 6 species observed. They were resident amongst the rocky parts of the site where they could find refuge.

Overall, this site appeared to be significantly impacted by the stream outfall by the thickness, type and proportion cover of algae growing. However, the fish and corals observed indicate that even where water quality may be low, a rocky substrate was found to contain healthy marine life.

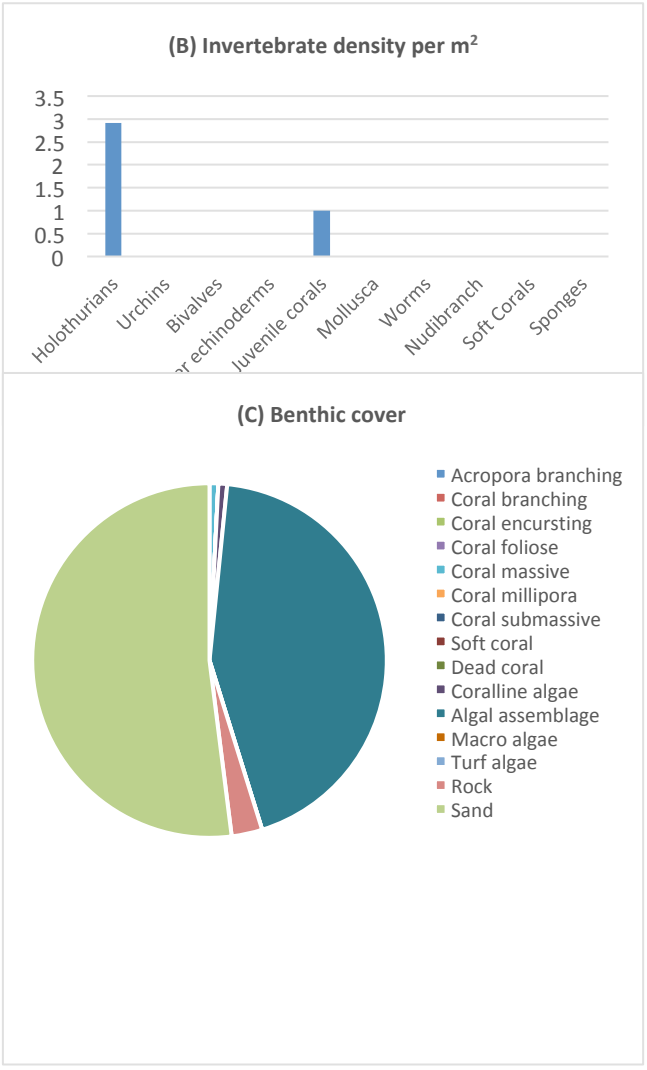


Figure 1: Parengaru A1 near shore (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

A2 Parengaru Lagoon Inner

This site was a completely sandy bottom with *Caulerpa* sp. algae forming a mat that other green algae were growing from.

There were no invertebrates inside the sampling quadrats and no fish present at the site.

The sediment core indicated coarse sand with some grey sulphite rich silt towards the bottom. The core was 14 cm deep.

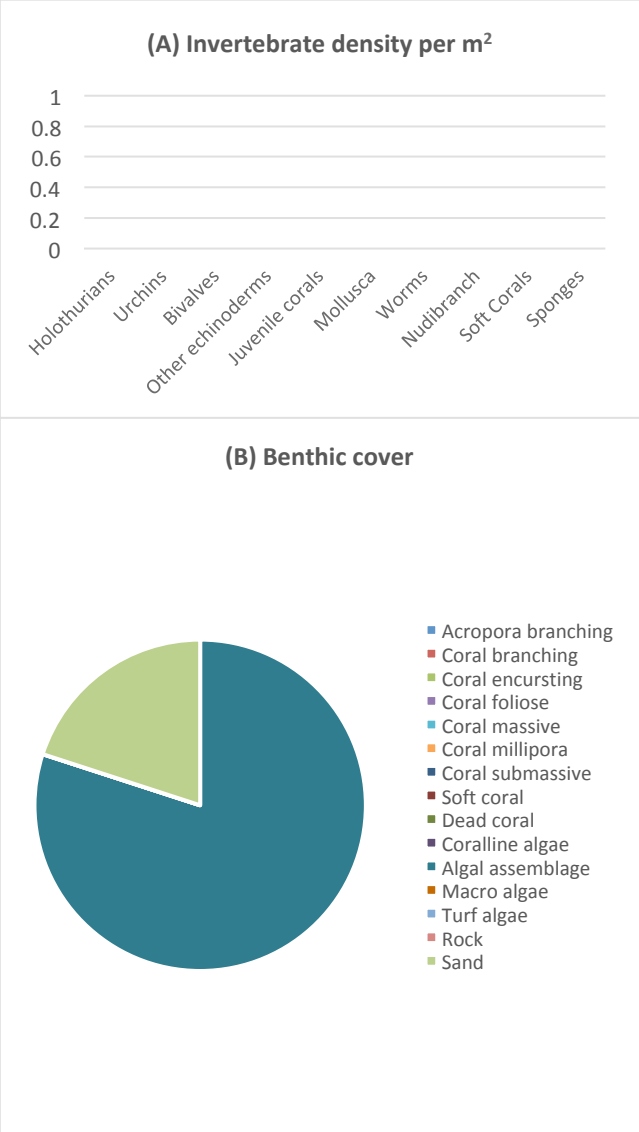
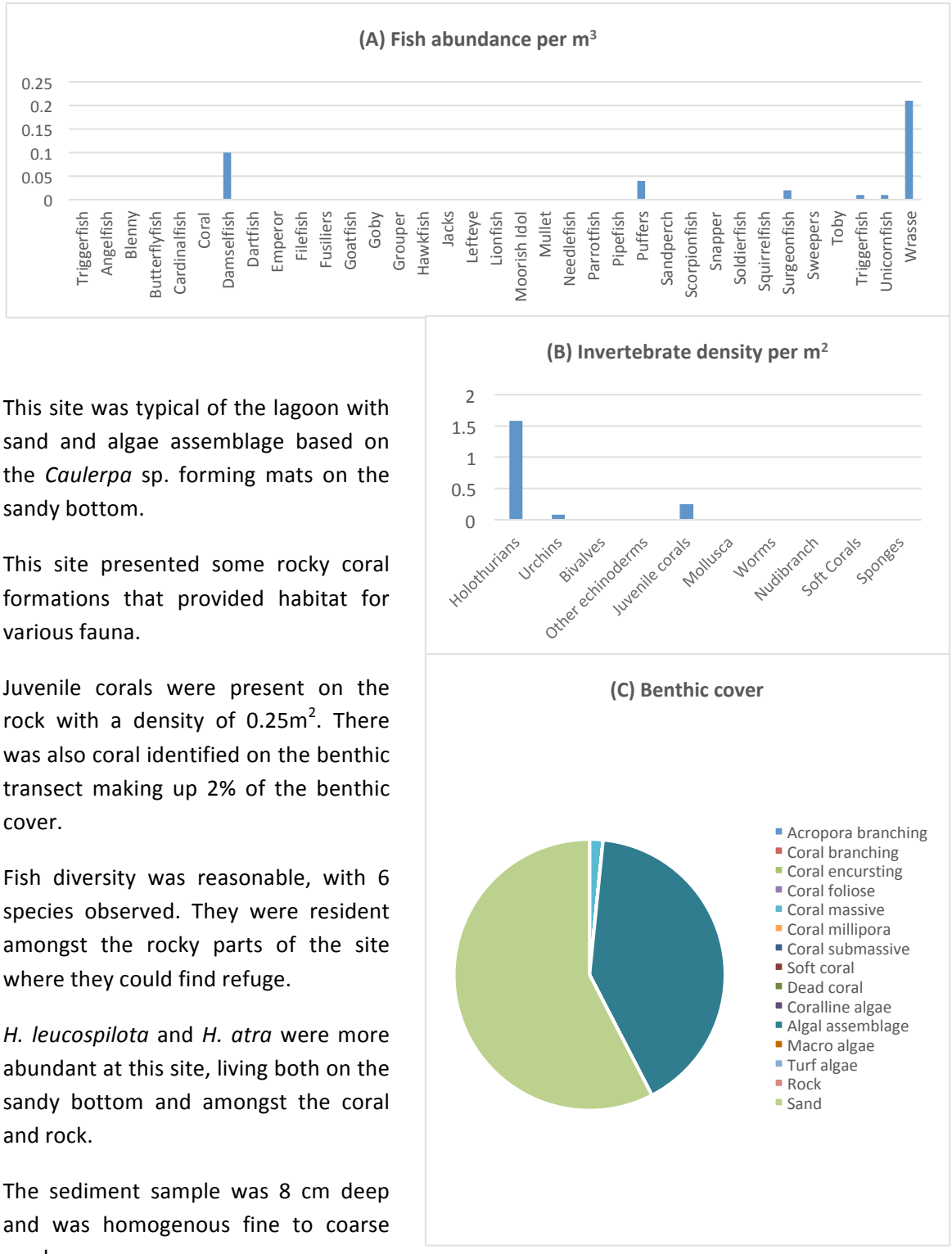


Figure 2: A2 Parengaru lagoon inner (A) Invertebrate density per m^2; (B) Benthic cover.

A3 Parengaru Lagoon Mid



This site was typical of the lagoon with sand and algae assemblage based on the *Caulerpa* sp. forming mats on the sandy bottom.

This site presented some rocky coral formations that provided habitat for various fauna.

Juvenile corals were present on the rock with a density of 0.25m^2. There was also coral identified on the benthic transect making up 2% of the benthic cover.

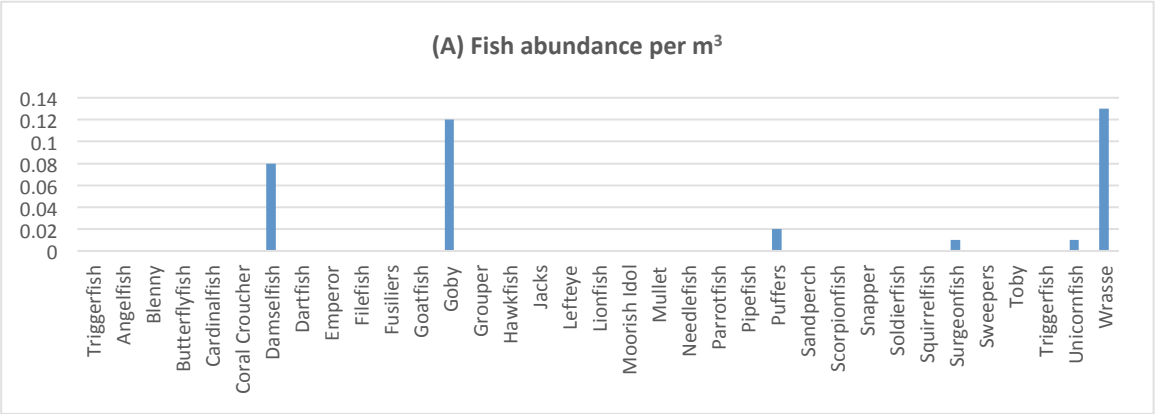
Fish diversity was reasonable, with 6 species observed. They were resident amongst the rocky parts of the site where they could find refuge.

H. leucospilota and *H. atra* were more abundant at this site, living both on the sandy bottom and amongst the coral and rock.

The sediment sample was 8 cm deep and was homogenous fine to coarse sand.

Figure 3: A3 Parengaru lagoon mid: (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

A4 Parengaru Lagoon Outer



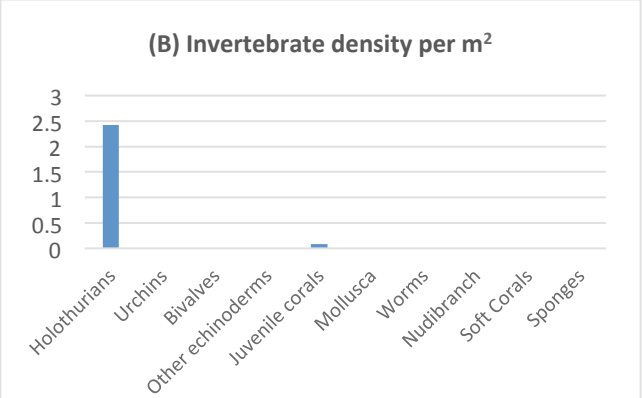
This site was typical of the lagoon with sand and algae assemblage based on the *Caulerpa* sp. forming mats on the sandy bottom.

Holothurians dominated the invertebrate data with low counts of juvenile corals noted. *Holothuria leucospilota,* and *H. atra* were more abundant at this site.

Fish diversity was reasonable, with 6 species observed. They were resident amongst the rocky parts of the site where they could find refuge.

The benthos was dominated by algae growing on basement limestone and sand. Notably, massive corals and fire corals registered on the survey indicating the presence of rocky coral bommie structures typical for this part of the lagoon.

The sediment core was 5 cm deep, well mixed, fine to coarse calcium carbonate sands.



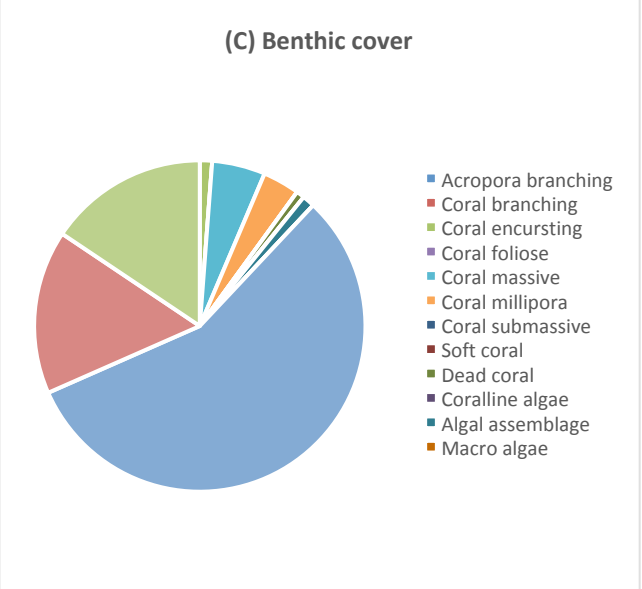
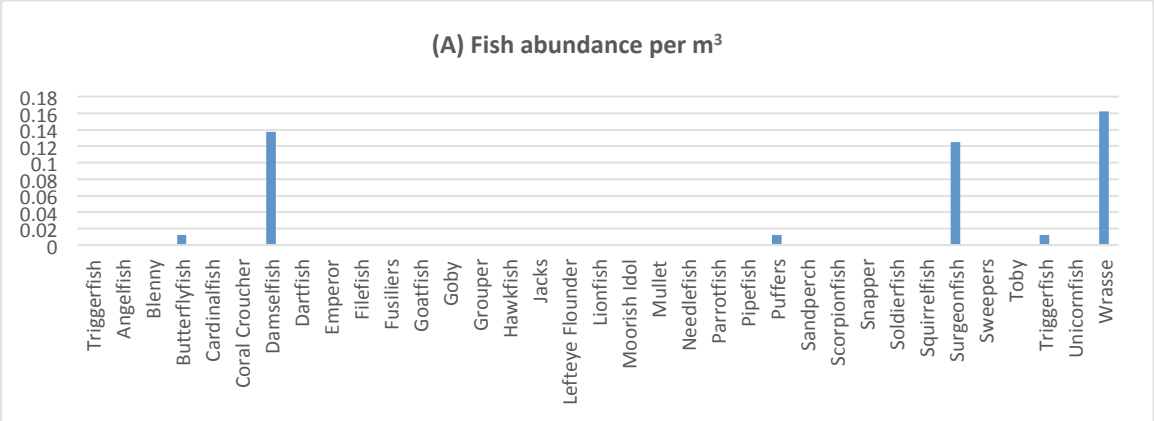
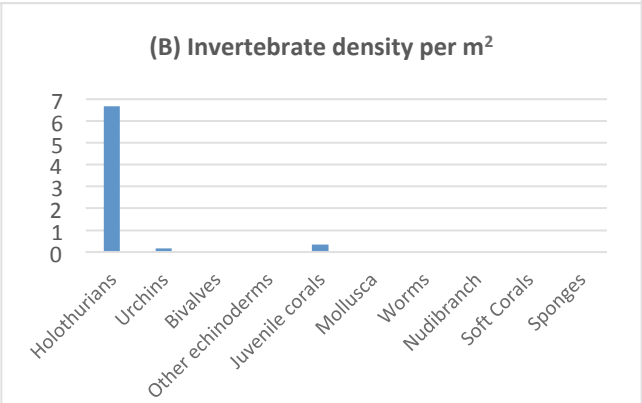
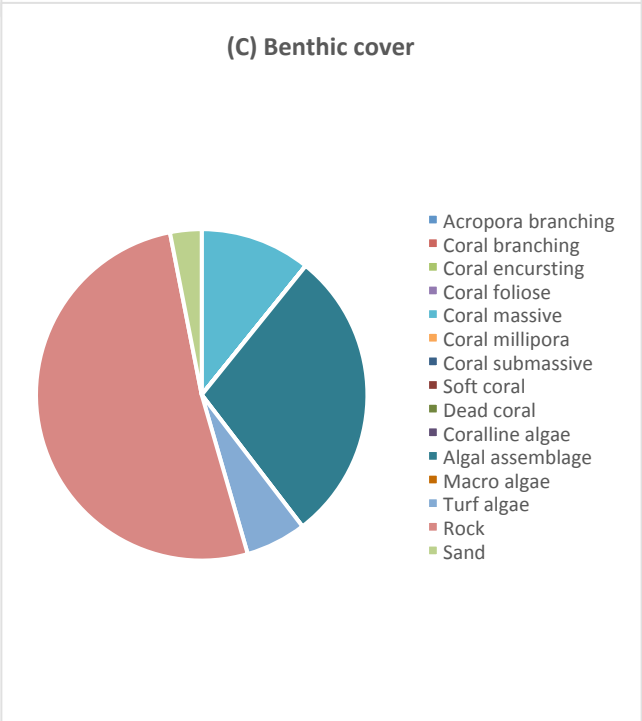


Figure 4: A4 Parengaru lagoon outer (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

A5 Parengaru Back Reef







This site was the first sampled. It was as close to the reef crest as possible while still being deep enough to swim and conduct the survey. Rock and algae assemblage dominated the benthos with representation of corals as well. There was a range of algae present including *Caulerpa* sp., *Turbinaria* sp. and others.

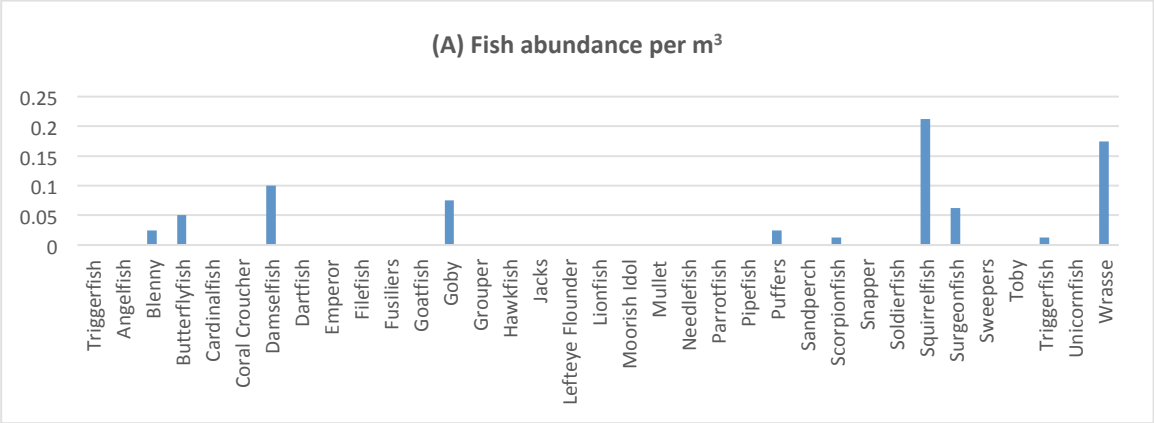
Holothurians dominated the invertebrate data with low counts of juvenile corals noted. *Holothuria leucospilota,* and *H. atra* were more abundant at this site. Urchins were found on the larger rock formations, most common was *E. mathaei. Leptoria* was the most common juvenile coral found at this site.

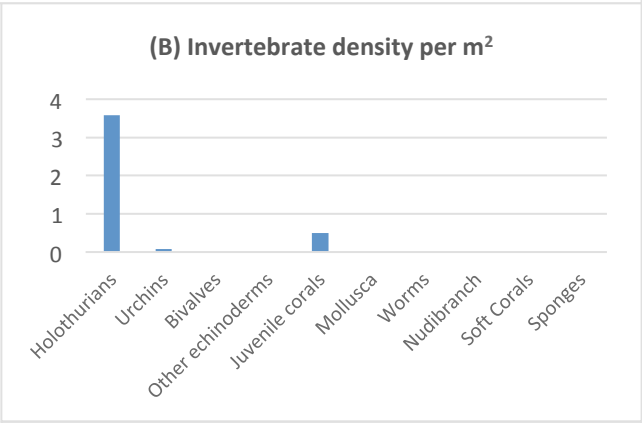
Fish diversity and abundance was consistent with other sites, with 6 species observed. They were resident amongst the rocky parts of the site or foraging on the algae.

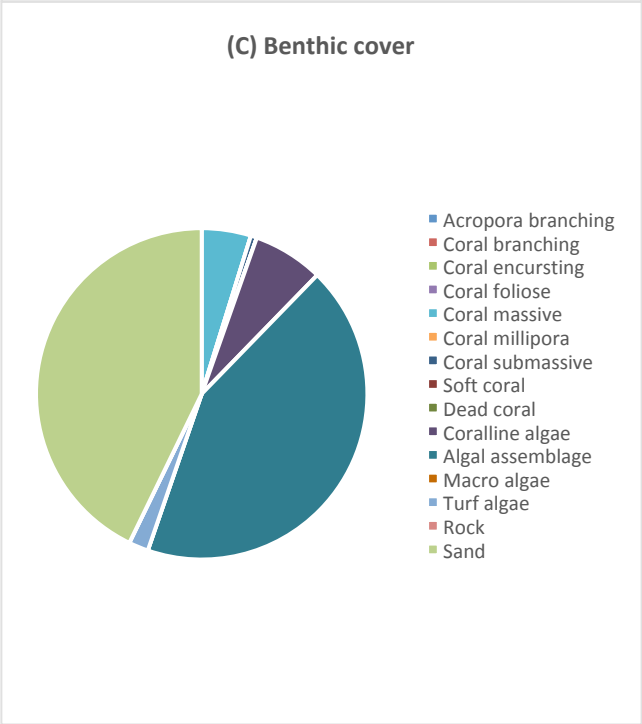
The sediment core was 9 cm deep, well mixed fine to coarse calcium carbonate sands.

Figure 5: A5 Parengaru back reef (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

B1 Taakoka Near Shore







This site was located between the beach and the island of Taakoka. Sand and algae dominated the benthos, however there was a reasonable representation of living coral at this site considering its proximity to the shore and the Parengaru stream mount.

