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Niue sustainable coastal fisheries pilot project: Marine baseline survey

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Abbreviations

COTS	crown of thorns starfish
ICWM	integrated coastal and watershed management
ID	identification
IWP	International Waters Project
ha	hectare
m	meter
min	minutes
SCP	Secretariat of the Pacific Community
SPREP	Secretariat of the Pacific Regional Environment Programme
USP	University of the South Pacific

Executive summary

The International Waters Project (IWP) aims to strengthen the management and conservation of marine, coastal and freshwater resources in the Pacific Islands region. It is financed through the International Waters Programme of the Global Environment Facility, implemented by the United Nations Development Programme, and executed by the Secretariat of the Pacific Regional Environment Programme (SPREP), in conjunction with the governments of the 14 participating independent Pacific Island countries.

This report contains the results of a full marine baseline assessment conducted in March 2004. This follows an earlier pilot survey visit in December 2003, and a participatory situation analysis consultation conducted in 2002 as part of the Niue IWP sustainable coastal fisheries project.

The baseline assessment provides a current status report on the coastal marine resources of Niue. It offers recommendations for the management options available to address the concerns of local villagers with respect to deterioration of coastal resources. The lessons learned from the pilot project are expected to have national importance and should provide a guide to the best approach to sustainable fisheries management for all of Niue.

Photo 1. Reef survey using a belt transect.

Belt transects are used to estimate the density of selected reef flat organisms that are commonly harvested for food. Transects are 40 to 50 m in length and 5 m in width.

The baseline assessments focused on the pilot site coastal villages of Alofi North and Makefu, as well as selected sites on the west coast outside this area. An opportunistic assessment of the impacts of a major cyclone was included in the baseline work plan, as Cyclone Heta passed through Niue in early January 2004 (following the pilot survey visit in December 2003, but prior to this baseline survey, conducted in March 2004). The baseline assessment combined descriptive and quantitative methods that included general descriptions of habitat and marine communities present, timed swims and reef flat walks that recorded the status of standard characteristics, and density samples of selected organisms. The assessments focused on health and status indicators and selected invertebrate species, but not on fish species; the objective was to provide an overview of the current health and condition of coastal marine habitats and plant and animal communities. The goal is to assist participating villages make decisions regarding resource management from an ecosystem or holistic — rather than an individual species-based — viewpoint. An understanding of the current relative health and status of resources is also an important prerequisite for sound decision making.

Photo 2. A typical healthy reef flat pool lined with live coral and occupied by a number of holothurians (*loli*).
A layer of fine sand is present on the reef surface, trapped by abundant turf algae. The photo is from Namoui reef flat in December 2003, prior to Cyclone Heta.

Photo 3. Reef slope scene from Omahi Sea Track.
Photo taken in December 2003, prior to Cyclone Heta. Live coral cover and species diversity were relatively high.

Photo 4. Giant clams (*Tridacna maxima*).
Low numbers of moderately sized giant clams were observed on reef slope habitats in the Alofi North and Makefu village areas in December 2003.

Cyclone damage

The results of the extended survey that covered most of the western coastal area (including the pilot village areas) indicated that cyclone damage was highly variable, from virtually no damage to complete removal of the living coral reef veneer; overall damage in the pilot village coastal areas was very significant, with portions of the area suffering from high to severe damage. The impacts and consequences of Cyclone Heta included:

- major reduction in coral cover on the slopes in the most exposed locations, which included the more northerly and southerly portions of the pilot village areas;
- substantial reduction in abundance of all reef flat macro invertebrates, more or less in proportion to their relative abundance prior to the cyclone, resulting in local extinction of some species; and,
- the proliferation and dominance of a single macro algal species (*Liagora* spp.) in most slope and reef flat pools, as well as extensive expansion of turf algae and blue-green algae mats in both reef flat and slope habitats.

The impact of the cyclone will have significant effects on the regeneration potential of all fishery species. An area of important larval replenishment supply exists on the west coast south of the Alofi township (from approximately Ana Blowholes to Avatele, and centred on the village of Tamakautoga), which could be significant for fishery dynamics in the future if managed wisely.

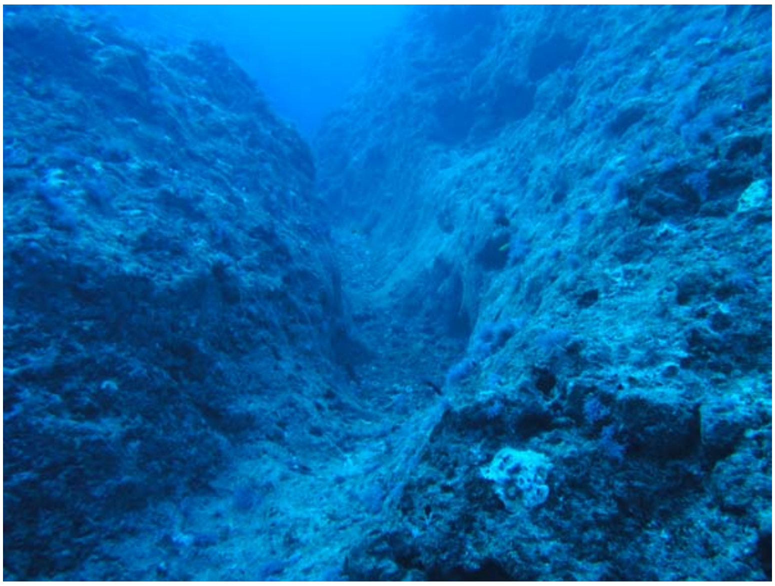

Photo 5. Post-Cyclone Heta damage.
Following the passing of Cyclone Heta in January 2004, much of the north and north-western coastal reef areas were severely disturbed with much of the previously living reef veneer removed.