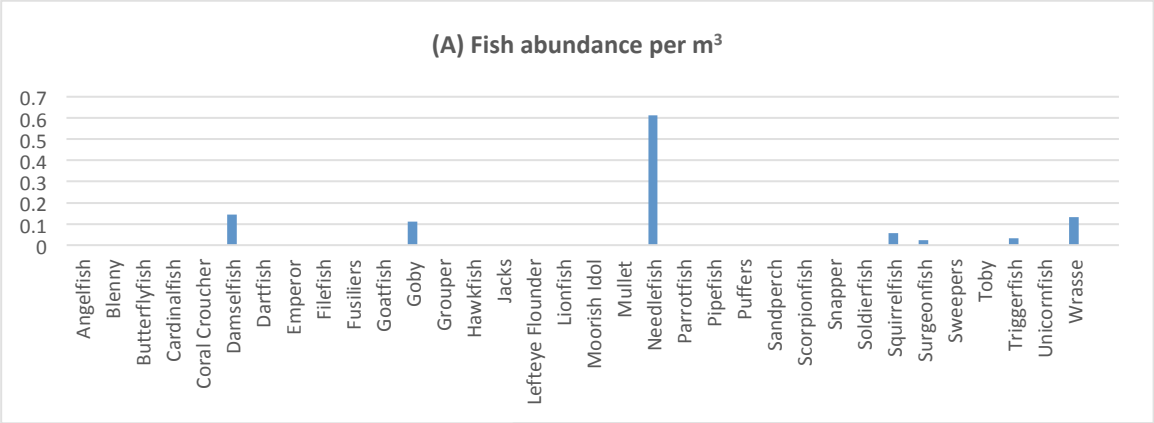
Holothurians dominated the invertebrate data with juvenile corals present at an abundance of 0.5m^2. *H. atra* was the only holothurian species present at this site. Urchins were found on the larger rock formations, most common was *E. mathaei. Favid* or *Goneastera* type corals were the type of juvenile coral found at this site.

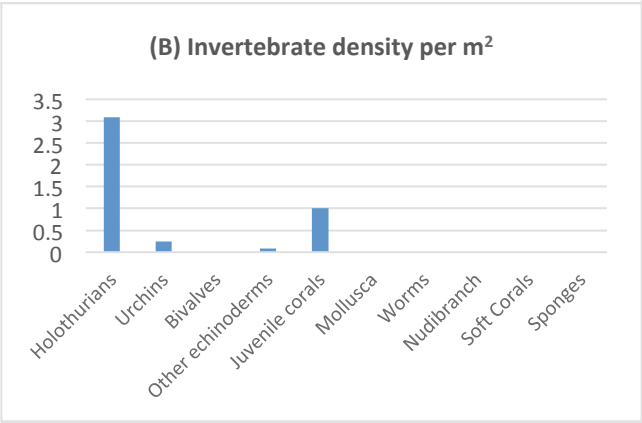
Fish diversity and abundance was higher than other sites, with 10 species observed. The site was quite diverse with a sandy bottom and coral and rock formation reaching the surface. The habitat seemed to suit the fish.

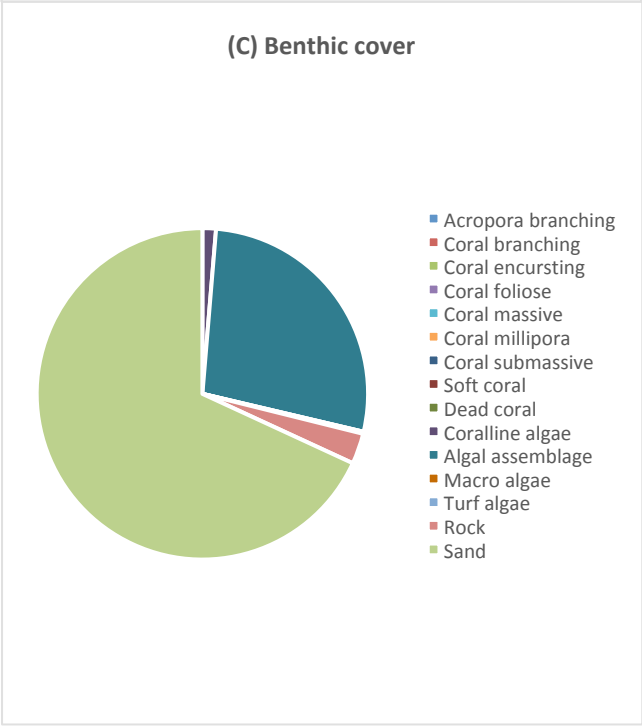
The sediment core was 13 cm deep, very fine to fine with some coarse calcium carbonate sands. There was a grey coloration halfway down and a sulphite rich smell to the sample.

Figure 6: B1 Taakoka near shore (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

B2 Taakoka Lagoon Inner







This site is NE of Taakoka and on the edge of the part of the lagoon that is completely sandy. Sand and algae dominated the benthos with the algal assemblage being typical for this lagoon, *Caulerpa* sp. forming a base for other algae to grow off. However, there was still significant amount of bare sandy habitat represented.

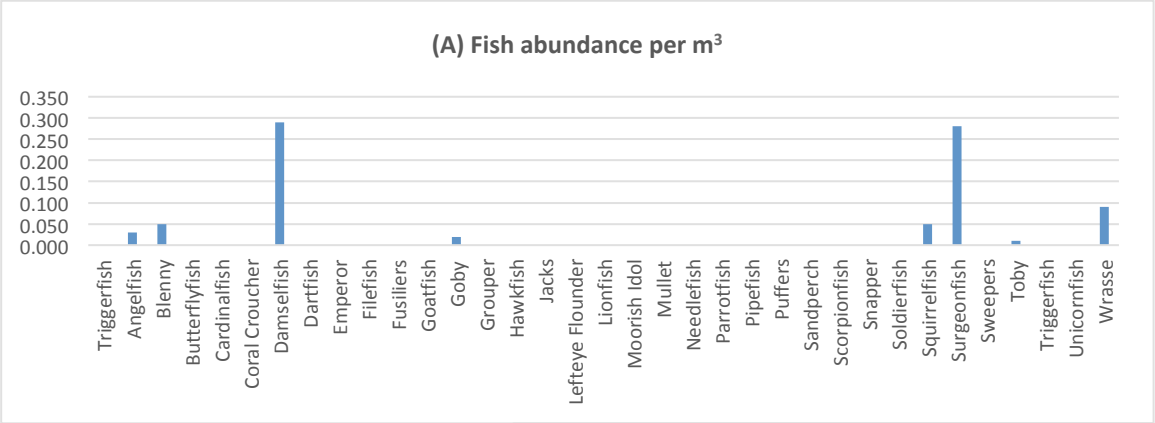
Holothurians dominated the invertebrate data with juvenile corals present at an abundance of 1m^2. *Holothuria atra* was the dominant holothurian species present with a few *H. leucospilota present where rocky substrate presented. Favid* or *Goneastera* type corals were the type of juvenile coral found at this site with 1 instance of a *Leptoria* sp.

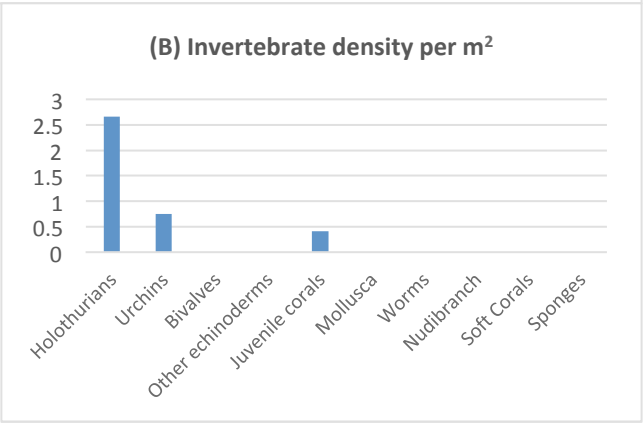
Fish diversity and abundance was consistent, with 7 species observed. In addition to the bottom dwelling fish previously seen, needlefish were counted here, a species that swims near the surface.

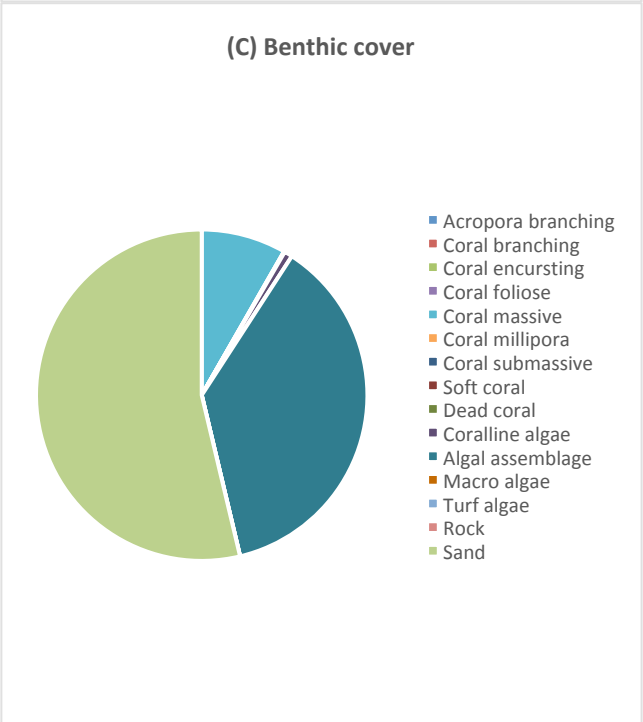
The sediment core was 13 cm deep, very fine to fine with some coarse calcium carbonate sands. There was a grey coloration halfway down and a sulphite rich smell to the sample.

Figure 1: B2 Taakoka lagoon inner (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

B3 Taakoka Mid Lagoon







This site is central to the lagoon adjacent to Taakoka. Sand and algae dominated the benthos with the algal assemblage being typical for this lagoon, *Caulerpa* sp. forming a base for other algae to grow off. 8% of the benthos was represented by massive coral. Rock covered with coralline algae registered as well, although less than 1%.

Holothurians dominated the invertebrate data with urchins and juvenile corals present. Juvenile corals had an abundance of 0.4m^2.

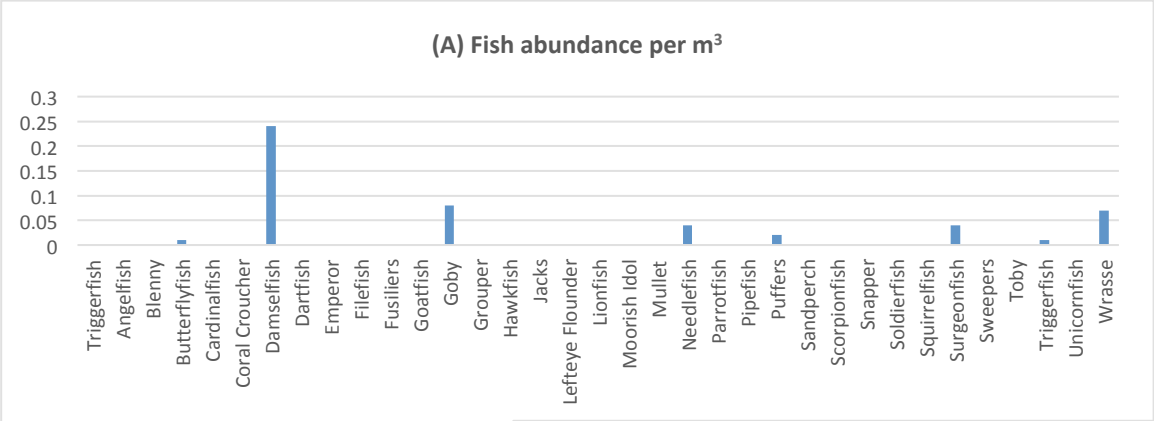
The urchin present is *E. mathaei. Both H. atra* and *H. leucospilota* were common.

Fish diversity and abundance was higher than at other sites, with 8 species observed and at higher densities as per the chart.

The sediment sample was 11 cm deep with a mix of coarse to fine calcium carbonate sands.

Figure 8: B3 Taakoka mid lagoon (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

B4 Taakoka Lagoon Outer Channel



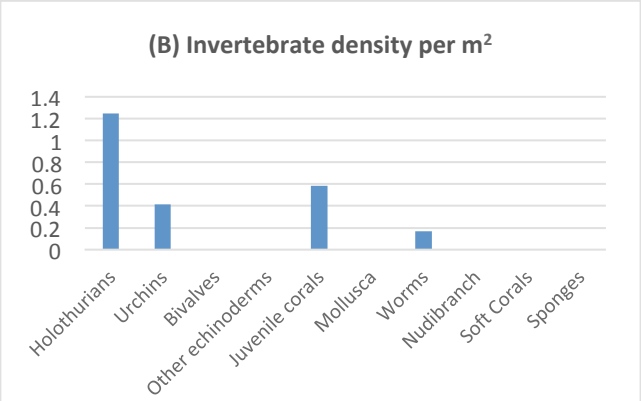
This site is between the outer reef and Taakoka motu. It forms a channel where flow is concentrated from SW to NE. It is the deepest site surveyed in the lagoon at 1.8 m. It was characterised by a sandy bottom with coral bommie formations and remnant formations with algae overgrown.

Holothurians, urchins, juvenile corals, and worms were all present in the survey.

Dendropoma maxima is the worm present, with the same urchin and holothurians as other sites. Coral species remained consistent with Leptoria, Porites and Favids present.

Fish diversity and abundance remains roughly the same as neighbouring sites, with 8 species observed. Density remained consistent as well.

The sediment sample was 9 cm deep with a mix of coarse to fine calcium carbonate sands.



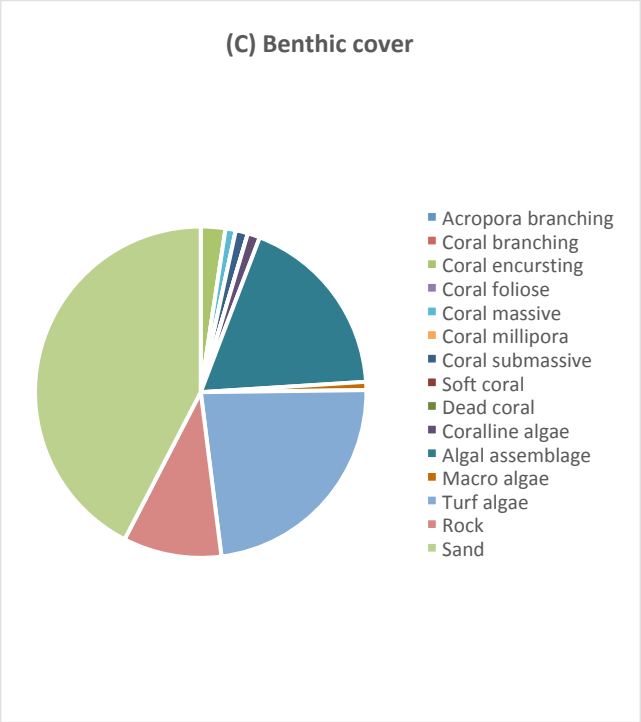
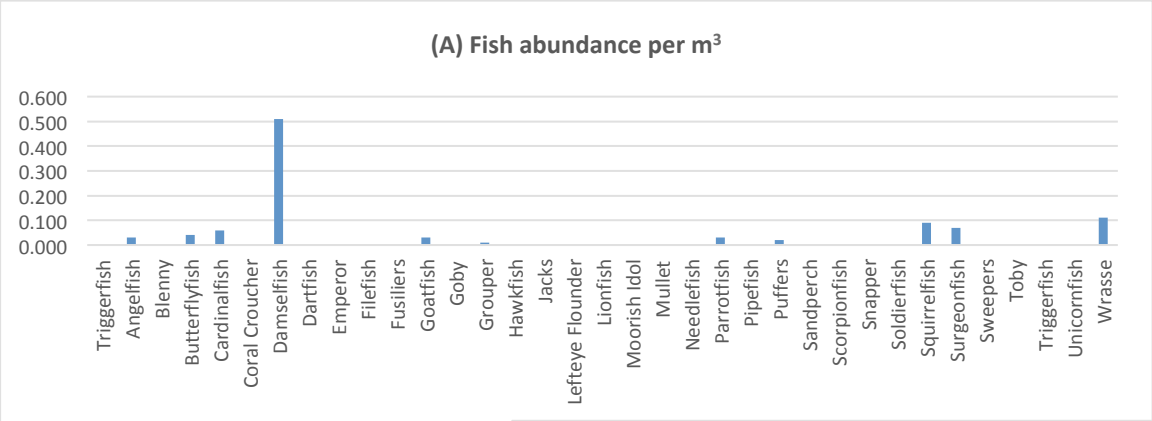
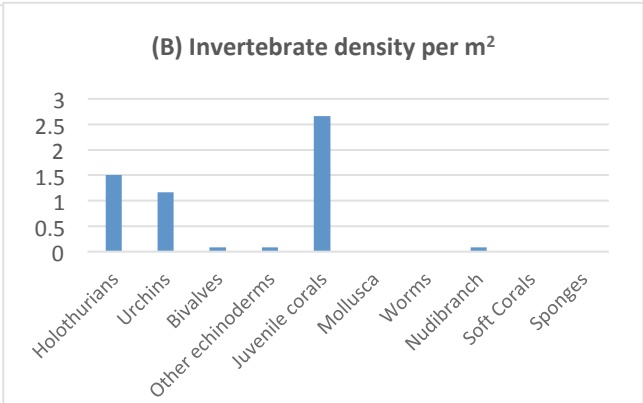
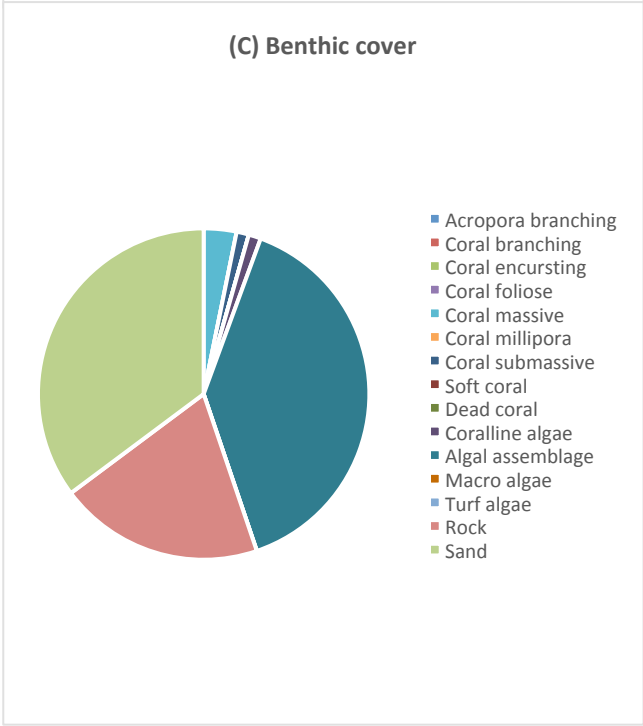


Figure 9: B4 Taakoka lagoon outer channel (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

B5 Taakoka Back Reef







The back reef environment presented as the most healthy and abundant part of the lagoon, despite its high energy and susceptibility to disruption from waves and rock movement. The site adjacent to Taakoka was the first of 4 healthy back reef sites along the outer edge of the lagoon.

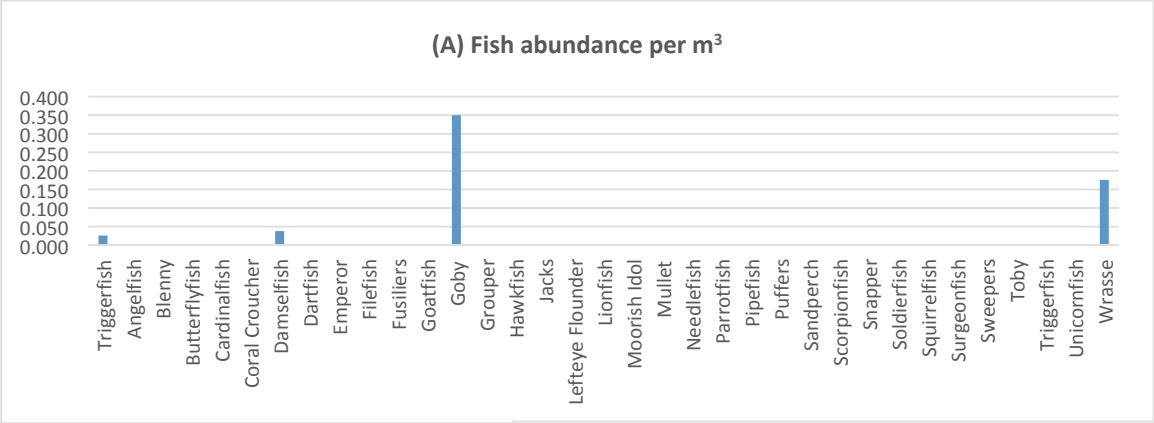
Juvenile corals dominated the invertebrate count with a density of 2.5m^2. A much higher diversity of invertebrates was found here, including holothurians, urchins, sea stars, juvenile corals, giant clams, and nudibranchs. Refer to the raw data table in the appendices for details on species present.

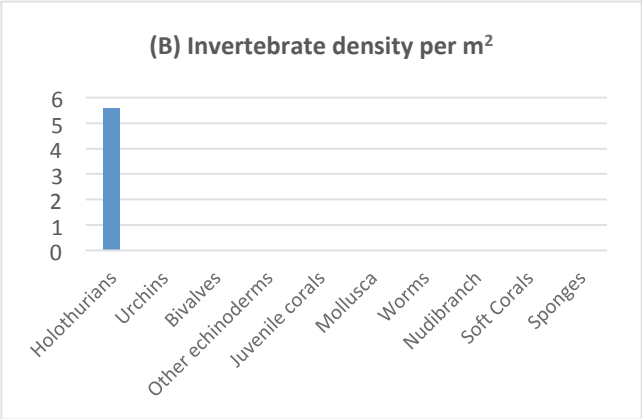
Fish diversity and abundance is higher here than on both the neighbouring sites, with 12 species observed and densities up to 5m^3 for damselfish.

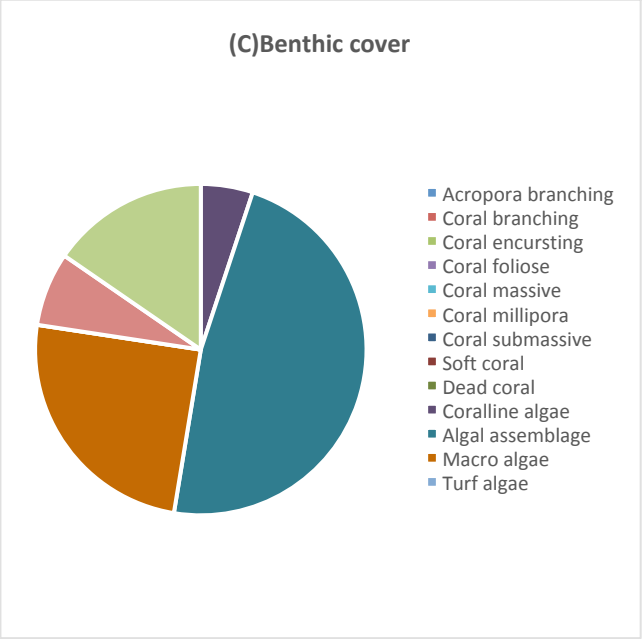
There was no sediment sample at this site as the coarse sand formed a very thin and mobile layer on the rock below.

Figure 10: B5 Taakoka back reef (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

C1 Aremango Near Shore







This site was located just off the beach in front of the Aremango Guesthouse. The benthos was dominated by a sandy substrate with intermittent rocky patches and abundant algae growth.

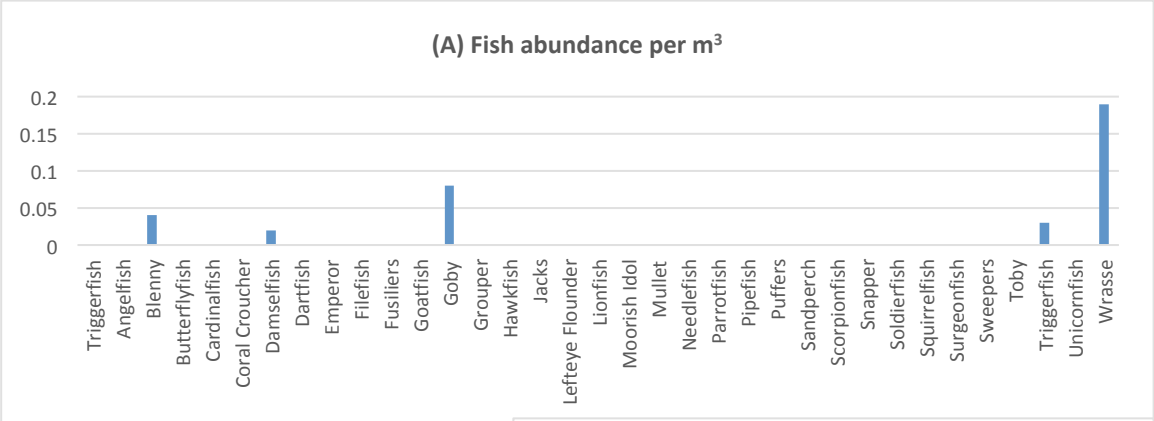
Holothurians were the only invertebrate present and in high abundance. *Holothuria atra* was the dominant species.

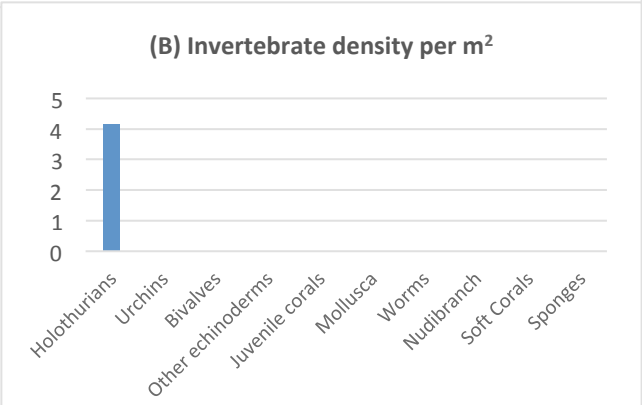
Fish diversity was low. Gobies were the most common, with juvenile wrasse also present living in holes excavated in the bottom.

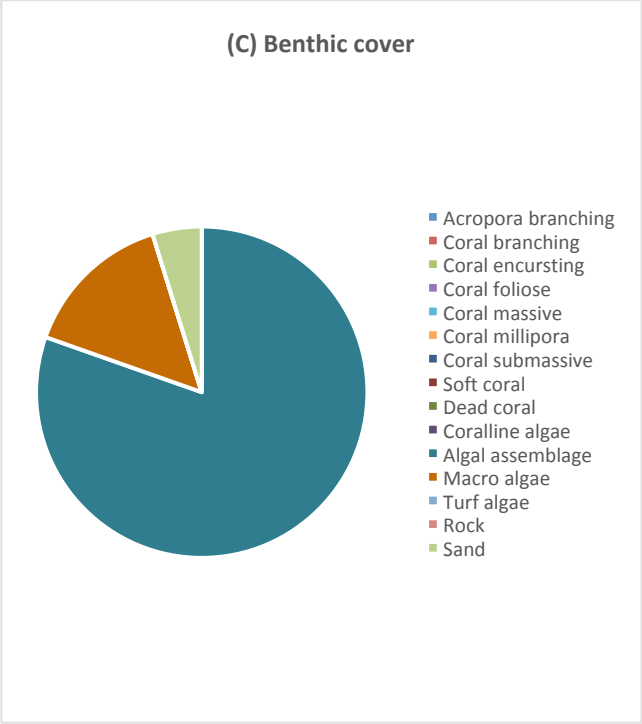
The sediment core was 12 cm deep, algae on top with some coarse sediment mixed amongst mostly fine calcium carbonate sands. Grey sulphite rich colouration and odour was present in the sample.

Figure 11: C1 Aremango near shore (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

C2 Aremango Lagoon Inner







This site was located in the sandy, shallow part of the near shore lagoon. The benthos was entirely sandy substrate with algae overgrowing it. The algae assemblage was the same as other sites, with a variety of algae growing off a *Caulerpa* vine matt.

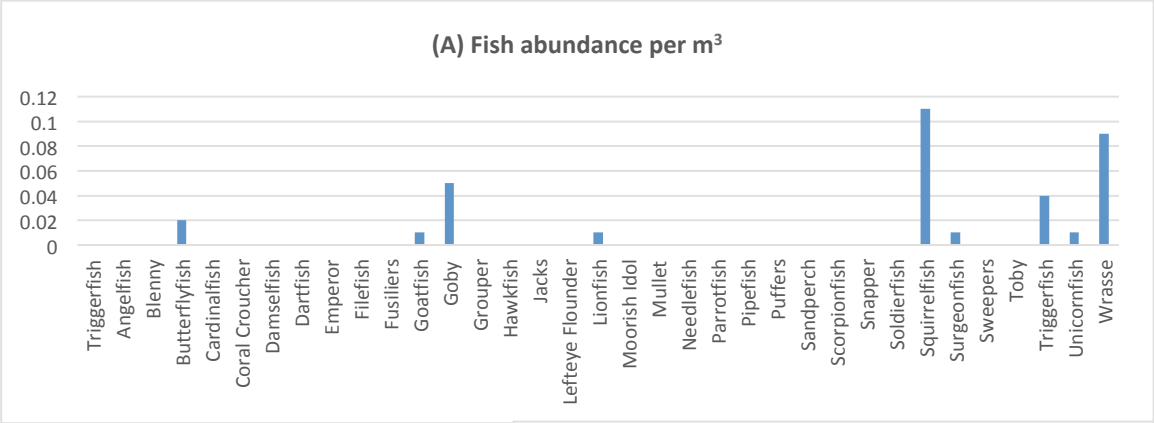
Holothurians dominated the invertebrate data with only *Holothuria atra* present.

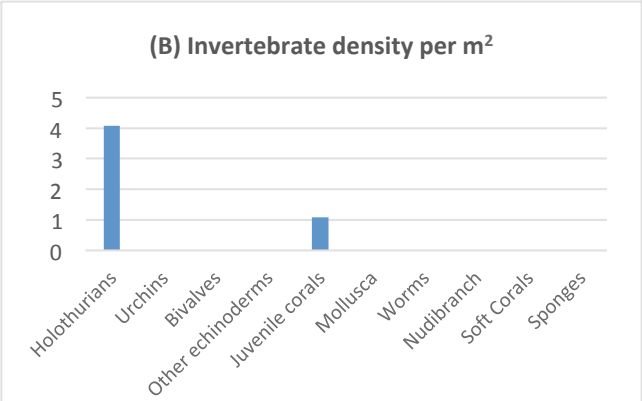
Fish diversity and abundance was low with mostly juvenile fish living and foraging amongst the sandy patches.

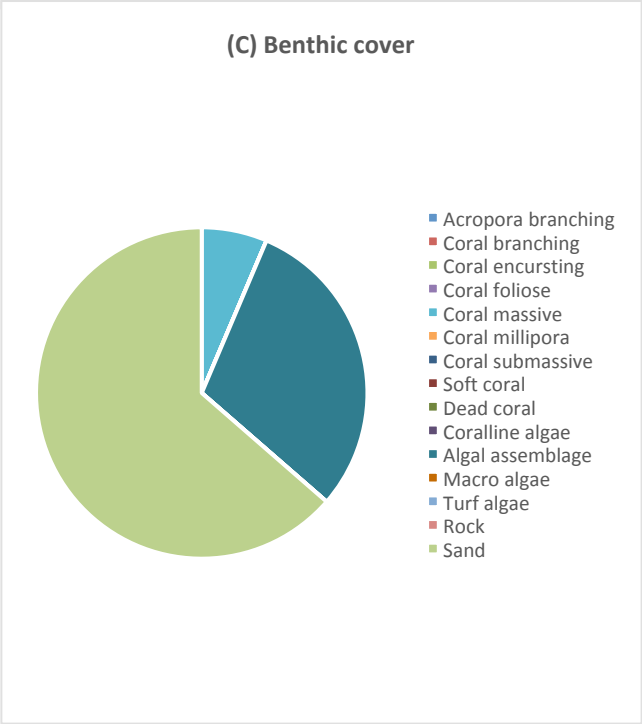
The sediment core was 7 cm deep, homogenous fine to moderate calcium carbonate sand with a grey sulphite rich colouration and odour throughout.

Figure 12: C2 Aremango lagoon inner (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

C3 Aremango Lagoon Mid







This site is located in the central part of the Muri lagoon, beyond the immediate coastal area. The benthos is predominantly a sandy bottom with patches of algae growth typical of the other sites. There were also coral bommie formations of massive *Porites* sp. colonies in the area.

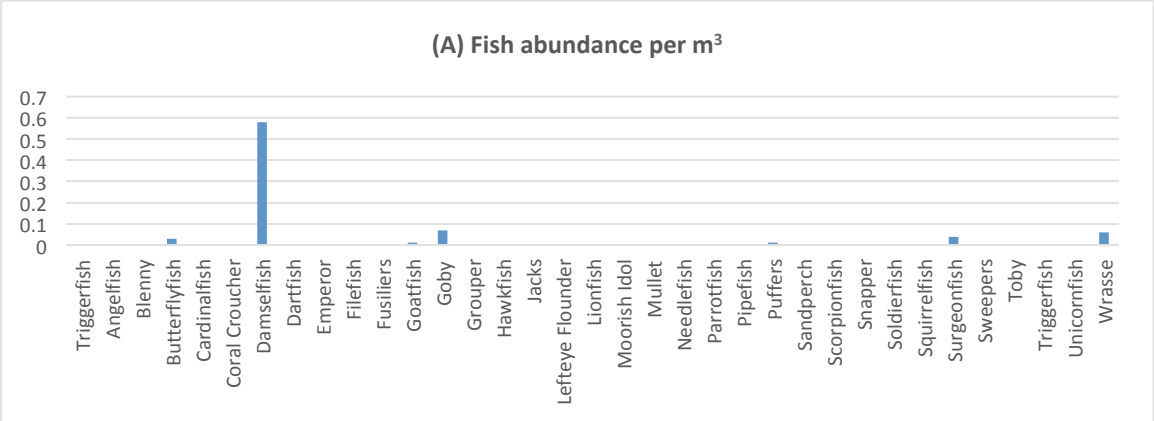
Holothurians dominated the invertebrate data with both *Holothuria atra* and *H. leucospilota* present. Juvenile corals were present at a relatively high abundance for the lagoon, of 1 m^2.

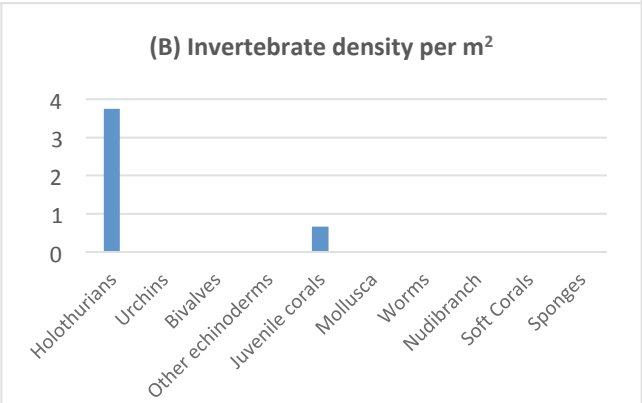
Fish diversity and abundance was higher with 9 family groups present. Abundance was only moderate for the study, with most fish moving through the area rather than being resident.

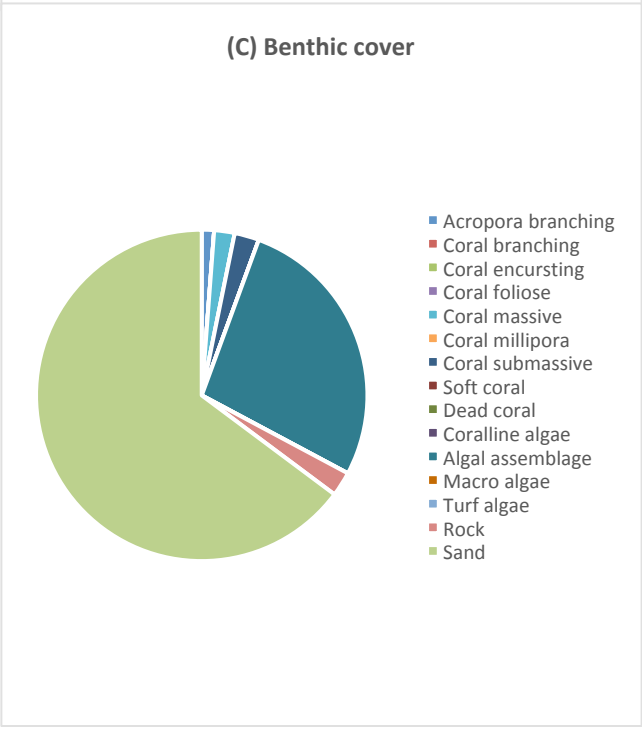
The sediment core was 10 cm deep, homogenous fine to moderate calcium carbonate sand.

Figure 13: C3 Aremango lagoon mid (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

C4 Aremango Lagoon Outer







This site is located in the outer part of the Muri lagoon, in the deeper area. The benthos is predominantly a sandy bottom with patches of algae assemblage thinner and less abundant than sites shore ward. There were also coral bommie formations and some dead coral structures recorded as rock.

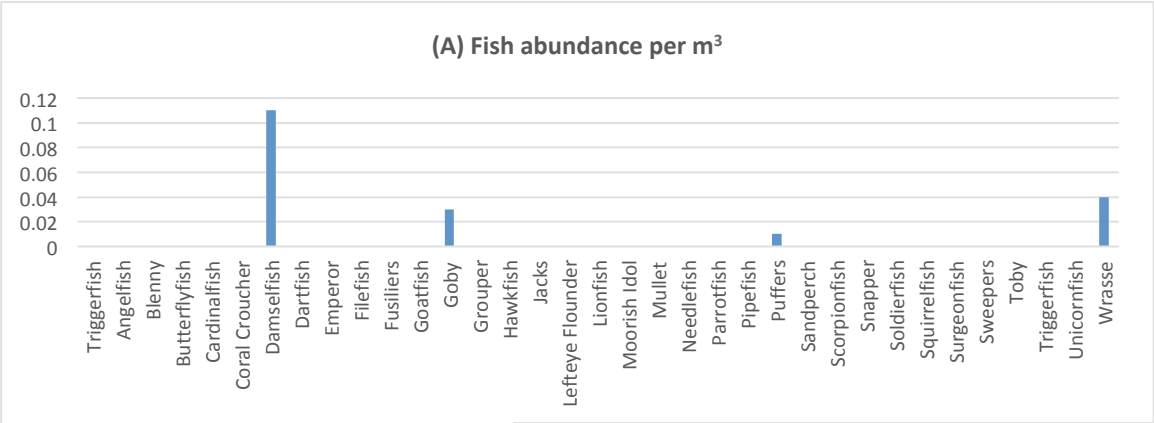
Holothurians dominated the invertebrate data with both *H. atra* and *H. leucospilota* present. Juvenile corals present were *Porites* sp.

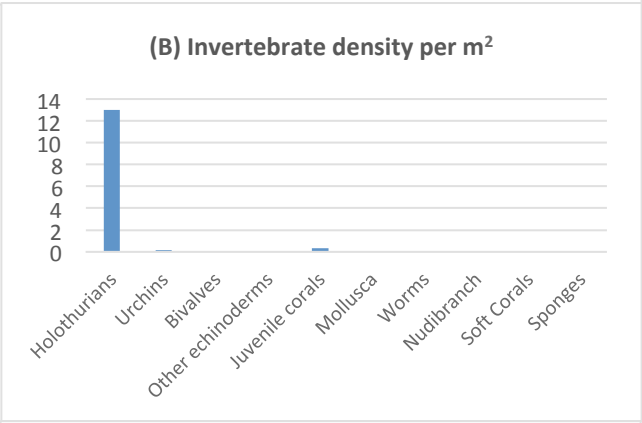
Fish diversity was moderate, but with low abundance except for damselfish.

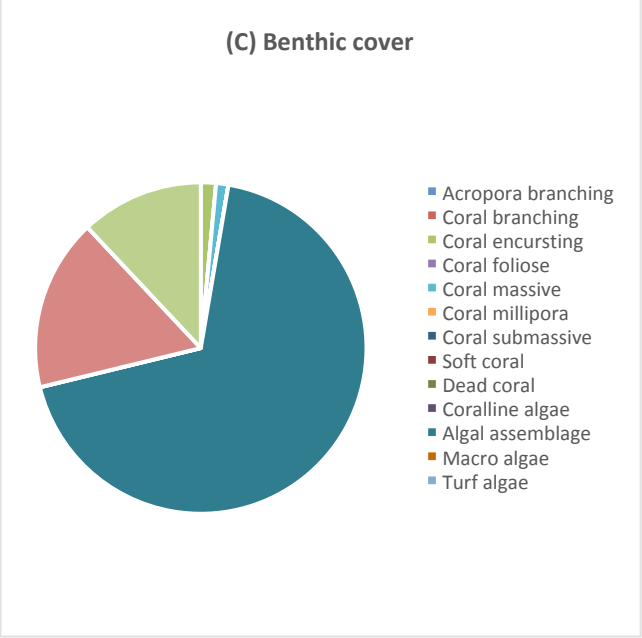
The sediment core was 6 cm deep, homogenous moderate to coarse calcium carbonate sand.

Figure 14: C4 Aremango lagoon outer (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

C5 Aremango Back reef







This site is located in back reef area. The benthic substrate was characterised by loose sand and rock or rubble with a thin algal growth covering most of it. There were patches of coral represented in the survey.

Holothurians were in high density. Urchins and juvenile corals were also present in low numbers.

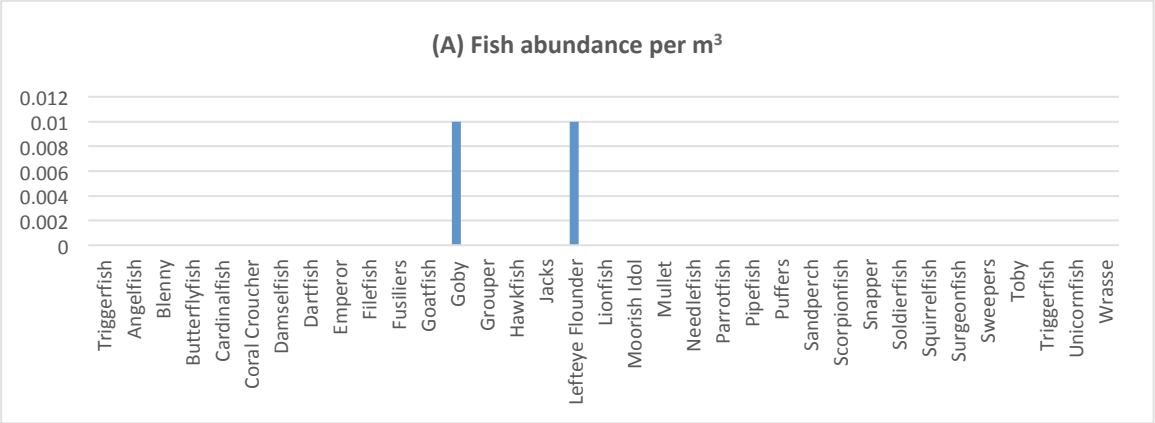
Fish diversity and abundance was low.

Compared to other back reef sites, this site was more barren than expected. The loose rock and rubble created less habitat than at other sites in the back reef environment. The greater presence of algae was also in interesting observation.

No sediment core was taken as the coarse sand formed only a thin and mobile layer over the basement limestone.

Figure 15: C5 Aremango back reef (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

D1 Kauvai Near Shore



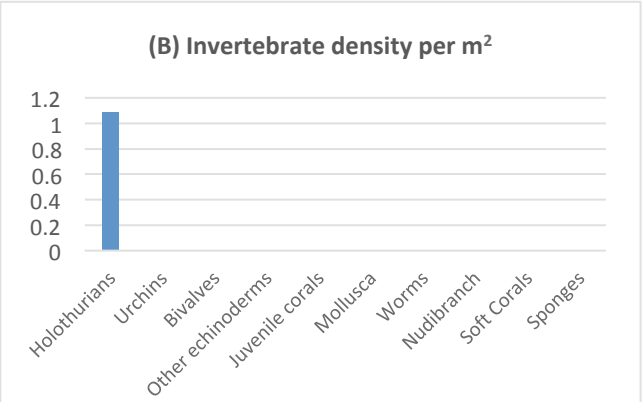
This site is located near shore central to the Muri lagoon in the vicinity of the lagoon cruise bases and Sails restaurant.

The benthos is completely dominated by an algal mat over the top of a sandy substrate. The algal mat is the same as other areas but appears more established.

Fish diversity and abundance was extremely low with just 2 single individuals being seen.

Invertebrate density was low also, with only *H. atra* present.

The sediment core was 19 cm deep, algae on top with a homogenous fine sand and silt mix with grey sulphite rich colouration and odour.



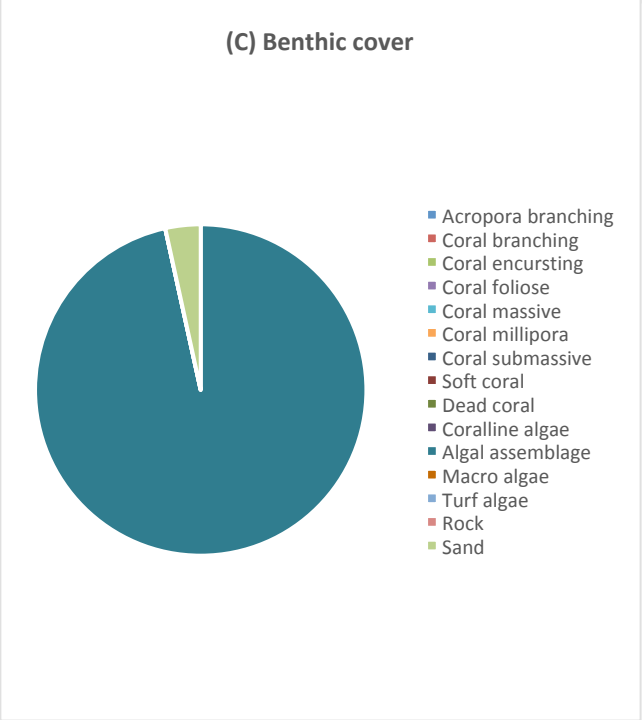
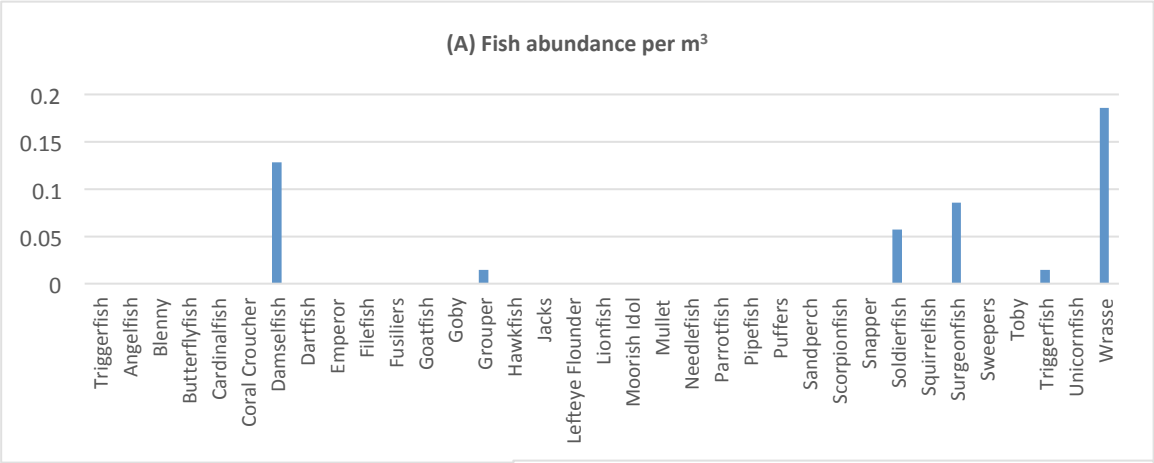


Figure 16: D1 Kauvai near shore (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

D2 Kauvai lagoon inner

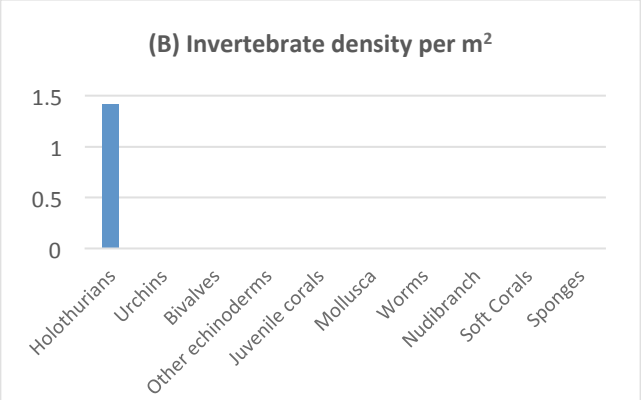


This site was located in the sandy, shallow part of the near shore lagoon. The benthos was entirely sandy substrate with algae overgrowing it. The algae assemblage was the same as other sites although not as dense as the previous site, with a variety of algae growing off a *Caulerpa* vine mat.