Photo 6. Highly disturbed reef slope areas in Alofi North and Makefu.
These slope areas were dominated by a macro algae (probably Liagora spp.) and relatively few live corals; corals present were mostly of the massive growth form shown in this photo.

Management options

The results of reef flat surveys showed that some macro invertebrates were more abundant in different parts of the reef flat (in any one site) and that their densities varied greatly along the coast in the pilot villages. The low abundance of many invertebrate fishery species are correlated with the relative ease of access to the reef flat as well as to the presence of adjacent human populations. This indicates that the perception that overharvesting is taking place is probably correct, but the situation has been exacerbated by the impacts of Cyclone Heta. The distribution patterns will influence where potential harvest restrictions and other management regimes may be imposed, and particularly the selection of sites that will be afforded high protection status, with the goal of hastening regeneration and replenishment processes.

Key factors that should be taken into account when considering management options include:

- Natural events such as coral bleaching and cyclones are significant factors in determining species abundance and distribution, and their effect varies, in terms of the intensity of disturbance, even within similar sections of coastal habitat.
- The significance of even relatively small natural refuge areas — where reef communities can develop to maturity — as a significant source of eggs and larvae for other sections of the coast.
- The isolated nature of Niue with respect to species replenishment from other regional reef systems.
- The characteristics, timing and intensity of harvest effort needs to be considered in the context of natural variations in abundance of target species.
- Species of particular concern that will be good indicators of management success include both reef flat invertebrates and slope-inhabiting fish.

Photo 7. Typical moderate-depth slope scene in the vicinity of Tamakautoga Sea Track in March 2004.

This was the only section of the west coast that was predominantly untouched by the effects of Cyclone Heta in January 2004.

Recommendations

Recommendation 1: Current protection of reef flat and slope habitats within the Namoui marine reserve should be strongly enforced with respect to harvesting of any species. In addition, consideration should be given to extending the boundaries (both north and south) so as to increase the area of protected reef flat, which is currently relatively underrepresented.

Recommendation 2: Reef flat habitats under consideration for harvest protection measures should be assessed for the presence of suitable habitat for most macro invertebrates. This can be done by assessing reef flat for the presence of shallow pools and water retention areas that occur at low tide.

Recommendation 3: The slope and reef flat habitat north and south of Tamakautoga should be considered as a significant refuge area and source of replenishment larvae for the remainder of the west coast, and therefore should be afforded high protection from harvest activities.

Recommendation 4: The resources of the east and south coast should be thoroughly assessed as to the health and status of the habitats and resources present, with the view that these locations may be significant in determining the overall replenishment potential of targeted fisheries species. This activity should be part of a national coastal fishery management plan.

Recommendation 5: Studies on the level of coastal resource harvest levels should be initiated as a matter of urgency under the IWP pilot village activities, as should the enforcement of the current fisheries regulations.

Recommendation 6: Where harvesting is to be allowed within the pilot village sites, there should be a systematic rotation system of open and closed areas that can be easily applied and understood with reference to coastal features. This will allow regular replenishment of those species that can rapidly re-establish their numbers if left sufficient time to do so.

Recommendation 7: The status of the following reef flat species should be considered as good indicators of management success: the vermetid tube worm (*ugako*), purple jewel box oyster (*papahua*), false limpet (*matapihu*), as well as the turban shell (*alili*), giant clam (*gege)*, and species of holothurian (*sepulupulu, loli*). The status of reef slope species that would be good indicators include: a few indicator fish species, giant clams, macro crustaceans, hard coral cover and coral recruit densities, sea urchins (*kina, vana*), and macro algae (*limu*) cover.

1 Background

1.1 Introduction

The International Waters Project (IWP)[1] is a 7-year, USD 12 million initiative concerned with management and conservation of marine, coastal and freshwater resources in the Pacific islands region, and is specifically intended to address the root causes of environmental degradation related to trans-boundary issues in the Pacific. The project includes two components: an Integrated Coastal and Watershed Management (ICWM) component, and an Oceanic Fisheries Management component (the latter has been managed as a separate project). It is financed by the Global Environment Facility under its International Waters Programme. The ICWM component is implemented by the United Nations Development Programme and executed by the Secretariat of the Pacific Regional Environment Programme (SPREP), in conjunction with the governments of the 14 independent Pacific Island countries: Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu. The ICWM component focuses on integrated coastal watershed management, and supports national and community-level actions that address priority environmental concerns relating to marine and fresh water quality, habitat modification and degradation and unsustainable use of living marine resources through a 7-year phase of pilot activities, which started in 2000 and will conclude at the end of 2006.

The theme and location of each pilot project was selected on the basis of community and government consultation. Each project is expected to have adopted an interdisciplinary approach involving the three pillars — economic, social and environmental — of sustainable development. Each project is intended to address the root causes of degradation affecting one or more of four focal areas:

- marine protected areas
- coastal fisheries
- freshwater resources
- waste reduction.

IWP's pilot project on Niue addresses community-based sustainable resource management and conservation issues associated with the focal area of sustainable coastal fisheries. The Niue IWP National Programme has completed a series of island-wide village consultations and a participatory situation analysis on coastal marine resources. From this process, two villages — Alofi North and Makefu — have been selected as sites for the initial pilot projects to local resident's priority environmental concerns with respect to sustainable coastal fisheries.

The next step in the process of establishing the pilot sustainable fisheries project is to undertake a baseline assessment of coastal marine resources. This work commenced in November and December of 2003 and was completed in March 2004. The baseline assessment was conducted in two phases. A preliminary appraisal and review of existing information was conducted in 2003 and a pilot study of the methods to be used in the full assessment were described (Fisk 2007b). The current report reflects a systematic follow up assessment of the current status of resources (including the impact on Niue's reefs from Cyclone Heta, in early January 2004). Data from both trips are included in this report.