Holothurians dominated the invertebrate data with only *H. atra* present at a density of 1.4m^2.

Fish diversity and abundance was low to moderate, with 6 species and an abundance of about 0.1m^3.

The sediment core was 11 cm deep, homogenous fine to moderate calcium carbonate sand with a grey sulphite rich colouration and odour throughout.



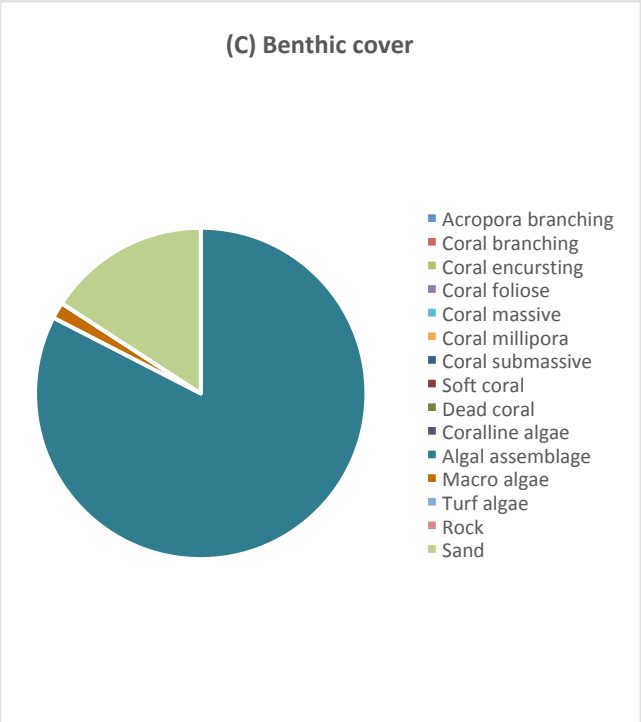
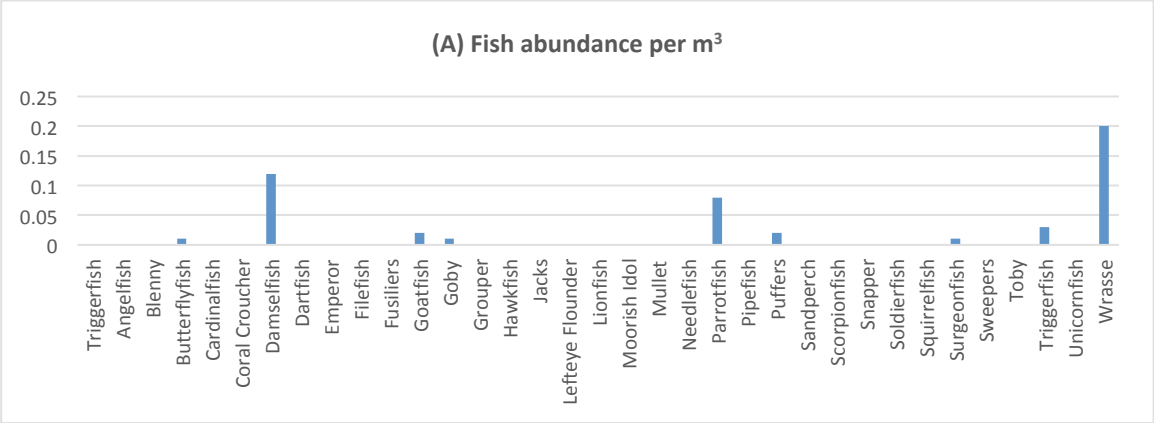


Figure 17: D2 Kauvai lagoon inner (A) Fish abundance per m3; (B) Invertebrate density per m2; (C) Benthic cover.

D3 Kauvai lagoon mid

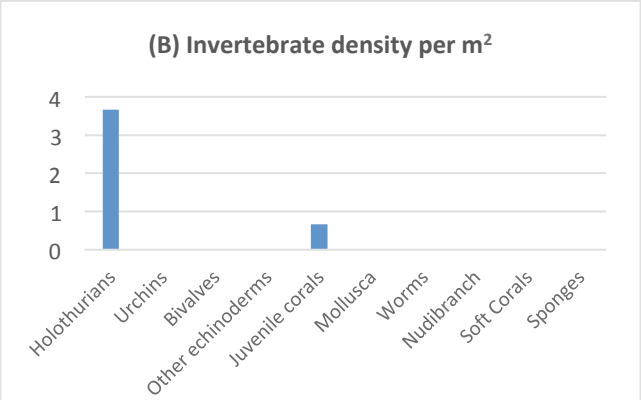


This site is located in the central part of the Muri lagoon, beyond the immediate coastal area. The benthos is predominantly a sandy bottom with patches of rock and algae growth.

Holothurians dominated the invertebrate data with both *H. atra* and *H. leucospilota* present but *H. atra* dominating. Juvenile corals were present at an abundance of 0.6 m^2.

Fish diversity and abundance was higher with 9 family groups present. Abundance was only moderate for the study.

The sediment core was 7 cm deep, homogenous fine to moderate calcium carbonate sand.



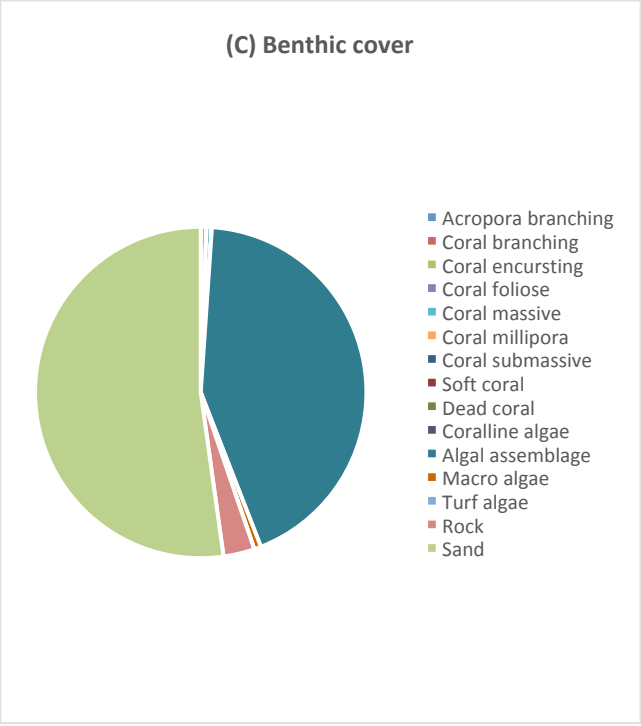
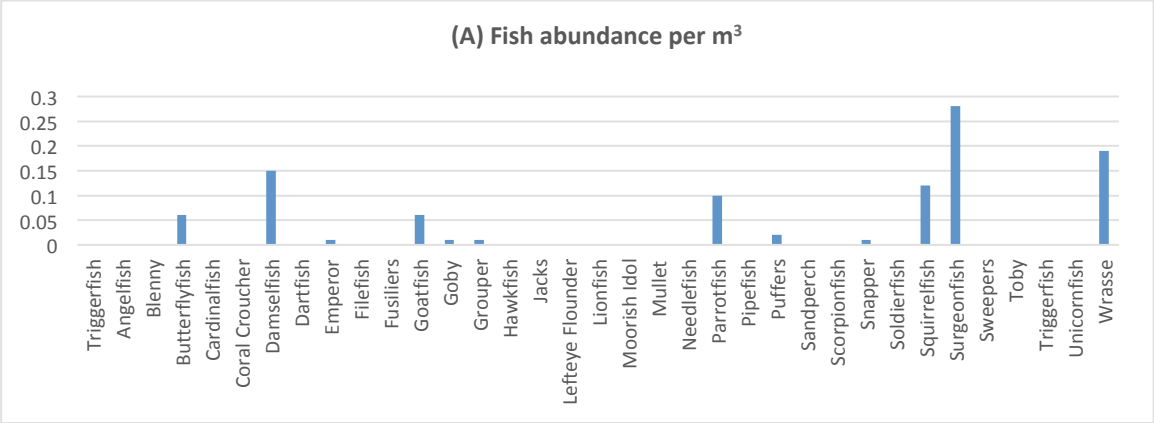
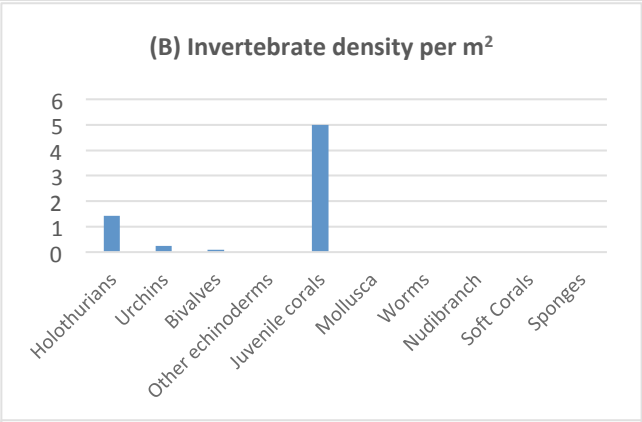


Figure 18: D3 Kauvai lagoon mid (A) Fish abundance per m3; (B) Invertebrate density per m2; (C) Benthic cover.

D4 Kauvai lagoon outer





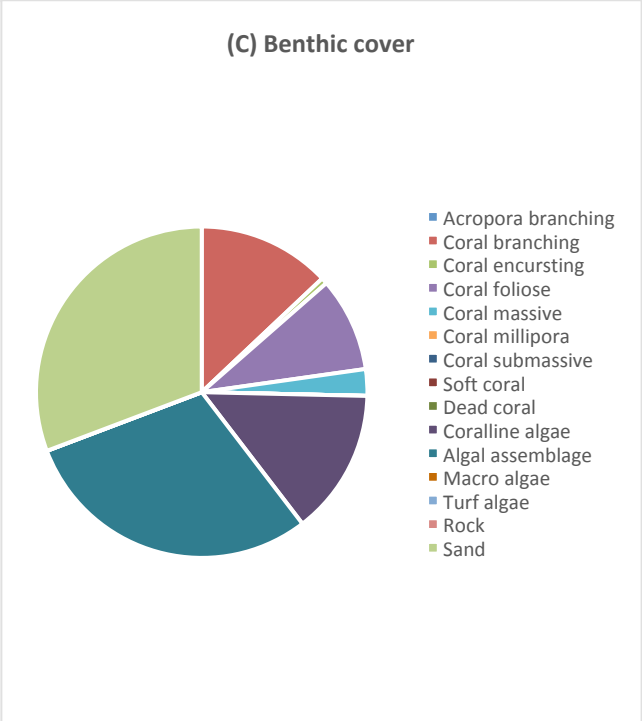


Figure 19: D4 Kauvai lagoon outer (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

This site is located in the outer part of the Muri lagoon, in the deeper area. The benthos is a sandy bottom with patch reef and coral bommies in the area. The rock was generally covered in a turfing or filamentous algal assemblage, with patches of coralline algae. Corals featured significantly at this site compared to other sites in similar locations.

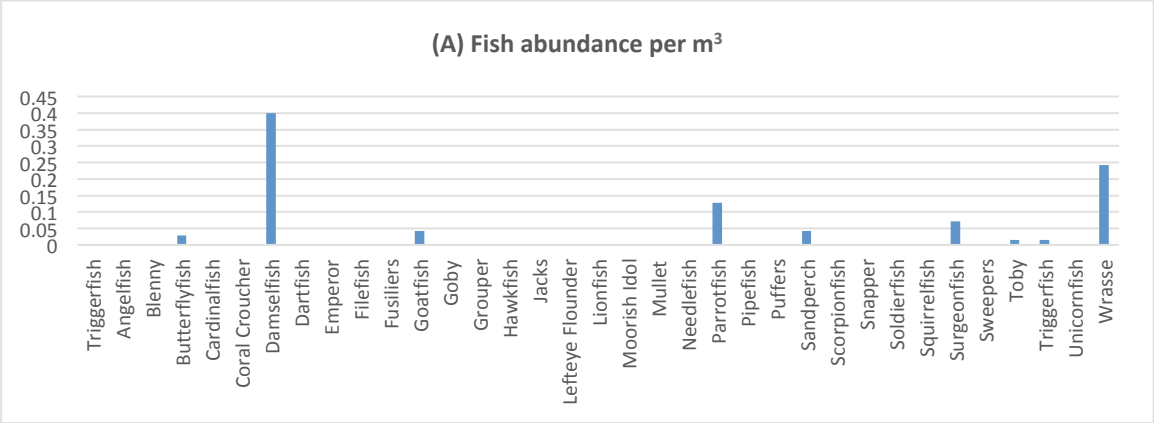
Like the benthic sampling, corals had a higher than usual representation in the invertebrate data compared to other lagoon sites, at 5 m^2. Holothurians were present as well, along with urchins and *Tridacna* clams.

Leptoria, Fungia, Porites, Favids/Goneastera, Pocillopora and *Millipora* were all present in the juvenile coral survey.

Fish diversity was also high with 12 family groups present. Abundance was moderate.

The sediment core was 8 cm deep, homogenous fine to moderate calcium carbonate sand with a slight grey colouration.

D5 Kauvai back reef

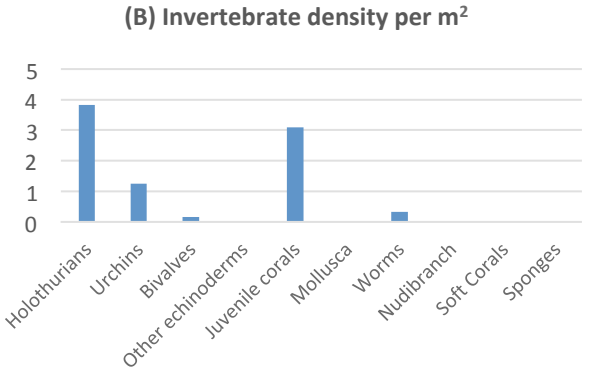


This site is located in back reef area. The benthic substrate was characterised by loose sand with a thin algal growth covering most of it. Coral colonies of varying sizes are spread throughout the area. The benthic survey identified massive, branching, branching *Acropora* and encrusting corals.

Invertebrate populations were healthy with holothurians and juvenile corals in relative abundance. Urchins were also common, and *Tridacna maximus* clams and *Dendropoma maxima* (vermetid worms) were identified in the survey.

Fish diversity and abundance was high for the study, with damselfish and wrasse continuing to dominate.

No sediment core was taken as the coarse sand formed only a thin and mobile layer over the basement limestone.



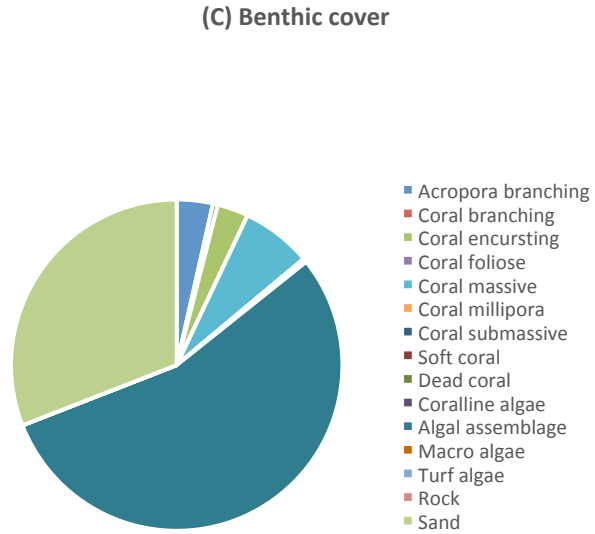
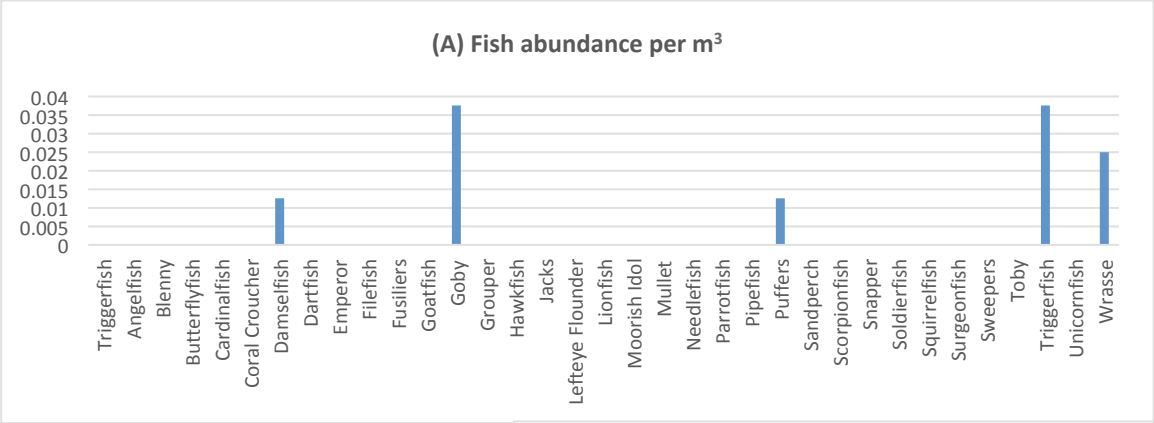


Figure 20: D5 Kauvai back reef (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

E1 Koromiri near shore



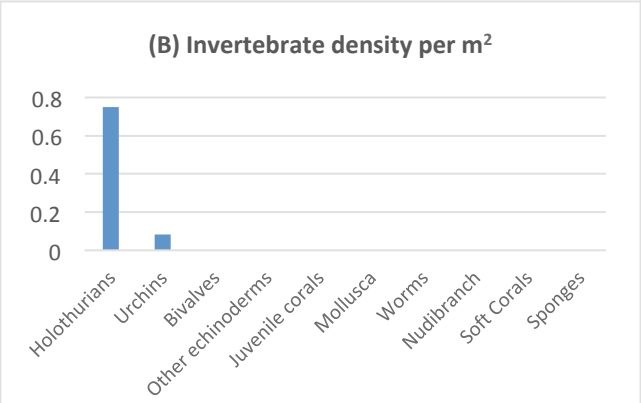
This site is located close to the beach between Pacific and Muri Beach Club resorts. There is a small stream that intermittently flows out, and the site is in the proximity of the delta that stream forms.

The benthos was sand with algae growing over, recorded as either macro algae or algal assemblage. One coral colony was sampled on the transect.

Invertebrate populations were predominantly holothurians, although in relatively low densities. Urchins were also present on the coral and rock feature on the transect.

Fish diversity and abundance was low and very low, with only 5 family groups represented, and at abundances below 0.04 m^3.

The sediment core was 17 cm deep, fine to moderate calcium carbonate sands with grey sulphite rich colouration throughout.



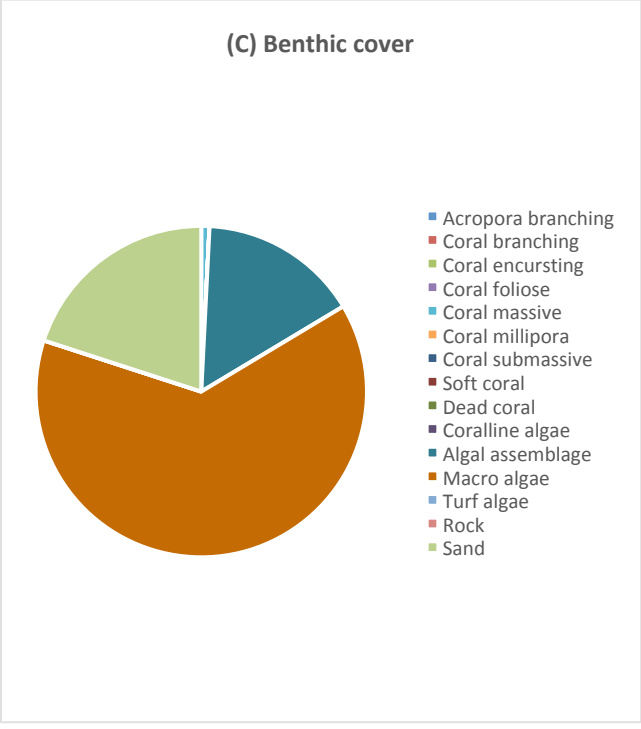
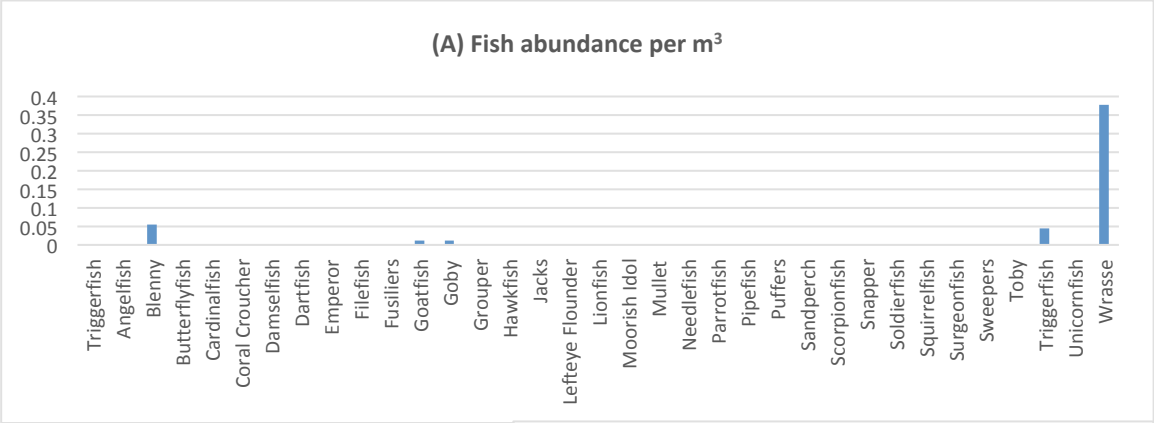


Figure 21: E1 Koromiri near shore (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

E2 Koromiri channel



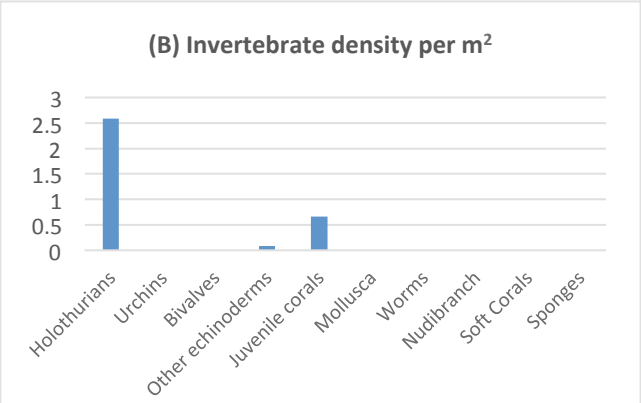
This site is located between the beach at Muri and the shoreward point of Koromiri motu. It is the area of fastest flow in the lagoon.

The benthos was sand and rock with algal growth covering over half the benthos. On the rock coralline algae was also recorded.

Invertebrate populations were predominantly holothurians and in moderate densities. A brittle star was sampled in the quadrats, along with a surprising amount of juvenile corals at 0.5 m^2.

Fish diversity was low, but abundance was relatively high for wrasse.

No sediment core was taken as the sand layer was thin and mobile.



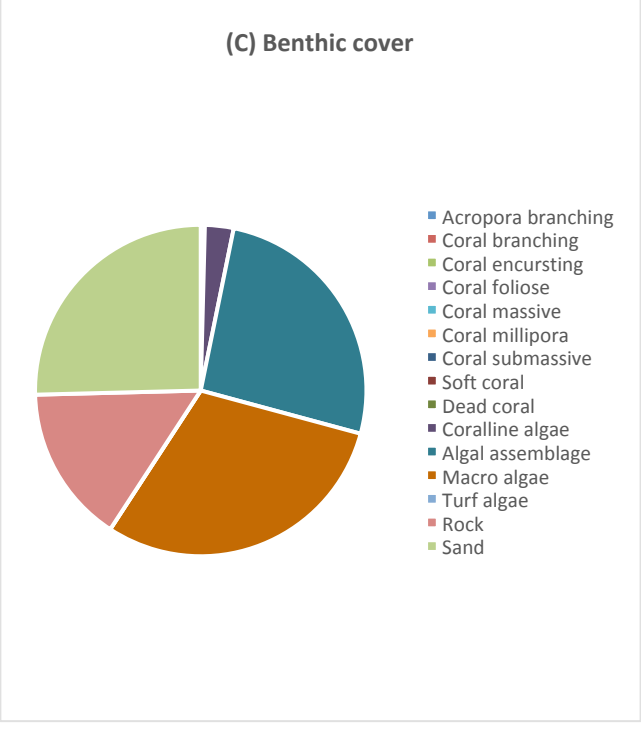
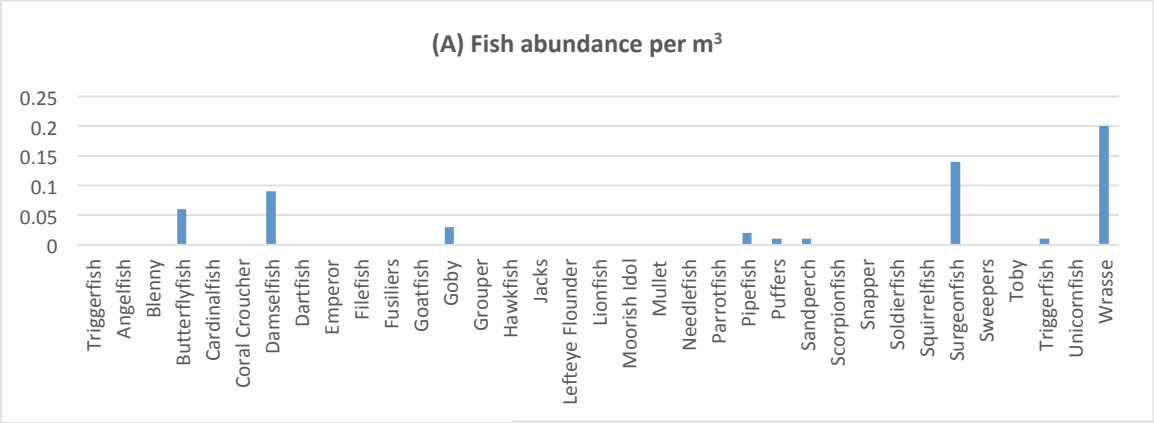
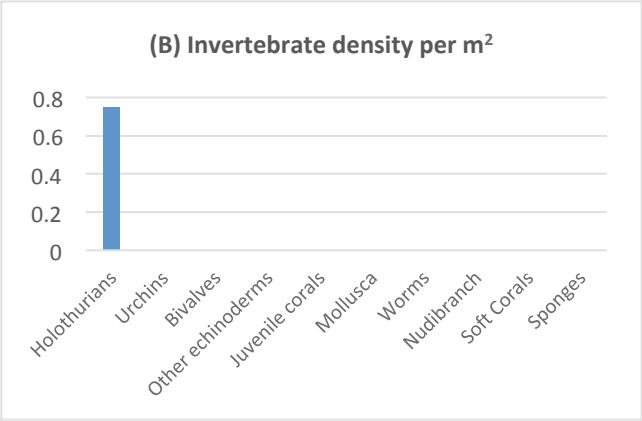
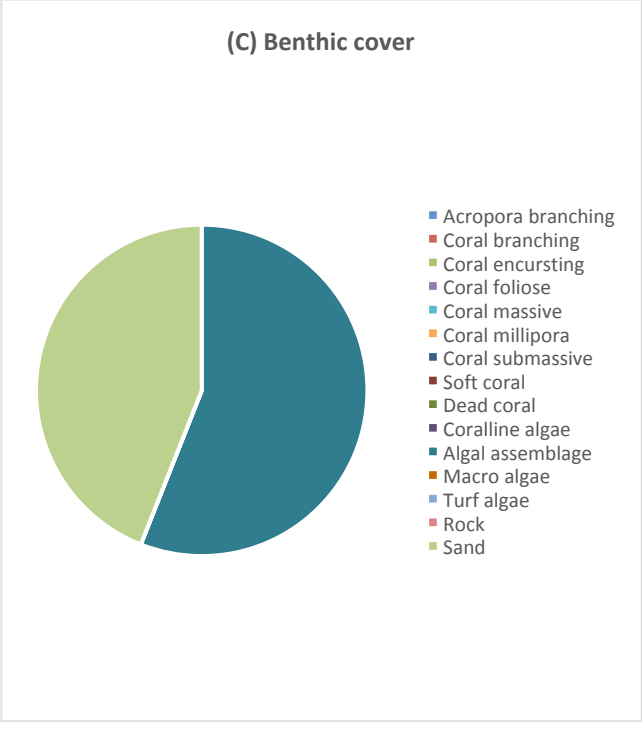


Figure 22: E2 Koromiri channel (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

E3 Koromiri Bay







This site is located in the bay of Koromiri motu. The benthos is predominantly sand with occasional coral formations in the area.

The transect ran over sand only, which had the typical algal mat found in the lagoon.

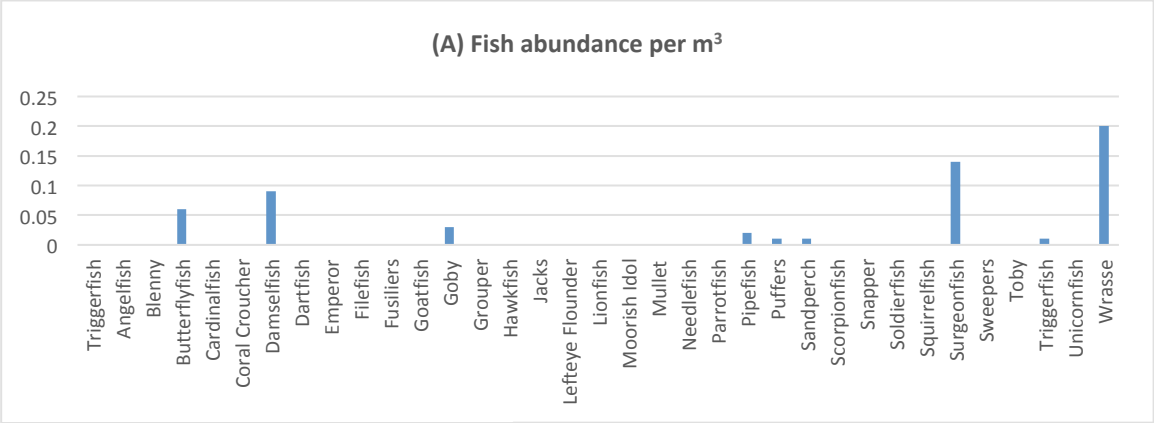
Invertebrate populations were predominantly holothurians but in low densities. No other invertebrates were recorded.

Fish diversity was moderate with 9 family groups present, and abundance low to moderate.

The sediment core was 13 cm deep, fine to moderate calcium carbonate sands with grey sulphite rich colouration throughout.

Figure 23: E3 Koromiri Bay (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

E4 Koromiri lagoon outer



This site is located on the ocean side of Koromiri motu. The benthos is dominated by sand and algae with some rock and coral colonies in the area.

Invertebrate populations were holothurians and juvenile corals with some urchins and worms on the rocky areas. Corals identified were *Leptoria, Fungia, Porites and Favids/Goneastera,* Holothurians were both *H. atra* and *H. leucospilota*. No other invertebrates were recorded.

Fish diversity was moderate with 9 family groups present, and abundance low to moderate.

The sediment core was 7 cm deep, coarse to moderate calcium carbonate sands.

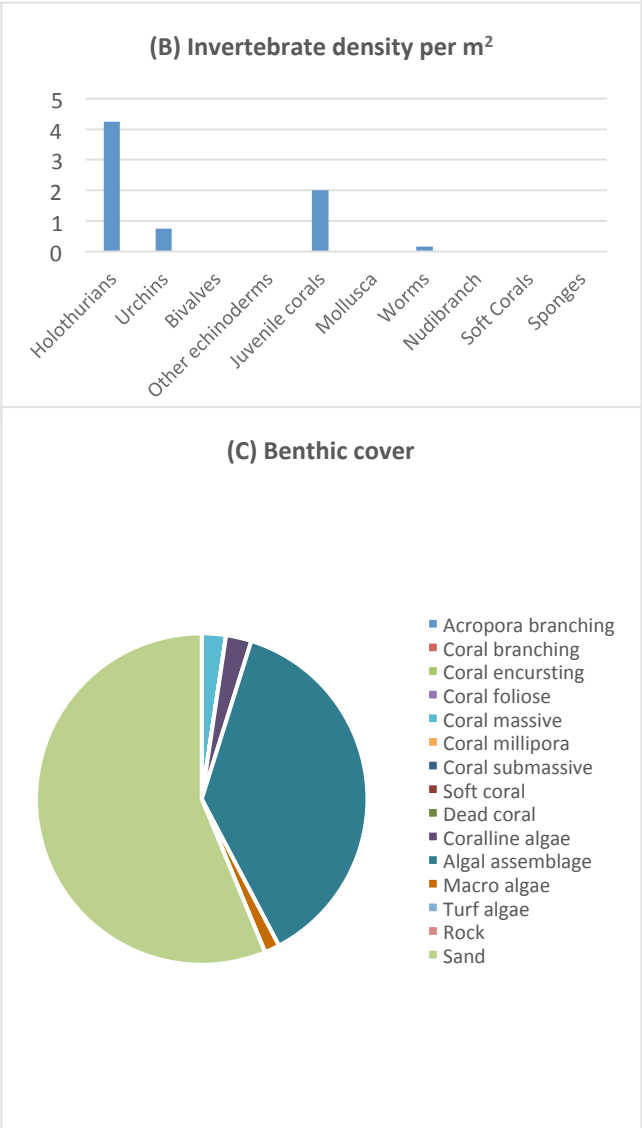
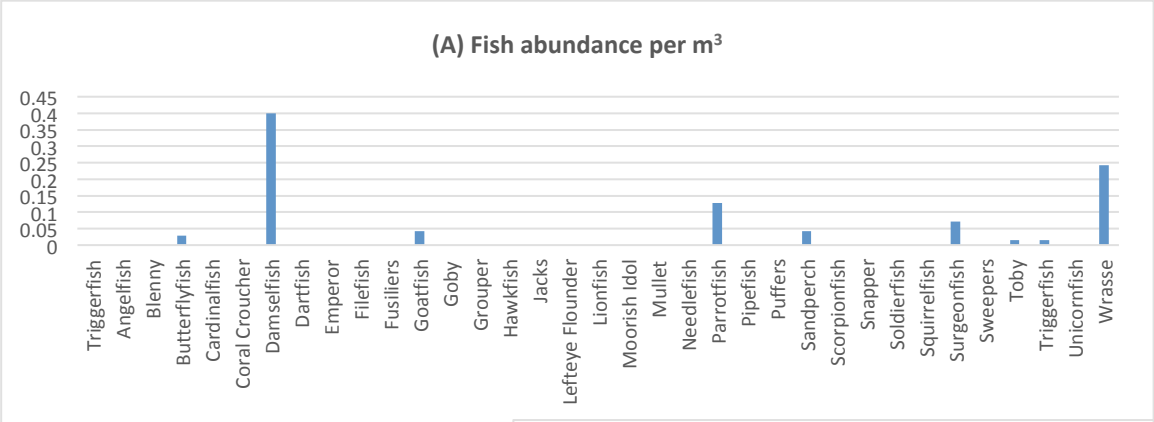
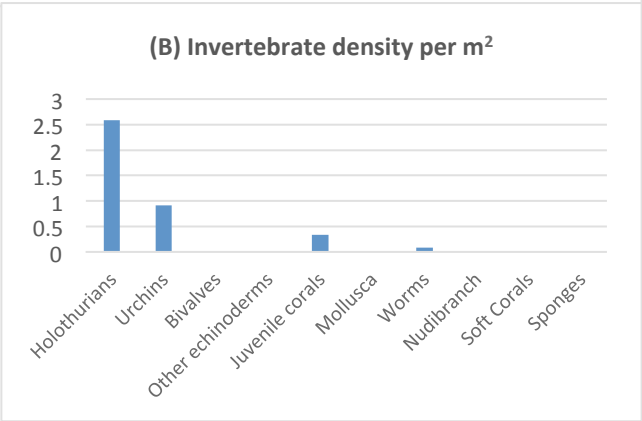
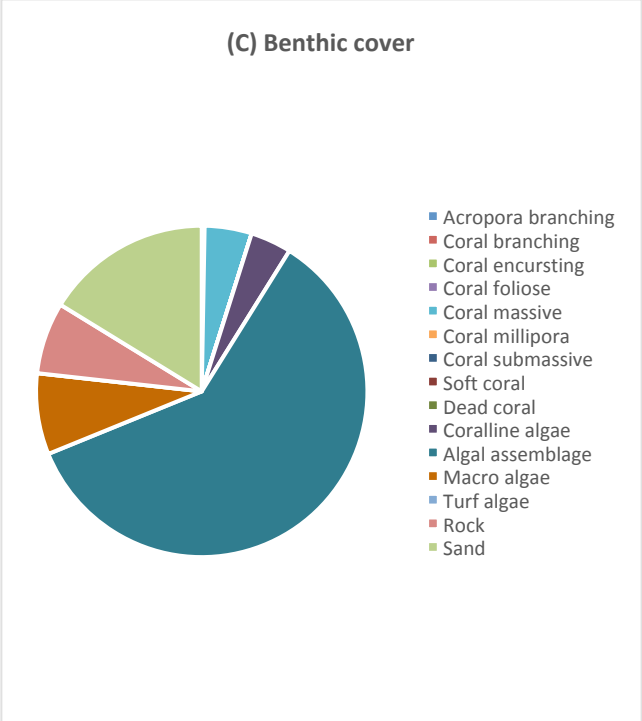


Figure 24: E4 Koromiri lagoon outer (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

E5 Koromiri back reef







This site is located in back reef area behind Koromiri motu. The benthic substrate was characterised by loose sand and rock with a thin algal growth covering most of it. Coralline algae was also present. Coral colonies of varying sizes are spread throughout the area. The benthic survey identified massive corals.

The environment was shallow and relatively high energy.

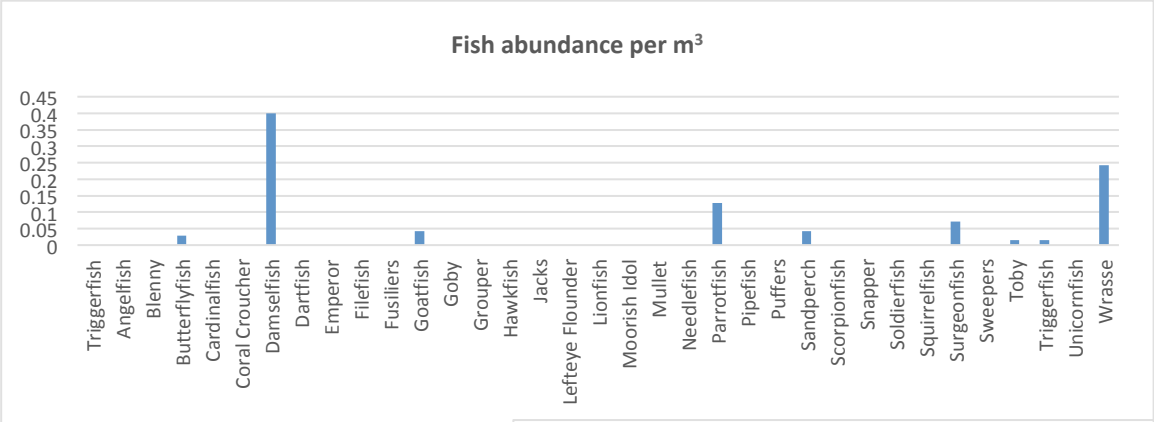
Invertebrate populations were moderate to low with holothurians being the most common. Urchins, corals, and worms were also identified in the study.

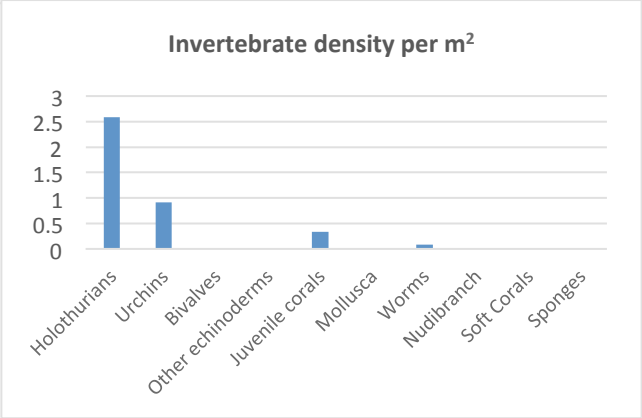
Fish diversity and abundance was moderate compared to other back reef sites with 9 family groups identified. Abundance of damselfish and wrasse were comparably high.

No sediment core was taken as the coarse sand formed only a thin and mobile layer over the basement limestone.

Figure 25: E5 Koromiri back reef (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

E5 Koromiri back reef





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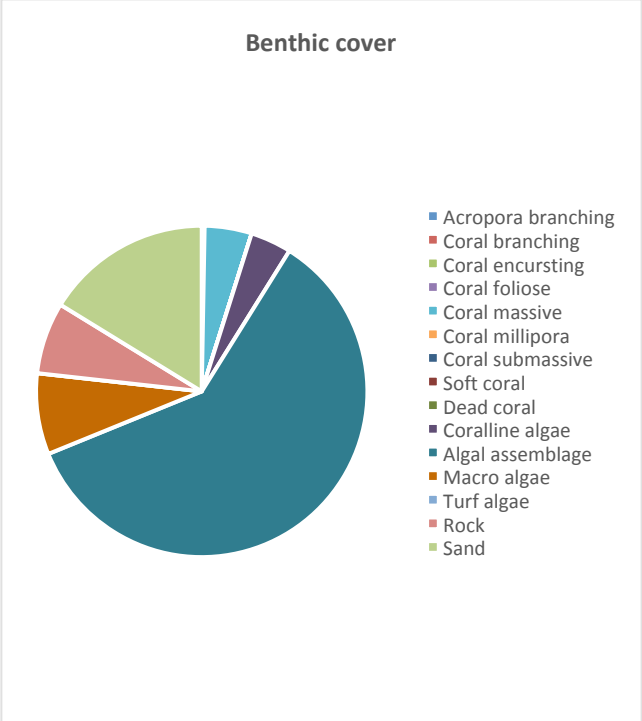
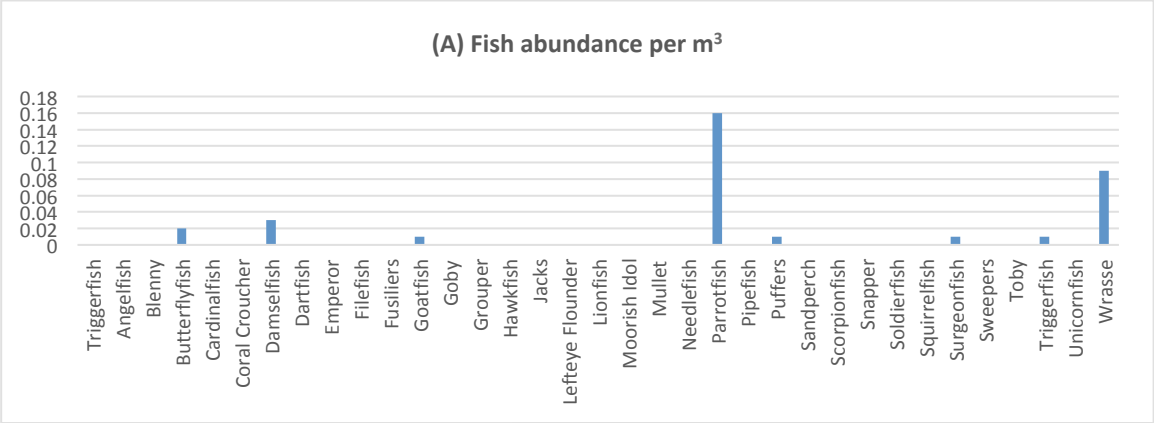
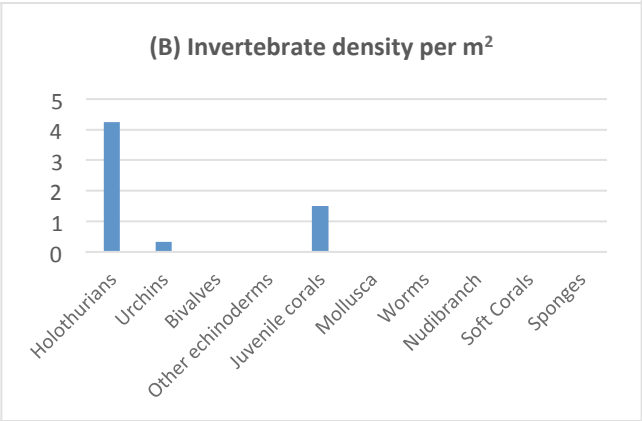
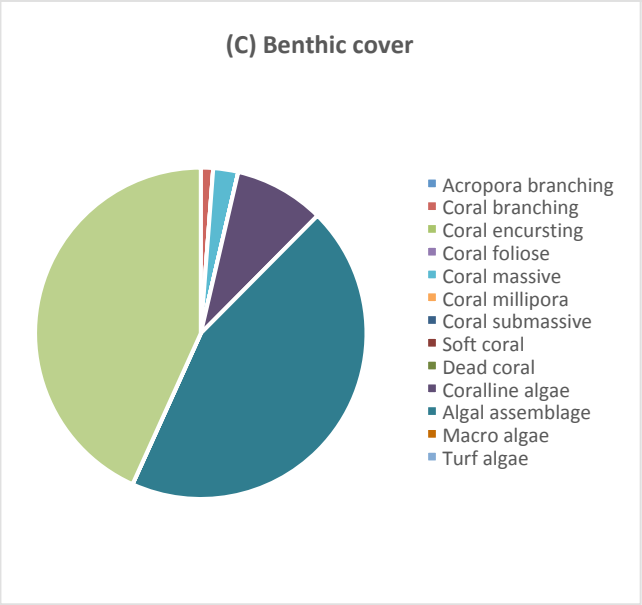


Figure 26: E5 Koromiri back reef (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

F1 Sokala near shore







This site is located close to the beach outside Manea Villas. The water flow forms a shallow channel, and the site was located central to the channel.