During the 2003 visit, information on possible sources of land-based pollution was investigated

[1] IWP is formally titled Implementation of the Strategic Action Programme of the Pacific Small Islands Developing States.

to validate the concerns of local communities. In addition, an assessment of potential harvest impact was carried out by reviewing published reports as well as by mapping and describing the degree of access to reef flat resources via sea tracks. This review is presented in Fisk (2006b).

Information from the 2003 visit and the literature review are from the situation on Niue prior to Cyclone Heta, which struck Niue on 5 January 2004, and severely impacted the marine and terrestrial environment on the north to western sides of the island. The marine baseline surveys were conducted approximately two months after Cyclone Heta, when the immediate impacts from the cyclone were still very evident and when damaged marine resources were at very early stages of recovery. Extra time was allocated during this visit to extend the survey area to include as much of the western coastal area of Niue as possible outside the pilot site area.

The baseline surveys (carried out in March–April 2004) are multifaceted, focussing on a range of habitat characteristics, biotic features (including fisheries species as well as other species or biological groups), and disturbance and health indicators. Thus the focus is far broader than strictly fisheries stock size or biomass. Focussing on this diverse array of parameters allows a holistic assessment to be drawn, and provides a sound information base on which to base management decisions in relation to fisheries sustainability.

This project is using the pilot site approach. As a consequence, the area assessed is relatively small in relation to the area that should be actively managed in order to deliver optimal fisheries management results. In the case of Niue, to be effective fisheries management should include — at a minimum — the entire west or east coast. However, it would be most effective if the entire island were included. The IWP project intends to use the lessons learned from the pilot projects to adopt a national approach, and a draft national coastal fisheries management plan is currently in preparation by the Niue Fisheries Department. This pilot project work will be of great benefit to the finalisation of this plan.

The baseline surveys were carried out with the support of the two IWP staff members (Mr Sione Leolahi and Mr Logo Seumanu), a New Zealand volunteer attached to the project, Mr Ron Paulin, Mr Charlie Tohovaka from Namoui, Makefu and Ms Fiafia Rex, a fisheries division staff member.

1.2. Objective and aims of the baseline assessment phase

The objective of this phase of the Niue fisheries pilot project is to develop a strong biological basis for community decisions on management actions.

The aims of the baseline-assessment program are to:

- Conduct baseline surveys within the pilot sites to assess the current status and health of coastal resources, with particular emphasis on fishery species of concern;
- Include a capacity-building component in the baseline work to ensure that village volunteers and national staff are capable of conducting future monitoring in relation to marine protected areas and sustainable fisheries;
- Make recommendations regarding village management options, based on the outcomes of the baseline survey in association with other social or economic surveys.

2 Approaches and methods

2.1 Rationale

The rationale behind the baseline assessment was to:

- Develop a contemporary status report (including principal fishery species and species groups, and the habitats they inhabit and depend on), for the specific study sites;
- Provide a context for the current resource status by assessing recent events and processes that have strongly influenced the current distribution and abundance of coastal resources (including an assessment of the impact of human activities); and
- Ensure that the assessment of the study sites is placed in context with the status and historical situation in adjacent and similar marine habitats.

This rationale recognises that fishery species and habitat health and functioning are intricately linked, meaning that species and their habitat have to be assessed simultaneously to arrive at an accurate assessment of their current and potential future status, and to guide decisions on the most appropriate management options that will enhance fisheries sustainability in the future. It also recognises that human activities, through resource harvesting and human-caused indirect pressures (e.g. pollution) have a major influence on resource status.

The impacts of natural processes on the distribution and abundance of resources can be affected by human activities, but unlike natural processes — which occur whether human activities are present or not — human activities can be controlled and managed. To ensure sustainable use of resources, fishery management options should be based on a detailed understanding of (i) how the local marine ecosystem functions and (ii) how local human activities may influence the natural variation that occurs in resources.

As a starting point for considering fishery management options, a contemporary baseline assessment that includes the distribution and relative abundance of marine species and marine community types, as well as habitat information, should be presented to relevant national and village managers and decision makers in Niue. A clear understanding of the problems, issues, constraints and opportunities with respect to coastal marine resources will enable appropriate decisions to be made for the sustainable management of these resources.

2.2 Approach

Prior to Cyclone Heta, the IWP baseline assessment sought only to assess the coastal resources within the village areas of Alofi North and Makefu. However, following Cyclone Heta in January 2004, IWP Niue agreed that the baseline surveys should be extended to also include other sites on the western side of Niue. The area to surveyed was consequently significantly expanded, and thus broad scale survey methods were employed in order to allow sufficient time to cover all the coastal habitats, while still assessing vital signs with respect to the status and health of coastal resources. Usually this meant that the categorization and description of target communities and processes was completed using broad, higher level taxonomic and descriptive parameters, where these were appropriate. In certain instances, species level assessment was necessary to fulfil the aims of the baseline survey. Visual assessments were employed as the basic assessment tool for this stage of the project, all of which were recorded by the author (to eliminate inter-observer bias).

Quantitative assessments of reef resource status were employed in some reef flat surveys to obtain pre- and post-Cyclone Heta data on reef flat fishery species. Quantitative assessments were initially planned for the third phase of the work, when it is anticipated that permanent baseline sites will be established. The third phase assessment would aim to monitor the effectiveness of management regimes that will be adopted by the community. However, following Cyclone Heta it was agreed that it was important to obtain cyclone impact data and to ensure that the pre-cyclone assessment summary was still valid. The post-cyclone impact information was especially valuable for Niue fisheries, as it represented the result of an extreme impact effect from a severe (category 5) cyclone. In addition, quantitative assessments were the most effective method for obtaining distribution and density data of macro invertebrates on the reef flat.