The benthos was sand and algal assemblage with some rock encrusted in coralline algae. Both massive and branching forms of coral were present and recorded.

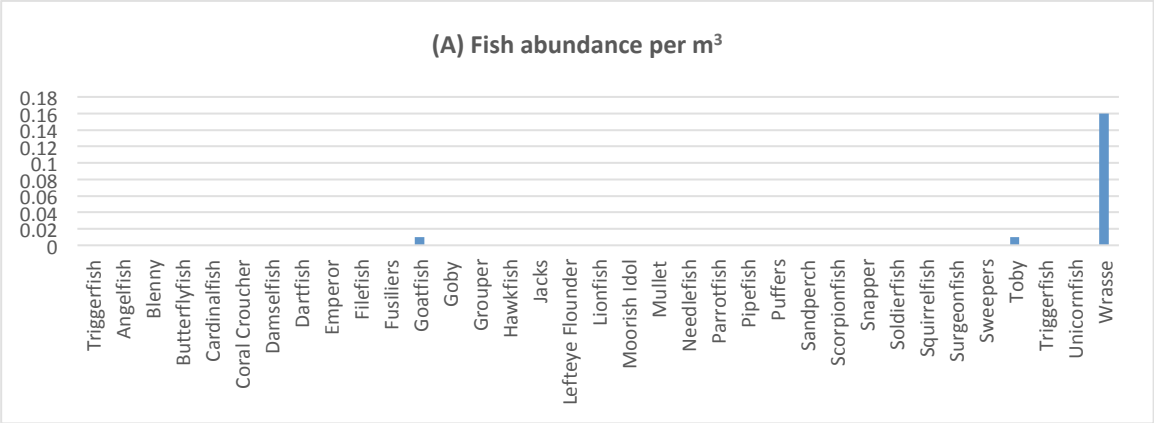
Invertebrate populations were predominantly holothurians. Urchins were present on rocky structures and juvenile corals were recorded in relatively high numbers.

Fish diversity was moderate at 8 family groups. Abundance was low with parrotfish being the most common, and at an abundance of 0.16 m^3.

The sediment core was 10 cm deep, fine to moderate calcium carbonate sands with a light grey sulphite rich colouration throughout except at the surface.

Figure 27: F1 Sokala near shore (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

F2 Sokala lagoon inner



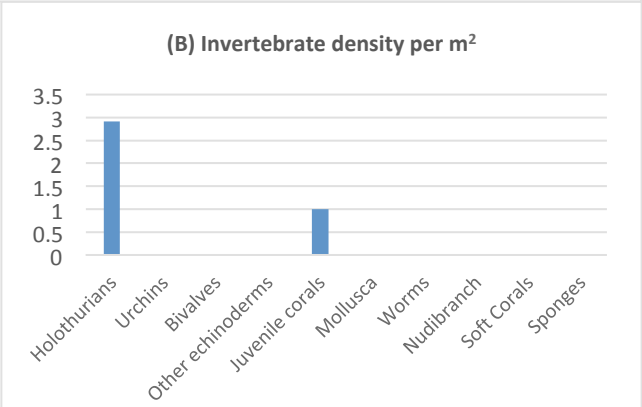
This site is located on the SW corner of Oneroa motu. It is located in a channel of flow where water from the ocean side of Koromiri and Oneroa flows.

The benthos was sand and algal assemblage with some rock encrusted in coralline algae.

Invertebrate populations were predominantly holothurians. Juvenile corals were recorded at a density of 1 m^2.

Fish diversity was very low with only 3 family groups recorded. Of those, wrasse was the most abundant, but still at low numbers comparable to other sites.

The sediment core was 9 cm deep, moderate to course calcium carbonate sands with a grey sulphite rich colouration throughout.



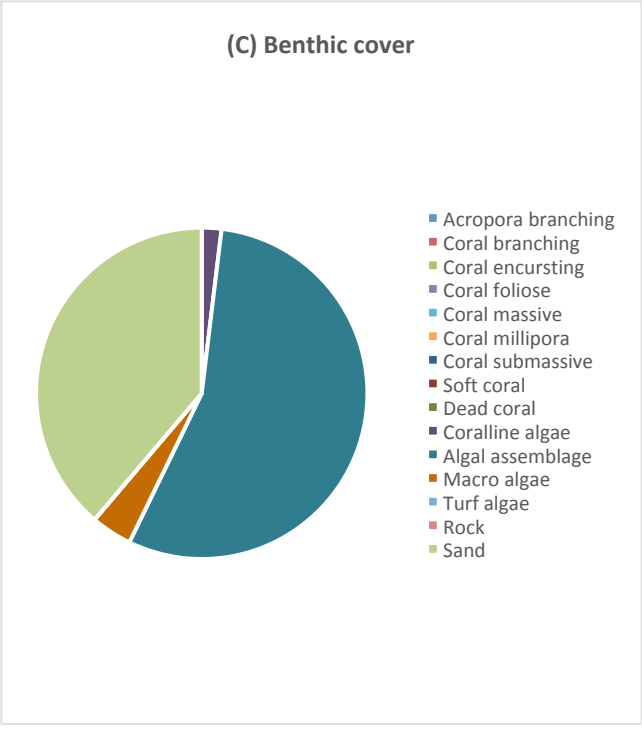
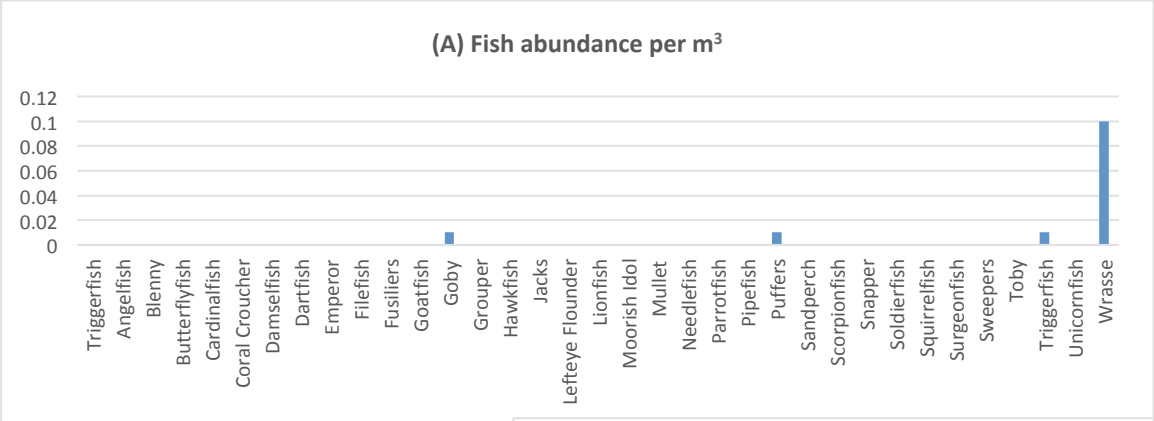
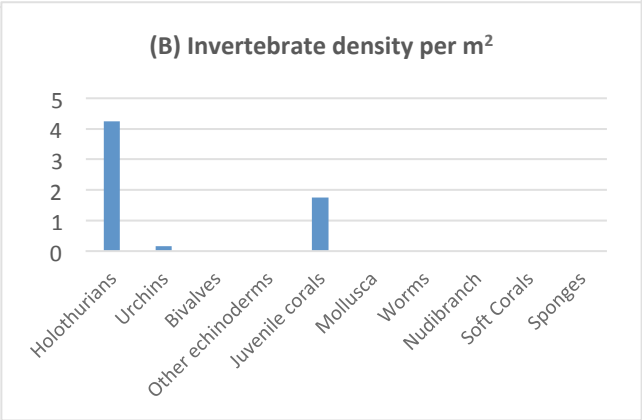
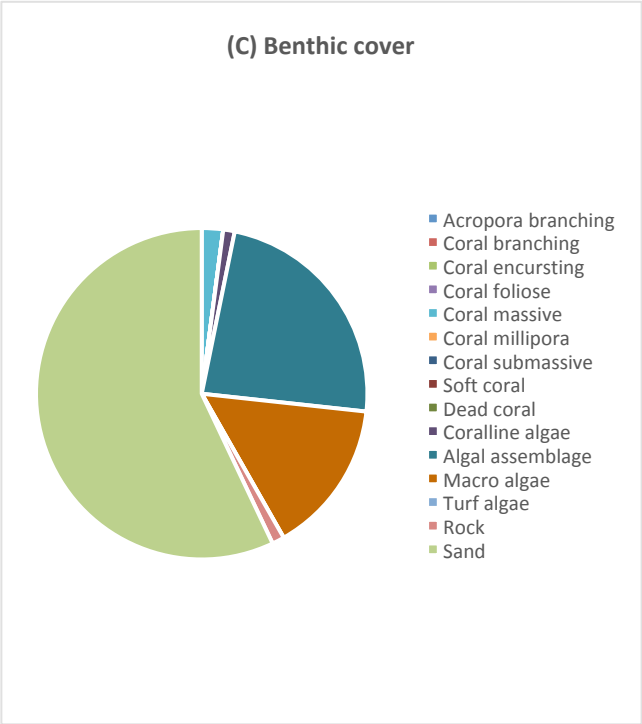


Figure 28: F2 Sokala lagoon inner (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

F3 Sokala lagoon mid







This site is located on the southern end of Oneroa motu. It is located in a channel of flow where water from the ocean side of Koromiri and Oneroa flows.

The benthos was sand with some rock and coral (coral massive) present. Macro algae were also abundant with some rock encrusted in coralline algae.

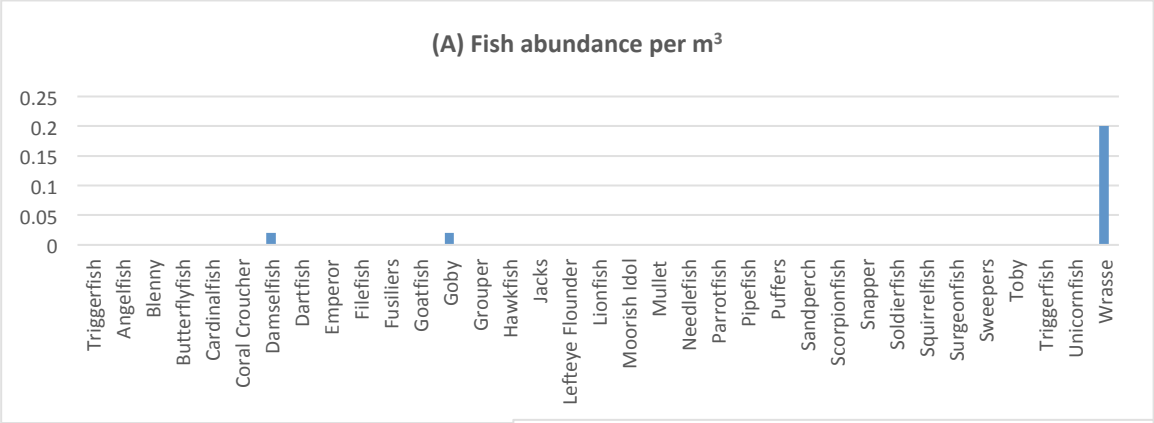
Invertebrate populations were predominantly holothurians. Juvenile corals were present in a reasonable abundance. Urchins were also identified in low numbers.

Fish diversity was low with only 4 family groups recorded. Of those, wrasse was the most abundant, but still at low numbers comparable to other sites.

The sediment core was 7 cm deep, composing of a loose mix of moderate to course calcium carbonate sands.

Figure 29: F3 Sokala lagoon mid (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

F4 Sokala lagoon outer



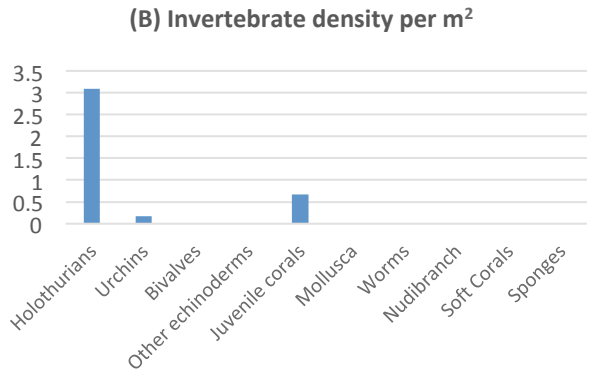
This site is located on the SE end of Oneroa motu.

The benthos was sand with algae abundant. Coral (coral massive) was recorded on the transect and noted in area.

Invertebrate populations were predominantly holothurians. Juvenile corals and urchins were also identified in low numbers.

Fish diversity was very low with only 3 family groups recorded. Of those, wrasse was the most abundant.

The sediment core was 4 cm deep, composing of a loose mix of course calcium carbonate sands.



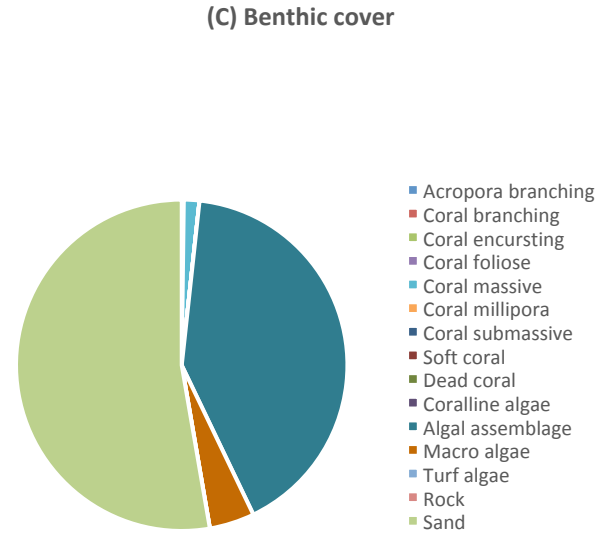
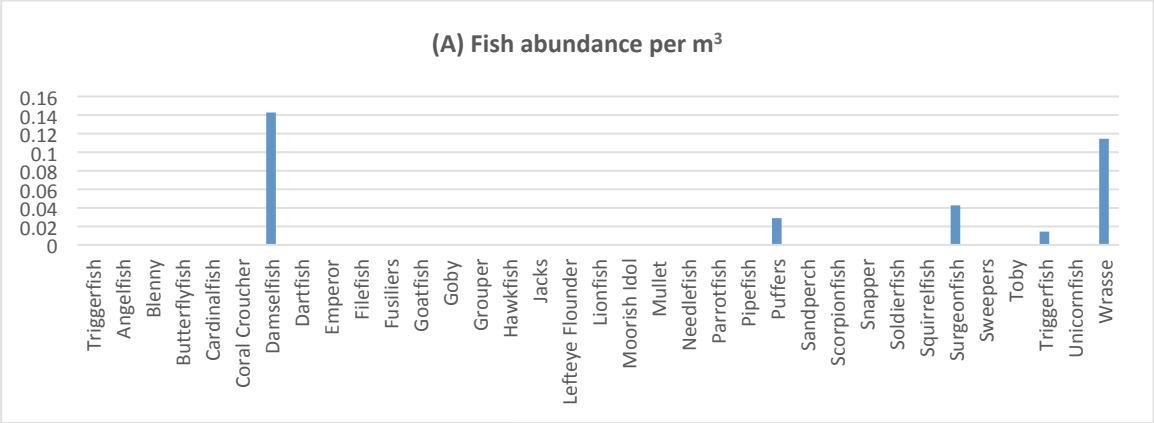


Figure 30: F4 Sokala lagoon outer (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

F5 Sokala back reef



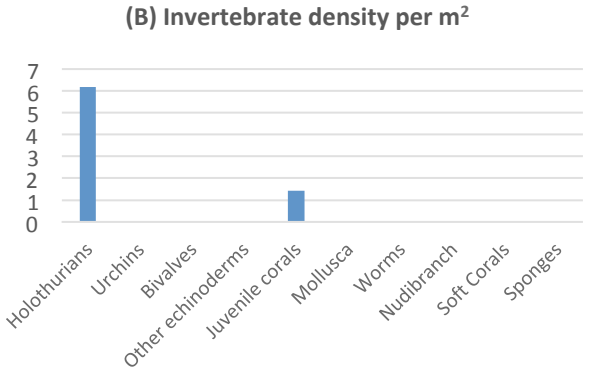
This site is located close to the reef crest behind Oneroa motu.

The benthos was sand with algae abundant. Coral (coral massive and encrusting) was recorded. Coralline algae was also recorded on the transect.

Invertebrate populations were predominantly holothurians and at high abundance of over 6 m^2. Juvenile corals were also identified with an abundance of 1.4 m^2.

Fish diversity was low for a back reef site, with only 5 family groups recorded. Of those, damselfish was the most abundant.

No sediment core was taken due to the nature of the loose coarse sand over the rock base layer.



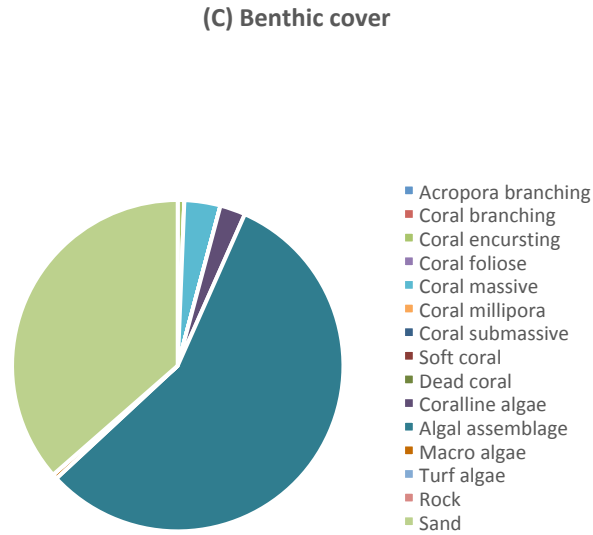
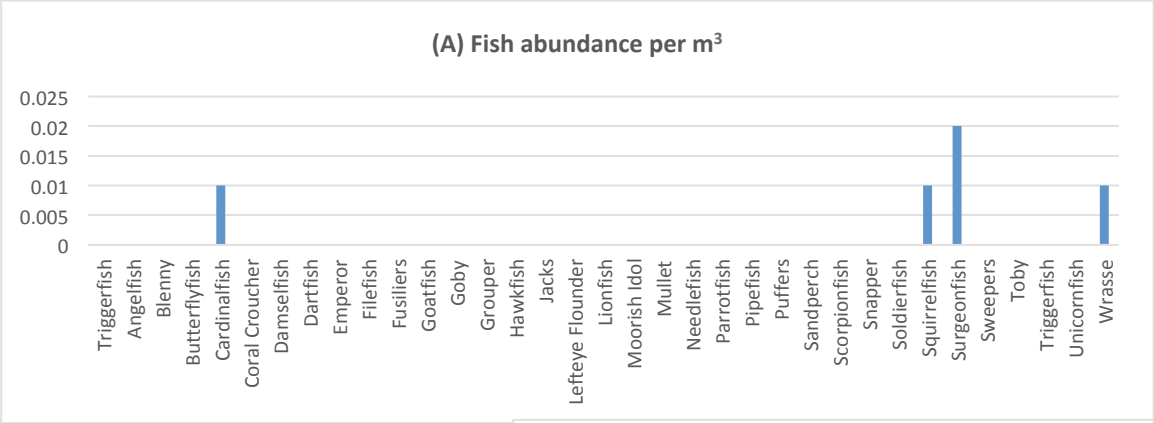
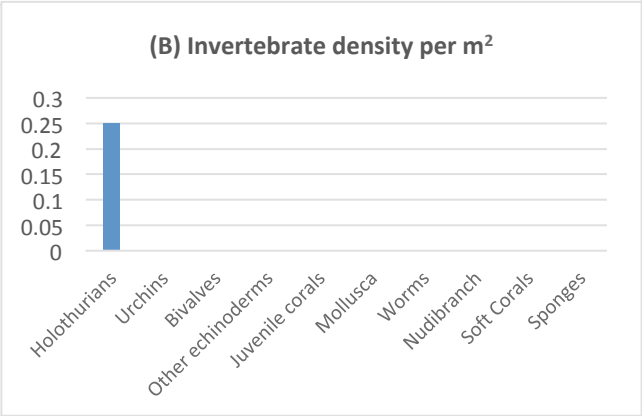
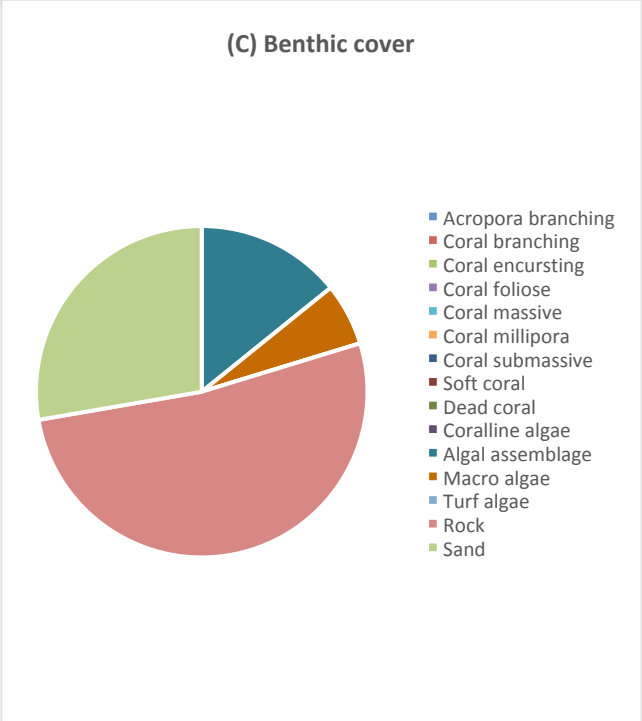


Figure 31: F5 Sokala back reef (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

G1 Avana near shore







This site is located at the mouth of the Avana stream. It is part of a rubble and delta that has formed where the stream flow meets the lagoon flow.

The benthos was rock with sand and some macro algae present.

Invertebrate populations were understandably low in this dynamic environment with only a few *H. atra* recorded on the survey.

Fish diversity was low with only 4 family groups recorded. Of those, surgeonfish was the most abundant, but still at very low numbers comparable to other sites.

The sediment core was 20 cm deep, composing of a layered mix of calcium carbonate and mineral sands, medium to fine grained with layers of organic material visible including leaf litter about 4 cm under the surface. The rotting organic matter gives the sediment a black appearance.

Figure 32: G1 Avana near shore (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

G2 Avana lagoon inner

This site is located in the bay of Motutapu directly opposite the Avana stream mouth, and in the vicinity of the Vaka mooring.

The benthos was only sand with algae growth on top. The algae were thick but patchy, forming mounds on the bottom.

There were no invertebrates or fish recorded at this site.