The baseline assessment included resurveying the pilot sites where data was recorded in December 2003. Table 1 contains a summary of the target parameters and the assessment methods employed to develop a status report for Alofi North and Makefu. The status report was put into a wider context by the inclusion of selected site assessments of adjacent coastal marine habitat along the west coast.

Video and photographic records were taken of key components of nearshore species and habitats throughout the baseline assessment phase. Many of the photos are included in this report for illustration and clarification.

Table 1. Target marine communities; habitat, health, and disturbance indices; and methods employed for the baseline assessment.

TARGET COMMUNITY or PROCESS	HABITAT	PARAMETERS	ASSESSMENT METHODS
Benthic Reef Community (Corals, Algae)	Reef Flat, Slope	Species composition and cover	Visual assessment using Manta Tows, Timed Swims, Photo & Video records
Fish Communities	Slope	Dominance and relative abundance	Visual assessment using Manta Tows
Macro Invertebrates	Reef Flat, Slope	Species composition, dominance and relative abundance	Visual and quantitative assessment using Manta Tows, Belt Transects (Reef Flat)
Habitat Features (Cyclone Damage, Physical Features)	Reef Flat, Slope, Deep Terraces	Abiotic features, physical damage	Visual assessment using Manta Tows, Timed Swims, Photo & Video records
Reef Health (Coral Disease, Bleaching)	Reef Flat, Slope	Presence, Affected Species	Visual assessment using Manta Tows, Timed Swims, Photo & Video records
Disturbance Indices (Coral Damage, Predator Outbreaks, Species Dominance)	Reef Flat, Slope	Presence, distribution, Affected Species	Visual assessment using Manta Tows, Timed Swims
Mega Fauna (Napoleon Wrass, Sharks, Snakes, Turtles)	Slope	Density and Distribution	Visual assessment using Manta Tows

2.3 Manta tow method

The manta tows method is a rapid broad ranging assessment technique, which was used only for reef slope habitats. An experienced diver is towed behind a boat at a constant slow speed for timed segments (2 minutes per tow). The average width of observation of each tow is set at a distance of 10 m. This results in an assessment of approximately 2–300 m of habitat for each 2-minute tow. A standard set of indices and visual assessment categories are recorded at the end of each timed tow. Unique sample identification numbers are assigned to all manta tows following each survey period; surveys on different days are reassigned tow numbers starting at 1, for ease of understanding between the note taker in the boat and the diver/observer, as well as for long term evaluations with future surveys. In addition, GPS positions and the general tow direction are recorded at the beginning of each tow by the note taker in the boat, because sequential tows are separated by only 20–30 m in distance. Land features are also noted during the tows for additional aid in locating the position of individual tows or sections of the coast where particular characteristics are of special note.

2.4 Timed surveys

Timed surveys (average 20 minutes per survey) were used as an additional method to ensure more detailed information was collected in sites of particular importance or relevance. For each swim, scuba dive, or reef flat walk, notes were taken on the species present, relevant habitat features, as well as reef health and status indices, using the same format as the manta tow method (see Table 2).

Reef flat assessments were conducted by walking at low tide, and were included in the timed survey category as they employed similar methods to the swims and dives conducted on the reef slope.

Unique sample number identifiers were assigned to each sample time for future reference, with GPS and other location information. Photographic and video records were taken as part of the timed surveys for future reference and for species validation where identification was uncertain.

2.5 Belt transects

Belt transects[2] were used in intertidal reef flat habitats during the baseline phase to assess the relative abundance of invertebrate fishery species. The sampling methodology followed that of prior surveys (see reference list) and was also opportunistically employed to assess the impact of Cyclone Heta on reef flat resources.

Belt transects assess the distribution and relative abundance of a select set of macro invertebrates. Most species are of importance to coastal fisheries (e.g. *papahua* or purple jewel oysters, *ugako* or vermetid molluscs, *gege* or giant clams, *matapihu* or false limpets, and subsistence as well as potential commercial holothurians [*loli tea*]). The presence of other common reef flat species that occur in association with targeted species were also recorded.

Transects were orientated perpendicular to the reef crest, starting from the inner reef flat out to the crest, and recording numbers of individuals in contiguous 10 m × 5 m wide belts. Two sites used for pilot method testing in December 2003 were re-surveyed in March 2004 (Vailoapu Sea Track (2 transects), and Namoui Sea Track (4 transects)). Additional sites were completed during the 2004 baseline surveys: Alofi Wharf (3 transects), Omahi Sea Track (3 transects), North Alofi (opposite Alofi North hall) (4 transects), Makefu Sea Track (2 transects), Lepetu (3 transects), Avaiki (4 transects). Site identification numbers were assigned to each sample site during post-field work recordings (see Fig. 1 for locations).

[2] Belt transects are specified length and width sample sizes within which target species are recorded.