Fish diversity was low with only 4 family groups recorded. Of those, surgeonfish was the most abundant, but still at very low numbers comparable to other sites.

The sediment core was 20 cm deep, composing of a layered mix of calcium carbonate and mineral sands, medium to fine grained with layers of organic material visible including leaf litter about 4 cm under the surface. The rotting organic matter gives the sediment a black appearance.

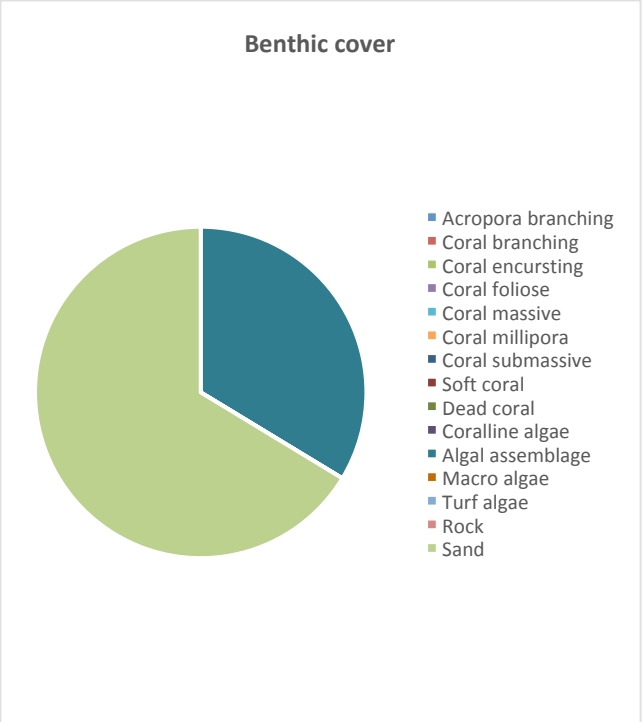
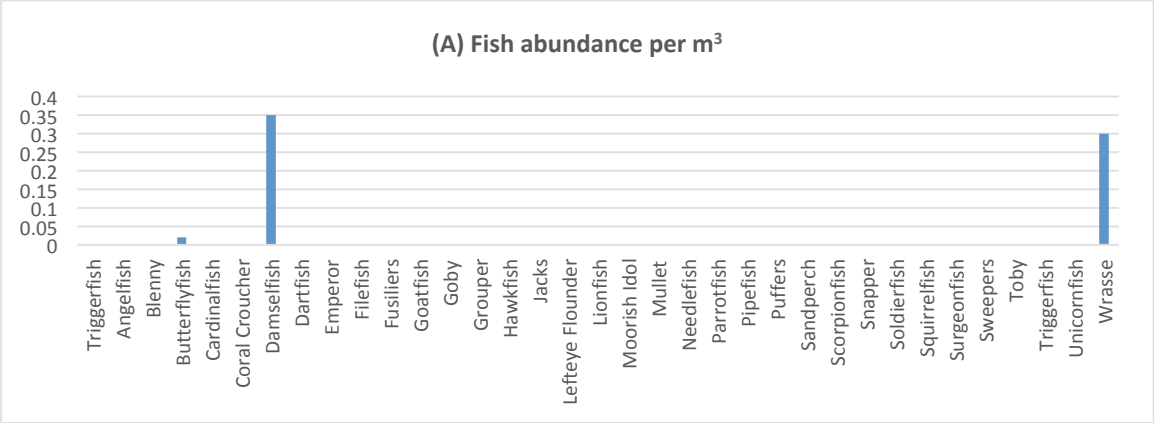


Figure 33: G2 Avana lagoon inner: Benthic cover.

G4 Avana outer lagoon



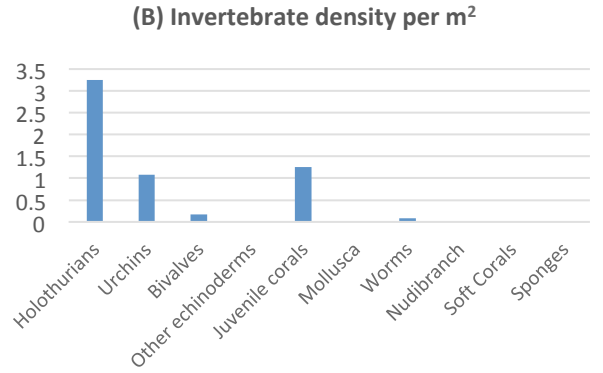
This site is located between Oneroa and Motutapu motus.

The benthos was predominantly sand or sand and rock with algae growth. 7% of the benthos recorded was coral.

Invertebrates were fairly diverse with holothurians, urchins, bivalves, juvenile corals, and worms all represented. Given the dominance of sand in the substrate the abundance of juvenile corals and urchins higher than other sites.

Fish diversity was very low for a site on the seaward side of the lagoon with only 3 family groups recorded. Damselfish and wrasse remain the most common, and in fairly good abundance.

The sediment core was 12 cm deep, composing medium to coarse calcium carbonate sands. There were 2 blue flecks of plastic noticeable within the core.



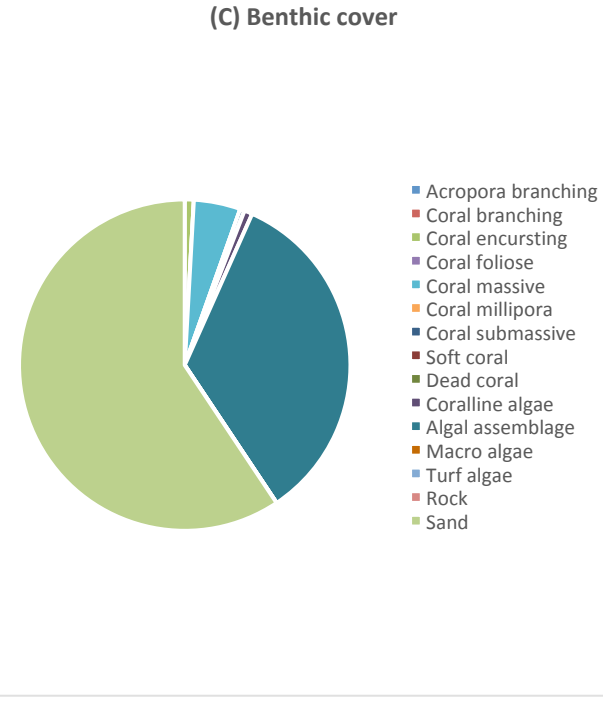
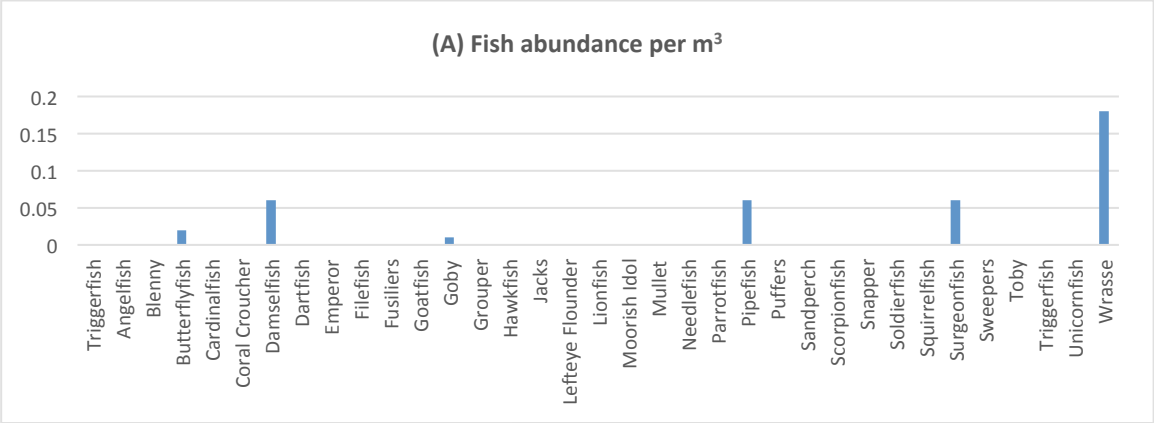
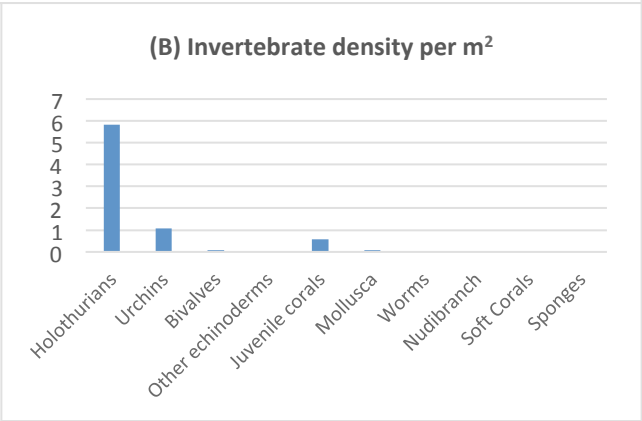
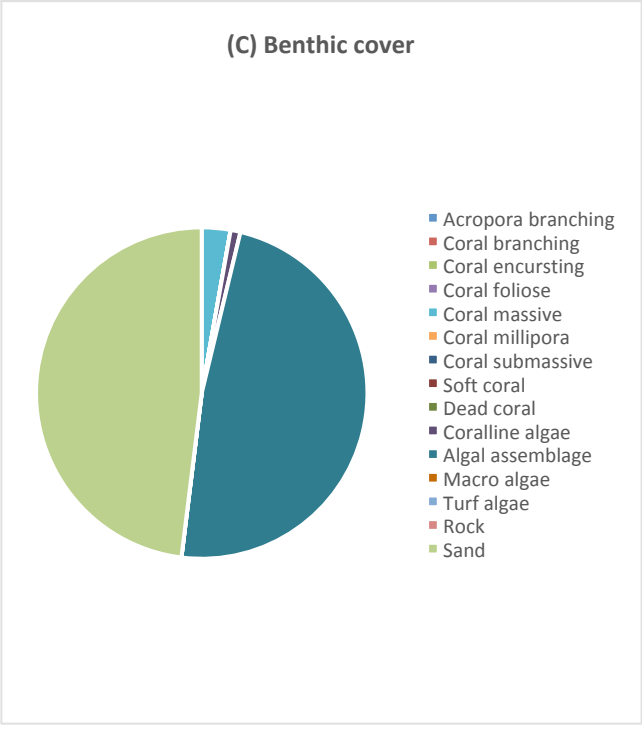


Figure 34: G4 Avana outer lagoon (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

G5 Avana back reef







This site is located as close as possible towards the reef crest between the Motutapu and Oneroa motus.

This was one of the most interesting and diverse sites to survey and the surrounding area looked to be one of the healthiest, if not the healthiest, we observed. There were species of coral here not seen elsewhere in the lagoon.

The benthos was predominantly sand or sand or sand and loose rock with algae growth. 3% of the benthos recorded was coral.

Invertebrates were fairly diverse with holothurians, urchins, bivalves, juvenile corals, and molluscs all represented. The density of holothurians was high, at just under 6 m^2.

Fish diversity was low again for a site on the seaward side of the lagoon with only 6 family groups recorded.

No sediment core was taken due to the shallow nature of the loose sand layer on the rock.

Figure 35: G5 Avana back reef (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

H1 Ngatangiia reef mid

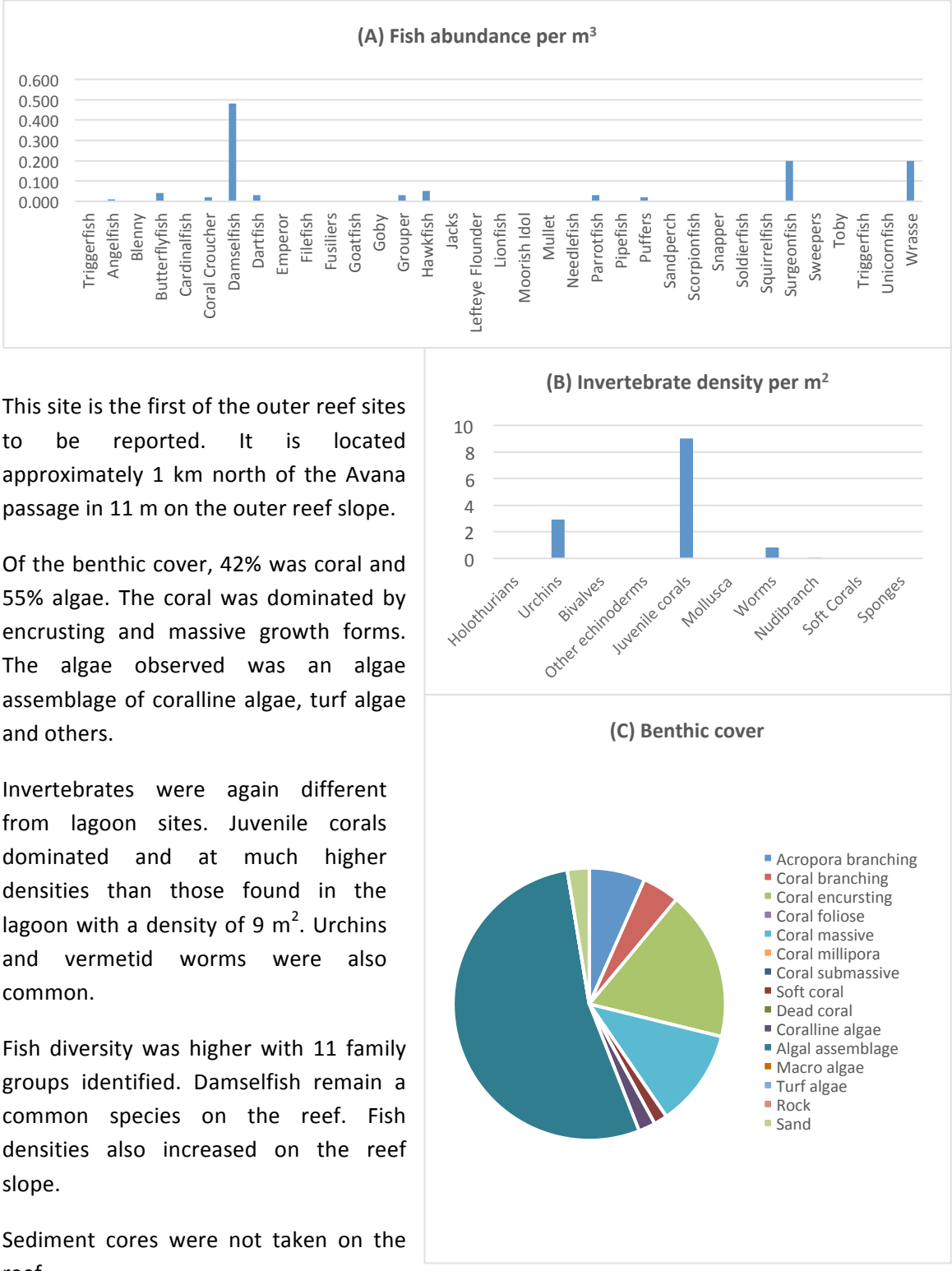


Figure 36: (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

This site is the first of the outer reef sites to be reported. It is located approximately 1 km north of the Avana passage in 11 m on the outer reef slope.

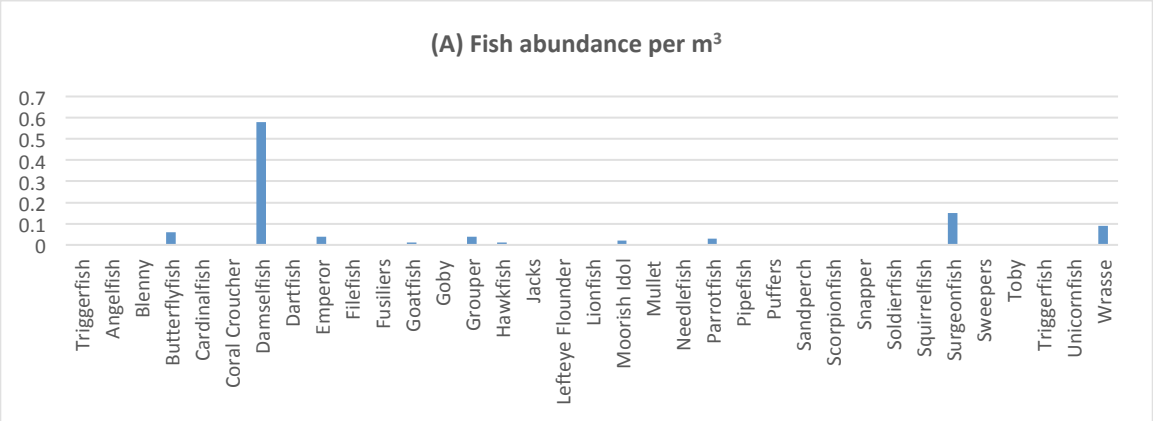
Of the benthic cover, 42% was coral and 55% algae. The coral was dominated by encrusting and massive growth forms. The algae observed was an algae assemblage of coralline algae, turf algae and others.

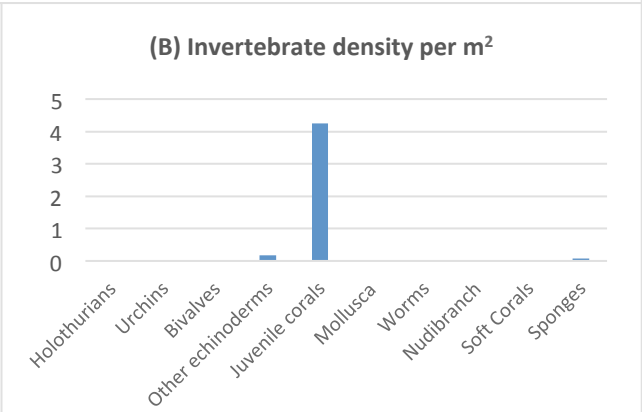
Invertebrates were again different from lagoon sites. Juvenile corals dominated and at much higher densities than those found in the lagoon with a density of 9 m^2. Urchins and vermetid worms were also common.

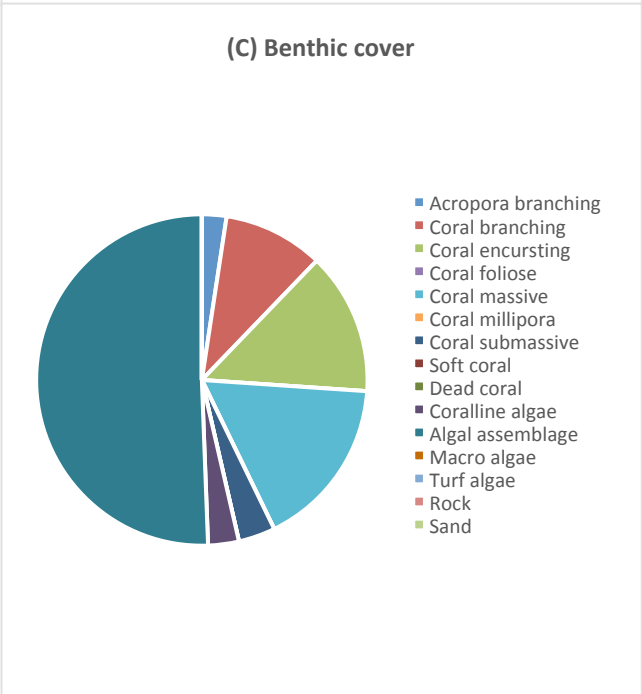
Fish diversity was higher with 11 family groups identified. Damselfish remain a common species on the reef. Fish densities also increased on the reef slope.

Sediment cores were not taken on the reef.

H2 Ngatangiia reef deep







This site is located approximately 1 km north of the Avana passage in 20 m on the outer reef slope.

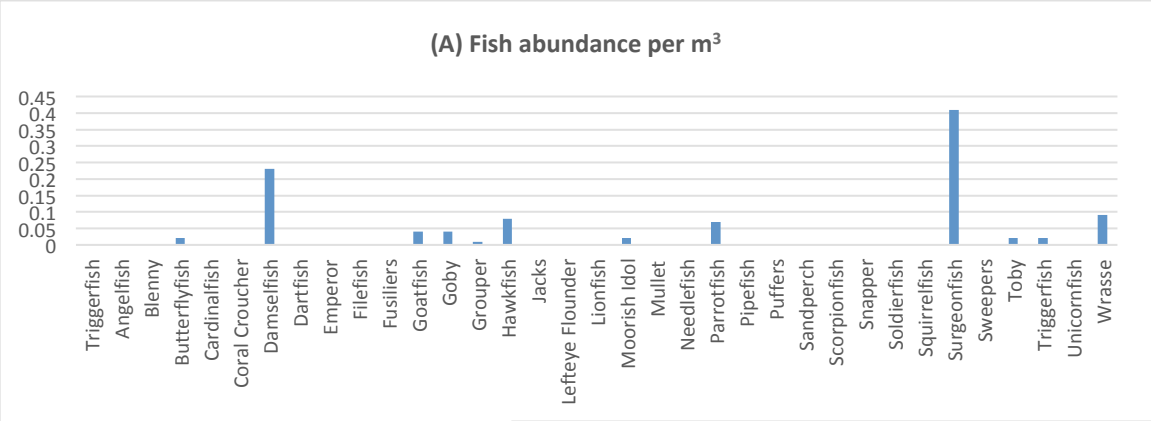
Of the benthic cover, 46% was coral and 53% algae. The coral was a range of growth forms as shown on the chart. The algae was an algae assemblage of coralline algae, turf algae and others. There were no abiotic benthos recorded.

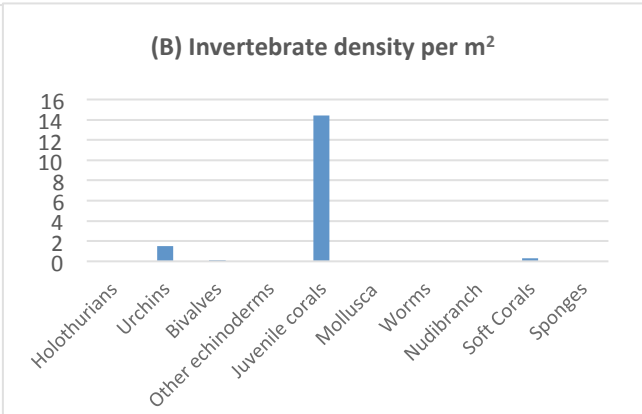
The invertebrate survey was dominated by small coral colonies. These are reported as juvenile corals and were present at a density greater than 4 m^2. Other invertebrates recorded on the survey include feather stars and a sponge.

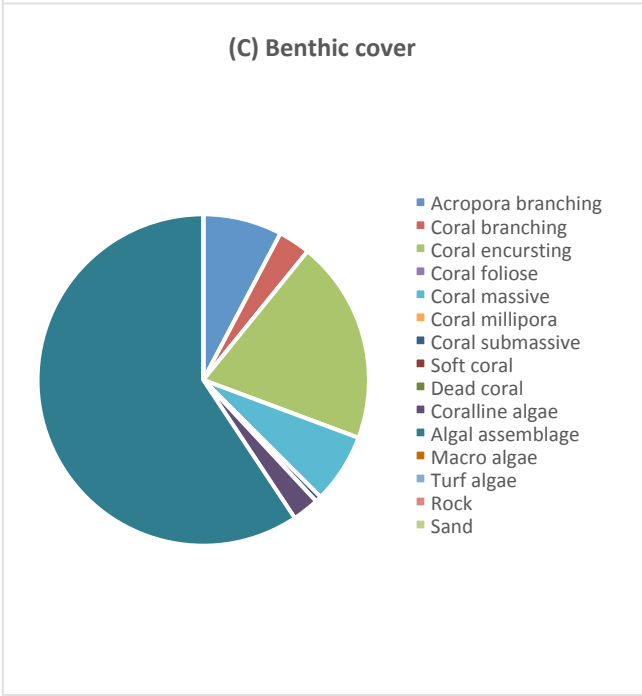
Fish diversity was high with 10 family groups identified. Damselfish remain common at this site also.

Figure 37: H2 Naatangiia reef deep (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

I1 Avana reef mid







This site is located approximately 200 m north of the Avana passage centre line in 10 m depth on the outer reef slope.

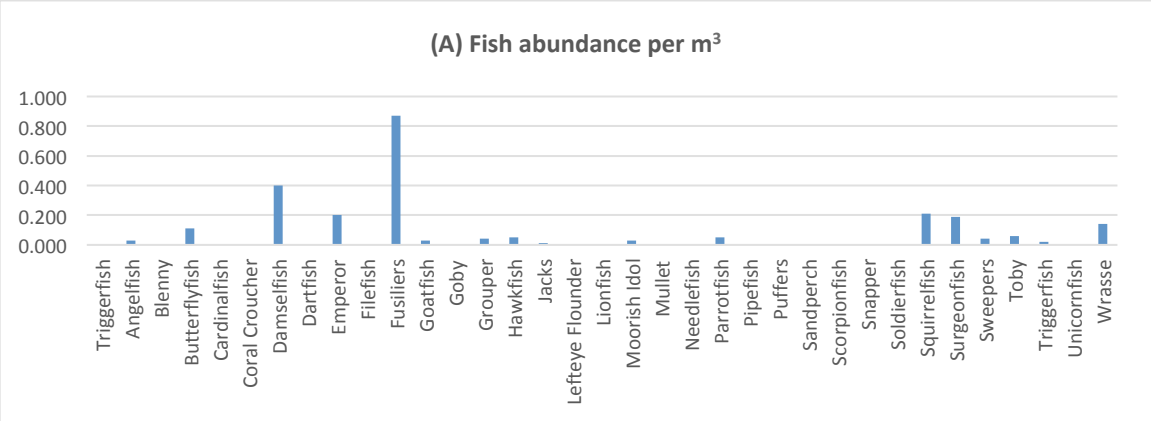
Of the benthic cover, 38% was coral and 62% algae. The predominant coral growth form was encrusting with massive, branching and *Acropora* branching recorded. The algae was an algae assemblage of coralline algae, turf algae and others growing on coral boulders and rubble.

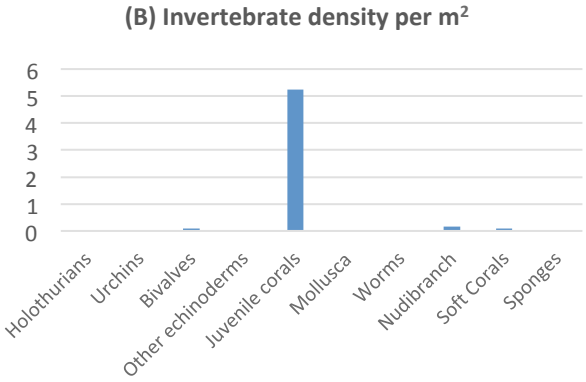
The invertebrate survey was dominated by corals. These juvenile corals were present at a high density greater than 14 m^2. Other invertebrates recorded on the survey include urchins and soft coral.

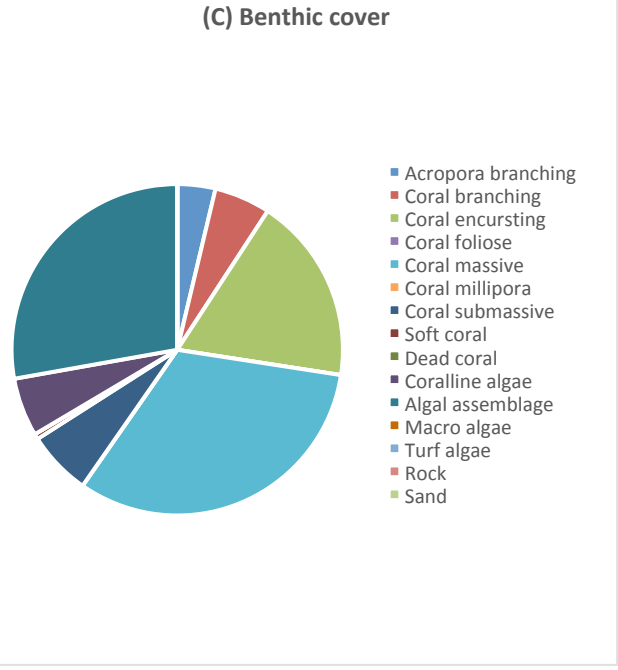
Fish diversity was high with 12 family groups identified. Surgeonfish were the most common fish at this site.

Figure 38: I1 Avana reef mid (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

I2 Avana reef deep







This site is located approximately 200 m north of the Avana passage centre line in 19 m depth on the outer reef slope. The site sat on the edge of where the formed coral growth shifted to more broken rubble as the reef sloped away deeper.

Of the benthic cover, coral was 66% while algae made up the other 34%. A range of coral growth forms were present. The algae present was an algae assemblage of coralline algae and turf algae.

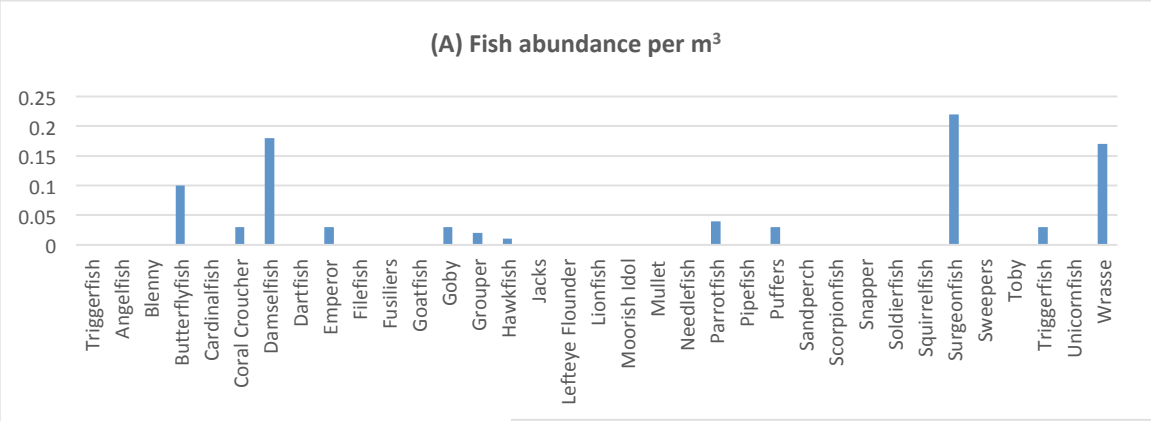
The invertebrate survey was dominated by corals with bivalves, nudibranch and soft corals also noted.

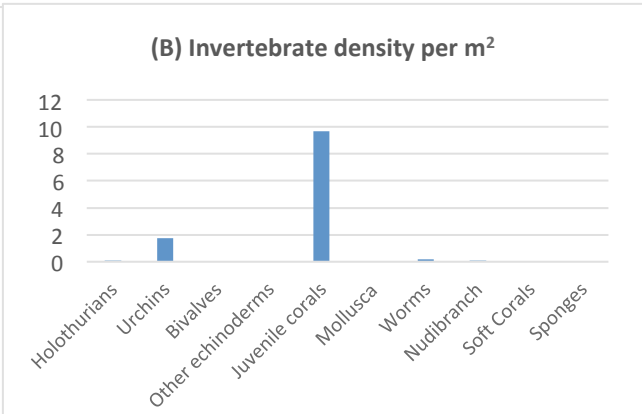
Fish diversity was the highest recorded with 17 family groups identified. During the survey a school of neon fusiliers circled constantly, feeding at the interface of lagoon and oceanic water.

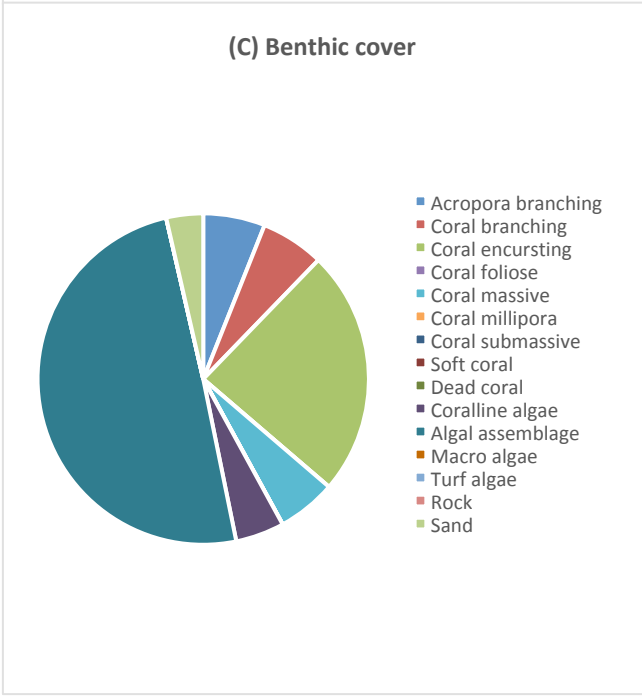
This was a beautiful site to survey; the coral and fish life were both quite beautiful.

Figure 39: I2 Avana reef deep (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

J1 Motutapu reef mid







This site is located approximately 200 m south of the Avana passage centre line in 12 m depth on the outer reef slope.

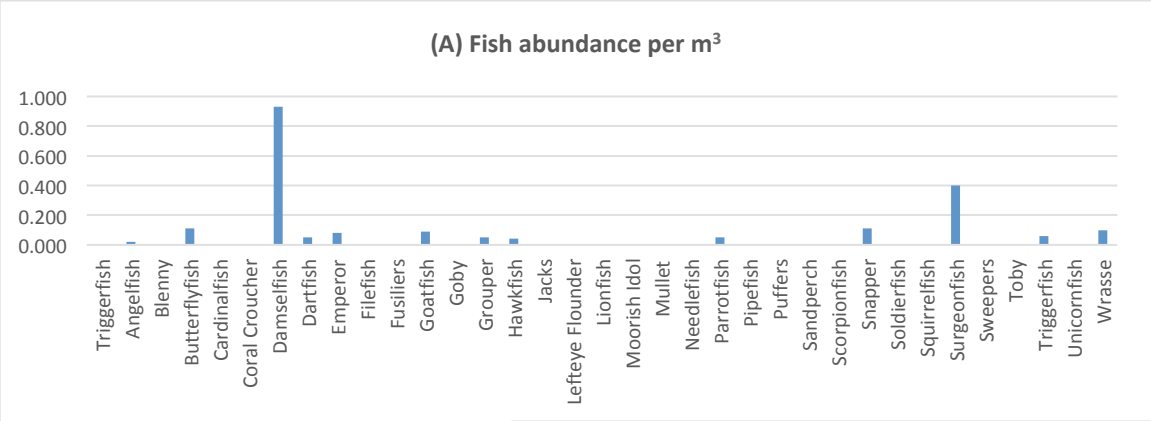
Of the benthos, 42% was coral while algae made up 54%. The balance of 4% was abiotic surfaces such as rock and sand. Encrusting coral was most common, but a range of forms were identified. Again, the algae assemblage was a mix of coralline algae, turfing algae, and other filamentous algae.

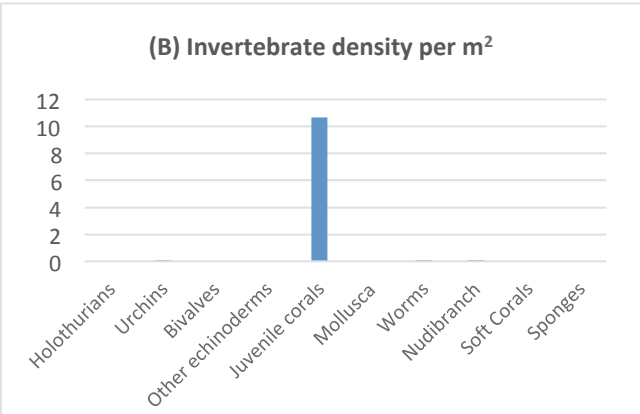
Juvenile corals were in high abundance in the invertebrate survey at almost 10m^2. Urchins and vermetid worms were also noted on the survey.

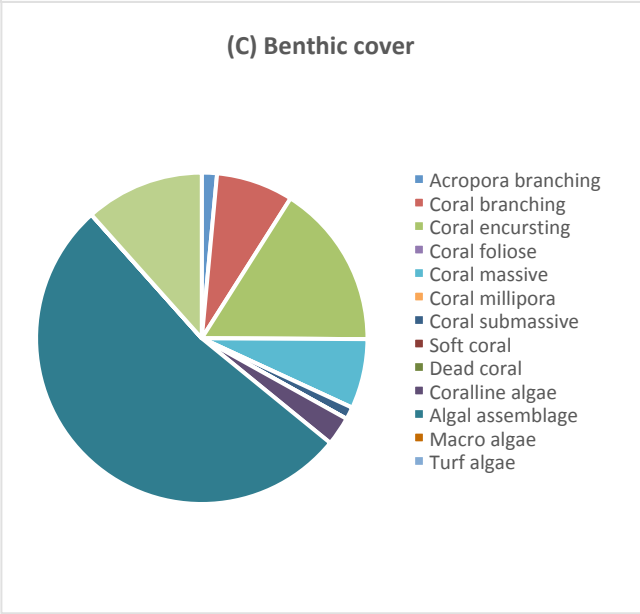
Fish diversity was high with 12 family groups identified. Damselfish and surgeonfish were most common.

Figure 40: J1 Motutapu reef mid (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

J2 Motutapu reef deep







This site is located approximately 200 m south of the Avana passage centre line in 22 m depth on the outer reef slope.

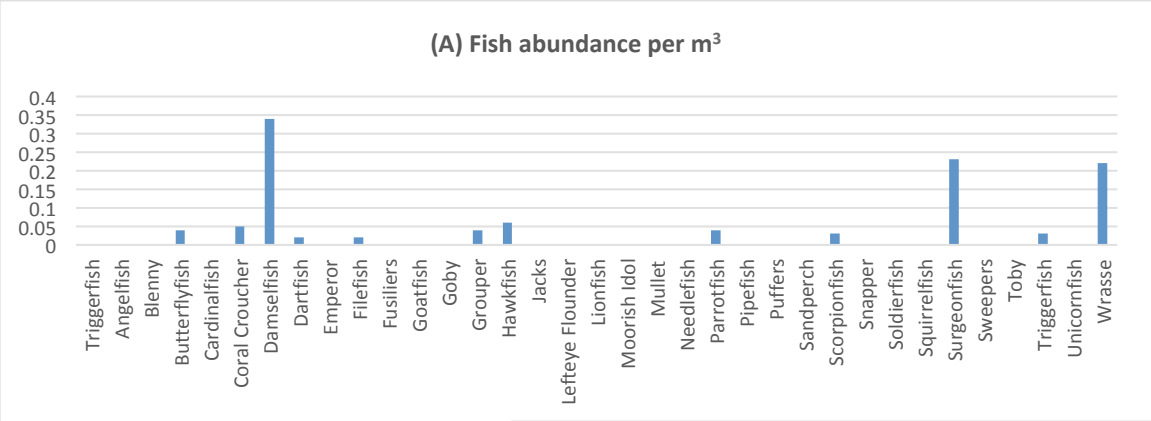
Of the benthos, 33% was coral while algae made up 55%. The balance of 12% was sand. Encrusting coral was most common, but a range of forms were identified including branching corals, massive and sub massive corals. The algae assemblage was a mix of coralline algae and turfing algae.

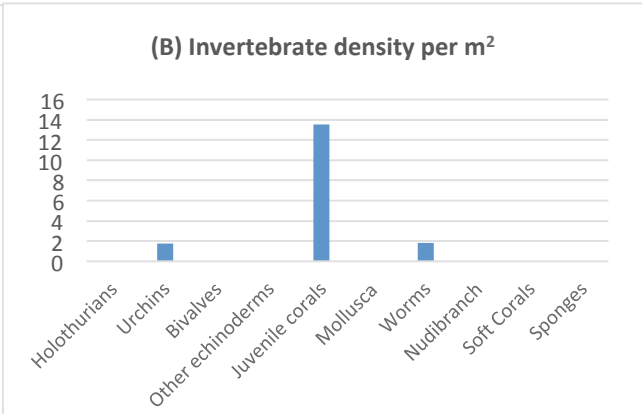
Juvenile corals were in high abundance in the invertebrate survey at over 10 m^2. No other invertebrates were recorded on the survey.

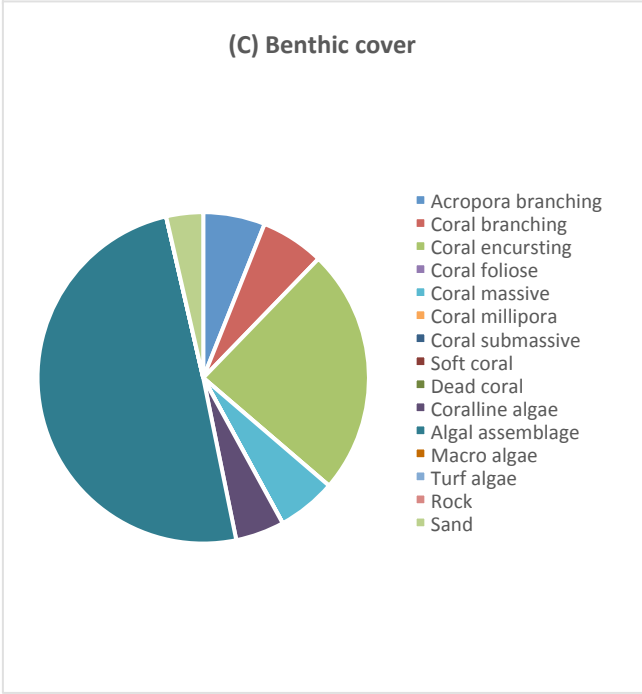
Fish diversity was high with 13 family groups identified. Abundance was high, especially for damselfish, with surgeonfish being second most common.

Figure 41: J2 Motutapu reef deep (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

K1 Oneroa reef mid







This site is located approximately 800 m south of the Avana passage centre line and in alignment with the gap between Oneroa and Motutapu motus. The site is in 11 m depth on the outer reef slope.

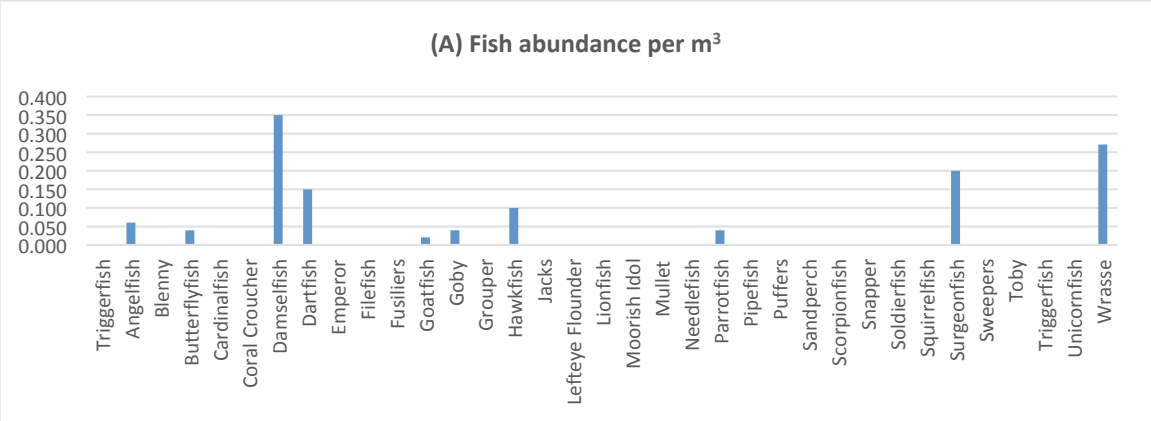
Of the benthos, 39% was coral while algae made up 59%. The balance of 2% was abiotic surfaces such as rock and sand. Encrusting coral was most common, but a range of forms were identified. Again, the algae assemblage was a mix of coralline algae, turfing algae, and other filamentous algae.

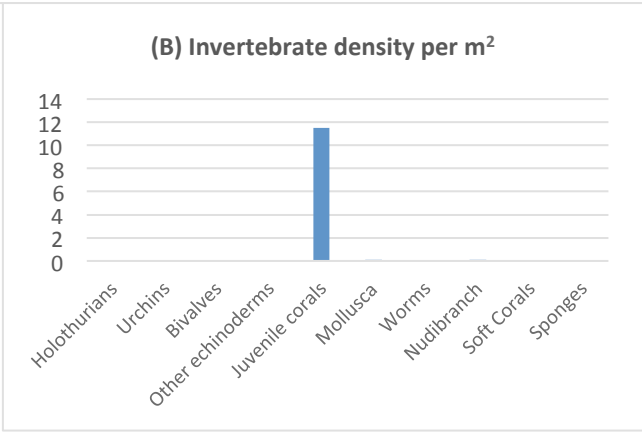
Juvenile corals were in very high abundance in the invertebrate survey at over 13 m^2. Urchins and vermetid worms were also common on the survey.

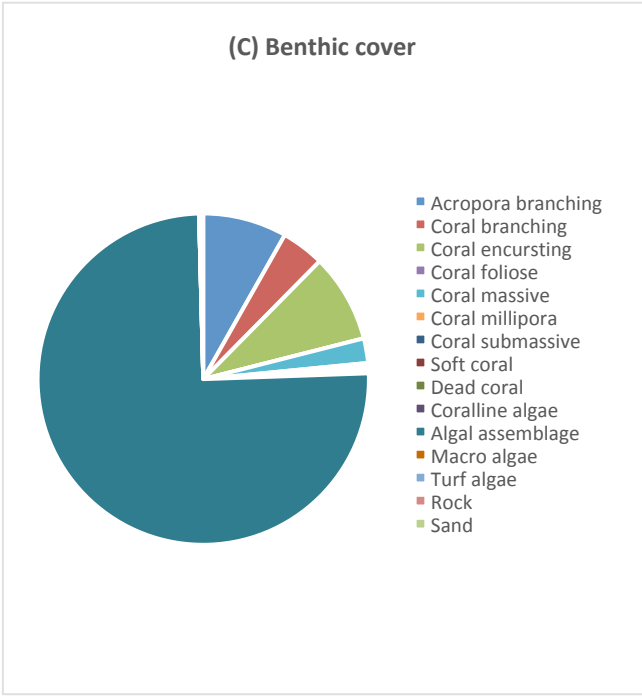
Fish diversity was high with 12 family groups identified. Damselfish were most followed by surgeonfish and wrasse.

Figure 42: K1 Oneroa reef mid (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.

K2 Oneroa reef deep







This site is located approximately 800 m south of the Avana passage centre line and in alignment with the gap between Oneroa and Motutapu motus. The site is in 20 m depth on the outer reef slope.

Of the benthos, 76% was algae while coral made up 24%. Branching and encrusting corals were the dominant growth forms. Again, the algae assemblage was a mix of coralline algae, turfing algae, and other filamentous algae.

Juvenile corals were in very high abundance in the invertebrate survey at over 11 m^2. There were no other invertebrates noted on the survey.

Fish diversity was high with 10 family groups identified. Abundance was moderate with damselfish being most common followed by surgeonfish and wrasse.

Figure 43: K2 Oneroa reef deep (A) Fish abundance per m^3; (B) Invertebrate density per m^2; (C) Benthic cover.