Table 2. Parameters recorded in Manta Tows

HABITAT CHARACTERISTICS	
Water Visibility and Depth	Low (<6m), Medium (6-12m), Good (13-18m), Very Good (>18m); Depth is estimated average depth below diver
Slope Steepness categories	**Slope steepness** refers to the slope angle at the edge of the reef that is adjacent to deeper open ocean water. The general shape of this edge influences the types of reef organisms that can live here. M (moderate angle <30˚), ST (steep angle, 30-60º), V (tending to vertical angle >60-90º)
Edge categories	**Edge** characteristics refer to the main forms of the slope. SPG (Spur and groove), CON (Continuous edge), BR (Broken edge to slope)
Dominant Substrate categories	**Substrate** characteristics describe type of surface that is present, and whether it is consolidated (platform) or loose with different sizes of particles (rock, rubble, or sand). PL (Underlying platform), RK (Terrestrial rock), S (Sand); RU (Rubble), SR (Sand and Rubble)
BIOTIC FEATURES	
Benthos (Dominant life form)	LC (Live coral), MA (Macro algae), CA (Coralline algae), SC (Soft coral), SG (Seagrass), SP (Sponge), TA (Turf Algae) (Macro algae refers to large distinct forms of marine plants that are soft to the touch. Coralline algae refers to types of macro algae that have a calcareous element to their form).
Coral Form	**Coral form** describes the shape and appearance of hard corals. ACC (*Acropora* corymbose), ACT (*Acropora* tabulate), ACB (*Acropora* branching), ACD (*Acropora* digitate), ACS (*Acropora* submassive), BRA (Branching), ENC (Encrusting), FOL (Foliose), MA (Massive), SUB (Submassive), CMR (Coral mushroom), CHL (*Heliopora* blue coral), CME (*Millepora* stinging coral)
LC (Live Coral cover)	0 = 0%, 1 = 1-10%, 2 = 11-30%, 3 = 31-50%, 4 = 51-75%, 5 = >75%.
DC (Dead Coral cover)	same as for LC
SC (Soft Coral cover)	same as for LC
Macro Invertebrates (Clams, Holothurians, Urchins)	0 (zero), L (Low, <10 individuals), H (High, >10 individuals) (Holothurians (sea cucumbers) live primarily on the reef substrate and are known as bêche-de-mer when processed).
Fish Abundance	L (Low, <100 individuals); M (Moderate numbers, >100 - <500), H (High, >500).
Fish Dominance	Dominant Family, excluding Damsel Fish & Small Wrass.
Other Mega Fauna	Total numbers of sea snakes; Large Predatory Fish (Sharks, Humphead Wrass, Barracuda), Stingrays, Turtles, Jellyfish, etc).
DISTURBANCE AND HEALTH INDICES	
Coral Damage categories	S (severe, >75% all colonies with scars), H (high, 30-75% all colonies), M (moderate, 11-30% all colonies), L (low, <10% all colonies), none (0).
Disturbance Indices	Crown of Thorns starfish (COTS) No. & Size (Diameter) ; Coral Disease, Coral Bleaching, Storm Damage, Destructive Fishing impacts (Dynamite, Bleach & Vegetation poisons), Sediment covering benthos; the proportion of colonies with signs of a disturbance indicator were assessed using the same categories as the coral damage categories.
Notes	Identified species; Presence of human derived rubbish, freshwater, and land vegetation.

2.6 Analysis

An analysis of the baseline data is mainly descriptive and includes the comparison of pilot data from before and after Cyclone Heta, using graphical representations and mean values for a wide range of parameters. For manta tow data, mean values for a range of parameters are calculated as an average of the total number of tows, treating each tow as a replicate sample. Belt transect data are presented as densities per hectare (ha), which are estimated based on an area of 250 m^2 per 50 m-long transect, which was the standard sample size used for reef flat invertebrates in this survey. A couple of transects had to be terminated at the 40 m mark as the reef flat was not wide enough in these positions, and in these cases, the density estimates were adjusted accordingly. Wherever possible, photos are added to clarify and illustrate the descriptive treatment of the baseline data.

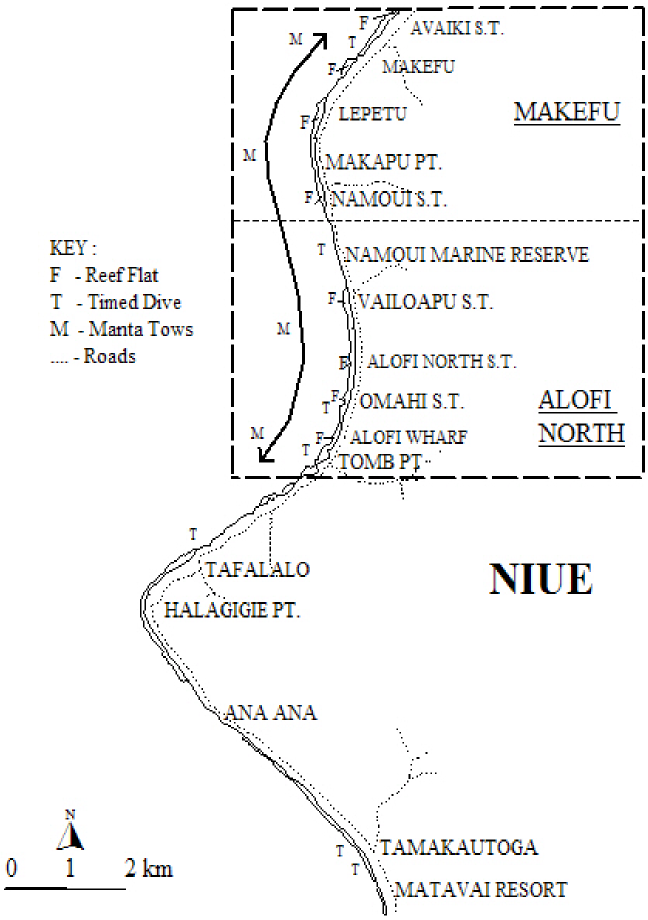

Figure 1. West coast place names and pilot community boundaries

Dashed boxes around Alofi North and Makefu show pilot community boundaries. Baseline survey methods and the approximate position of surveys indicated by: F = Reef flat belt transects; T = Timed Dives, M = Manta Tows. Coastal reef flats are shown as double lines. S.T. = Sea Track, PT = Point.

3 Results

The data presented from the manta tows and timed surveys are primarily from slope habitats, although a few reef flat walks are included in the timed surveys. The belt transect data are from the reef flat habitat. Figure 1 shows the place names referred to in the text, including the two pilot village areas and the approximate location of each of the baseline surveys.

3.1. Reef slope assessments

The results of manta tows conducted in December 2003 and March 2004 are presented in Appendix 1. Details of each tow position and direction are in Appendix 2.

3.1.1 Habitat characteristics

The average depth of the tows in Alofi North and Makefu ranged from 12–20 m, which corresponds with the mid- to lower slope depth range. The deepest observed area represents the beginning of a variable-width terrace that slopes out to a 30–40 m deep terrace edge, after which the substrate drops steeply into very deep water (hundred of meters in depth). The tow path covered mostly **steep slopes** (30º–60º); the major morphological features were spur and groove formations.

Spur and groove slopes are typical of exposed outer reef areas. The grooves typically contain sand, rubble, coral boulders, loose macro algae, and other refuse (such as terrestrial vegetation and human rubbish), which are moved down the grooves during high seas with the backwash from waves breaking onshore. The base of grooves in deeper water often displays a deposition zone of what was carried down the grooves. In the majority of grooves along the survey area, little to no loose material of any size was observed, signifying the extreme magnitude of waves that were experienced along this section of the coast during the height of Cyclone Heta. This was not surprising because of the extensive destruction of infrastructure on the adjacent coast from big waves, which were reported to have reached over the cliff edge and into the adjacent raised terrace. The exception was in the middle section of the Namoui marine reserve, where both sand and vegetation debris was observed at the base of many grooves. This reflects the relatively lower impact effect from cyclonic waves along this section of the coast.

A small number of **caves** were also observed in mid- to lower slope positions in the vicinity of Makapu Point (north of the Namoui Marine Reserve). Caves are often sites of high fish activity due to the protection from predators such cavities present. Caves are also used extensively by crayfish when they are not feeding (during the day). Elsewhere on the western side of the island, caves were found to contain crayfish after the passing of Cyclone Heta, underlying the importance of these specialised habitats as refuge areas (pers. comm., Ann Franklin and Ian Gray, Niue Dive). The caves in the pilot site areas were not investigated in detail during the baseline surveys.

3.1.2 Biotic features

The **dominant benthos** in 70% of tows was a single species of **macro algae**, compared to December 2003 pre-Cyclone Heta, where live coral was the most dominant benthic form. An exception was observed in the mid-Namoui Marine Reserve section where live coral dominated (19% of tows), although areas of macro algae were also present in shallower depths (< 6 m depth). The macro algae has been provisionally identified as *Liagora* spp.., although this has to be confirmed. Photos taken in December 2003 in the vicinity of Omahi Sea Track slope (adjacent to the Alofi Harbour area) confirm the presence of the same species of macro algae prior to Cyclone Heta, but it was then found in relatively low densities. The macro algae

Padina cf *australis* was dominant in the vicinity of Alofi Harbour in December 2003, and was correlated with the prevalence of ciguatera fish poisoning in the same area.[3] Most of the *Padina* cf *australis* algae were absent from the harbour area in April 2004, except for a few isolated small patches in steep shallow grooves in the upper slope south of the harbour. *Liagora* spp. was present in the harbour area in April 2004 but it was generally patchy in its distribution and rarely dominant in terms of substrate cover.

Turf algae were the dominant benthos in 11% of tows located close to the southern border of the Namoui Marine Reserve, where coral and macro algae were found to be largely absent, probably due to the impact of Cyclone Heta waves. There was no evidence of the dominance of *Liagora* spp. macro algae, however, as was typical elsewhere. In the first weeks after the cyclone, green turf algae dominated the exposed surfaces along large sections of the coastal slopes, but this was not present by the time of the baseline surveys in early April 2004. The green turf algae could be easily removed with a wipe of the hand (C. Vieux, Centre de Recherche Insulaire et Observatoire de l'Environnement, pers. comm., 2004) indicating that the alga was not firmly attached. This algae was probably temporarily dominant due to the high nutrient levels in the water immediately after the cyclone, combined with an extended period of extreme calm weather that followed the passing of the cyclone. These conditions allowed for the rapid growth of the green algae, which probably persisted until there was a reduction in nutrient loads in the coastal waters, in association with a return to more turbulent water conditions. This would have removed much of the turf algae layer and allowed other species to colonise available substrate. The turf algae observed in April 2004 was a different unidentified species (brown in colour), different from the green turf alga that earlier colonised much of the available substrate.

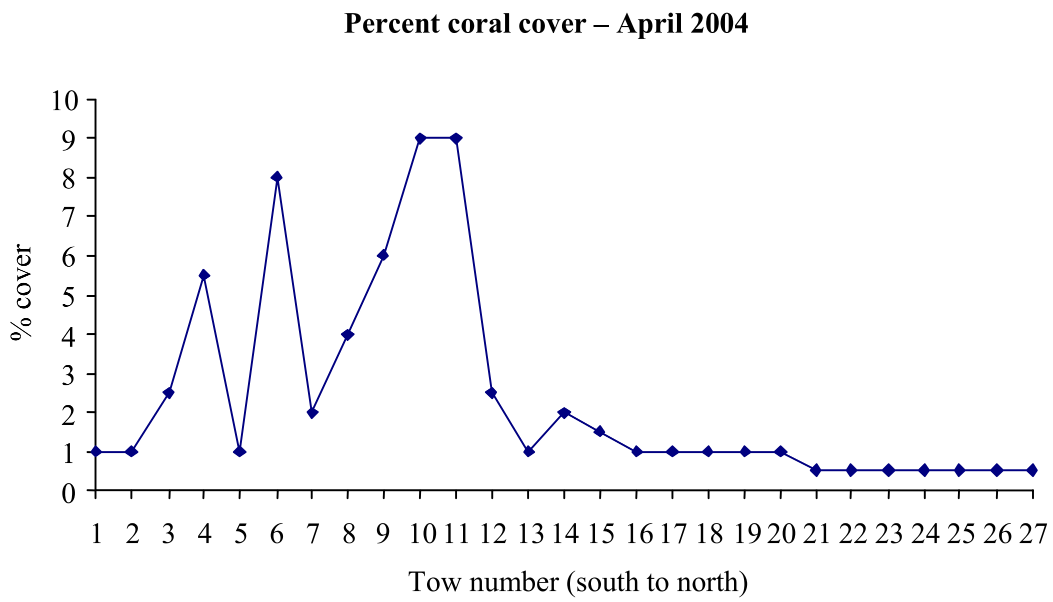

Figure 2. Live coral cover (%) estimated from April 2004 manta tow surveys.

Tows are numbered from the south, from Alofi harbour (#1) to the most northerly tow (#27) opposite Makefu Sea Track. Tows 4–11 are situated in the south to mid section of Namoui Marine Reserve.

Live hard coral is a significant component of reef areas, particularly in relation to reef fishery species, due to the spatial heterogeneity it provides, which functions as shelter and food for a myriad of fish and invertebrate species. Live coral communities are the essential base layer for

[3] The cause of ciguatera is due to the presence of microscopic dinoflagellates (*Gambierdiscus* spp.; Yeeting 2003) and not the macro algae.

a diverse and sustainable reef fishery. Live coral cover was significantly reduced — and consistently much less than 10% cover — at all locations in the survey area (81% of tows scored less than 5% coral cover; see Fig 2). This contrasts to the smaller area sampled in December 2003 in the vicinity of Omahi Sea Track, where the live coral cover was estimated to be approximately 20% to 50% cover. In the southern section of the Namoui Marine reserve, live coral cover was relatively higher than elsewhere in the survey area, ranging from 4% to 9% cover (Fig. 2).

Where live coral was observed, the dominant **coral form** was massive species[4] (in 96% of all tows). The dominant hard coral species south of Makapu Point (in terms of cover) was *Porites* spp., followed by some species from the family Faviidae (*Favia matthai* and *Leptoria phrygia*), and some colonies of *Astreopora* spp. (family Acroporidae). At sites north of Makapu Point the dominant massive coral form was the hard skeleton forming hydrozoan *Millepora* spp. At one location in the mid-section of the Namoui Marine Reserve, where near vertical slope angles were observed, the tabulate coral *Acropora paniculata* was the dominant growth form at the base of the slope, but very few corals were present in shallower water (less than 5 m in depth). However, there was a diverse range of coral species on the mid-slope (depth between 5–12 m). This section of the coast was in a position that would have been relatively protected from the most extreme wave conditions during Cyclone Heta, though most branching colonies (both alive and dead) were removed in this section of the coast.

Photo 8. Stressed corals, post-Cyclone Heta.

After the impact of Cyclone Heta, remnant corals remained in the slope habitat but most were either damaged or showing signs of stress (bleached or pale in colour). Also, many remaining corals were being colonised by turf algae on their damaged portions.

[4] Massive species are those that have a hemispherical form.

Photo 9. Occasional giant clams remained on the slope in March 2004.
Most were relatively small and were located in depressions that may have protected them from being removed during the high seas of Cyclone Heta.

Photo 10. The macro algae *Liagora* spp. dominated the slope and many reef flat locations for several months after Cyclone Heta.

Dead coral cover refers to the cover of coral skeletons that are still attached in their original living growth position but are covered by varying degrees of turf macro and/or coralline algae.[5] Sixty per cent of tows were observed with low (< 10%) cover of dead coral with the midsection of the Namoui Marine Reserve (15% of tows) containing up to 30% cover of dead coral skeleton. The presence of dead coral in pre-Heta conditions was attributed to the impact

[5] Mortality in these corals is usually due to a number of factors that result in the removal of the outer live coral tissue (such as low salinity water, disease, elevated sea temperature bleaching, and predation by crown of thorns starfish (*Acanthaster planci*) and corallivorous gastropods [*Drupella* spp.]).

of coral bleaching events in the previous summers of 2002–2003 (Fisk 2007b). The pattern of live and dead coral described here for the survey area can be explained by the fact that coral bleaching tended to cause the highest mortality in branching growth forms, which were removed by cyclonic waves, except for the small section of coast that appeared to be relatively less affected (the mid-Namoui Marine Reserve area). In the northern sector of the survey area from Makapu Point north, no dead coral was observed. The substrate on this section of the coast was a more or less smooth platform with very little relief in terms of holes or crevices, and with very low live coral (consistently less than 1% cover). This section of the coast northwards is the beginning of the most extreme wave-affected parts of the subtidal habitats in the survey area.

The low presence (15% of tows) and cover of **soft coral** in the mid-Namoui Marine Reserve is probably similar to the pre-Cyclone Heta situation, where there was low presence of soft coral throughout the survey areas. Low profile and encrusting forms of soft coral that can resist strong wave action are typical of the soft coral species present on Niue.

Large visible **macro invertebrates** (giant clams, holothurians, urchins) were noticeably absent from most of the survey slope areas. Many of the macro invertebrates are difficult to observe by the manta tow method except when present in moderate densities. However, in timed surveys (see below) macro invertebrates were also present in very low densities and when present were commonly small and cryptically located. Giant clams were present in low densities along the western coast in December 2003, and it appears that the larger individuals were removed by the cyclone, but some smaller specimens found in crevices appeared to have survived. Similarly, large holothurian specimens (*Thelenota anas* and *Holothuria nobilis*) were occasionally observed on the slope in manta tow and timed surveys, particularly in the mid Namoui Marine Reserve area. This differed from the distribution and presence of holothurians on the adjacent reef flats (see belt transect data below).

Fish abundance and dominance recorded in March 2004 was similar to that observed in December 2003 prior to the cyclone. Overall, there were low densities (<100 individuals per tow) of predominantly surgeon fish (F. Acanthuridae) in 81% of tows, with a tendency for parrot fish (F. Scaridae) to be dominant in a small number of tows (19%) in the middle and northern sections of the survey area. Relatively higher abundance of fish (moderate numbers of between 100–500 individuals per tow) was recorded in the southern portion close to Alofi harbour and the mid-Namoui Marine Reserve area. Overall, these broad fish abundance estimates indicate a relatively low standing stock for the entire survey area, which was similar to the situation prior to the cyclone. The results of a more detailed fish survey by the Secretariat of the Pacific Community (SPC) in February 2004 in the Namoui Marine Reserve may indicate a different situation when these data are made available (Yeeting 2004).

A small school (approximately 30) of dark fin barracuda (*Sphyraena qenie*) and a few great barracuda (*S. barracuda*) were observed in the mid-Namoui Marine Reserve area during a tow and later during a timed SCUBA survey in the same area (see below). The former species of barracuda is typically found associated with reefs while the latter species is typically found in deeper water offshore. No large fish or sharks (except for the above barracuda) were observed during any of the tows, which is in contrast to the occasional observation of both white tip reef sharks (*Triaenodon obesus*) and humphead wrass (*Cheilinus undulatus*) in December 2003 in the same sections of the survey area.

3.1.3 Disturbance and health indices

Wave damage to corals and associated habitat by Cyclone Heta was assessed be estimating:

- the proportion of the remaining live colonies that exhibited dead patches, or partial mortality due to impacts from debris; and
- the relative smoothness of the substrate surface due to direct removal of colonies (either dead or alive). Although very low numbers of coral colonies were present

in most sites, the degree of partial damage to the remaining colonies varied greatly within the survey area (Fig. 3). However, damage tended to be more pronounced in the southern and northern sections of the survey area.

Thirty-three per cent of tows recorded low numbers of damaged colonies (<10% of all colonies), 26% of tows recorded moderate damage (11–30% of colonies), 19% had high damage rates (31–75% of colonies), and 22% had severe damage rates (>75% of colonies).

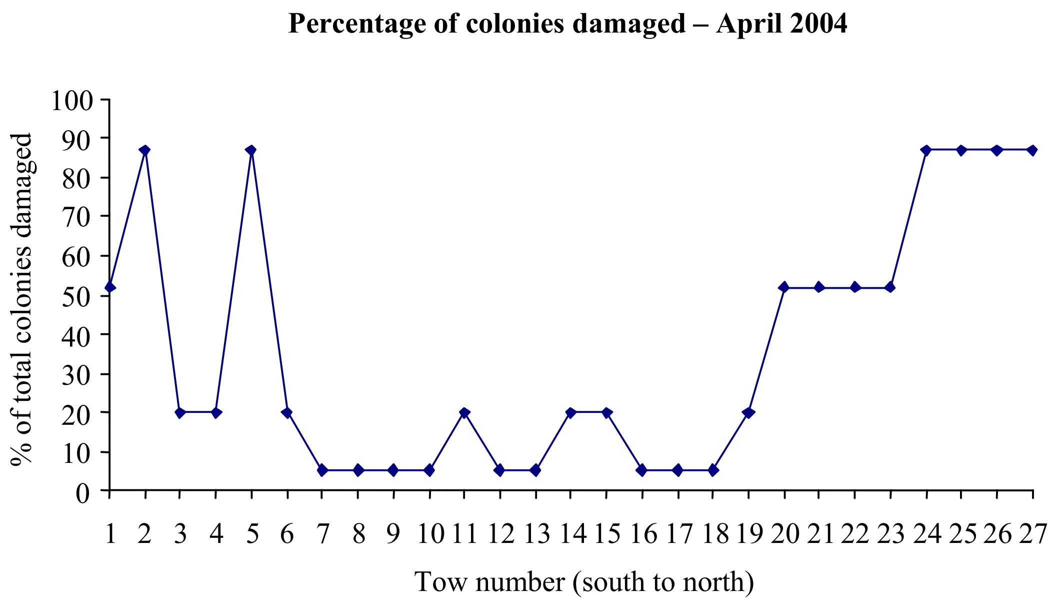

Figure 3. Live coral colonies showing mobile debris-related scar damage from Cyclone Heta (%).

Tows are numbered from the south starting at Alofi harbour (#1) to the most northerly tow (#27) opposite Makefu Sea Track. Tow numbers from #20 and higher are situated north of Namoui Marine Reserve and Makapu Point, where the most severe damage to the reef was observed. In this section there were very few remnant corals present and all observed were damaged so estimates were inferred to be severe in all tows.

The other index used for the assessment of damage was the presence of a dominant smooth substrate caused by strong scouring of the reef surface. A total of 33% of all tows was observed as having significant areas of slope with heavily scoured surfaces. The majority of these areas were concentrated in the most northern section of the survey area north of Makapu Point, with one tow area similarly scoured north of Omahi Sea Track. In most other tows where the slope was not recorded as having a predominantly smooth surface, scoured surfaces were observed in parts of the survey areas, but the scoured surfaces were not dominant.

Almost all of the most northern section, along with the most southern section of the survey area, were relatively more impacted by cyclone-related wave action, with the intermediate areas (centred on the Namoui Marine Reserve area) showing more variable degrees of damage. The variation in the middle section of the survey area is related to the shape and angle of the slope surface, as well as to the presence of reef flats or cliff faces. In general, the northern side of slope edges, and slope areas that extended out further than the surrounding areas, were severely impacted by waves that moved roughly parallel to the shoreline. This pattern was far less pronounced in areas with steep cliff faces, where the reef flat is absent.

Figure 4 shows a generalised descriptive assessment of the relative damage to reefs using a number of damage categories that integrate both quantitative and qualitative assessments of slope communities. Some of the information includes descriptions from consultations with Niue Dive and Niue Fisheries Division personnel, who undertook assessments in a broader area than the current survey. Damage categories of severe to low are used to describe the extent of damage.

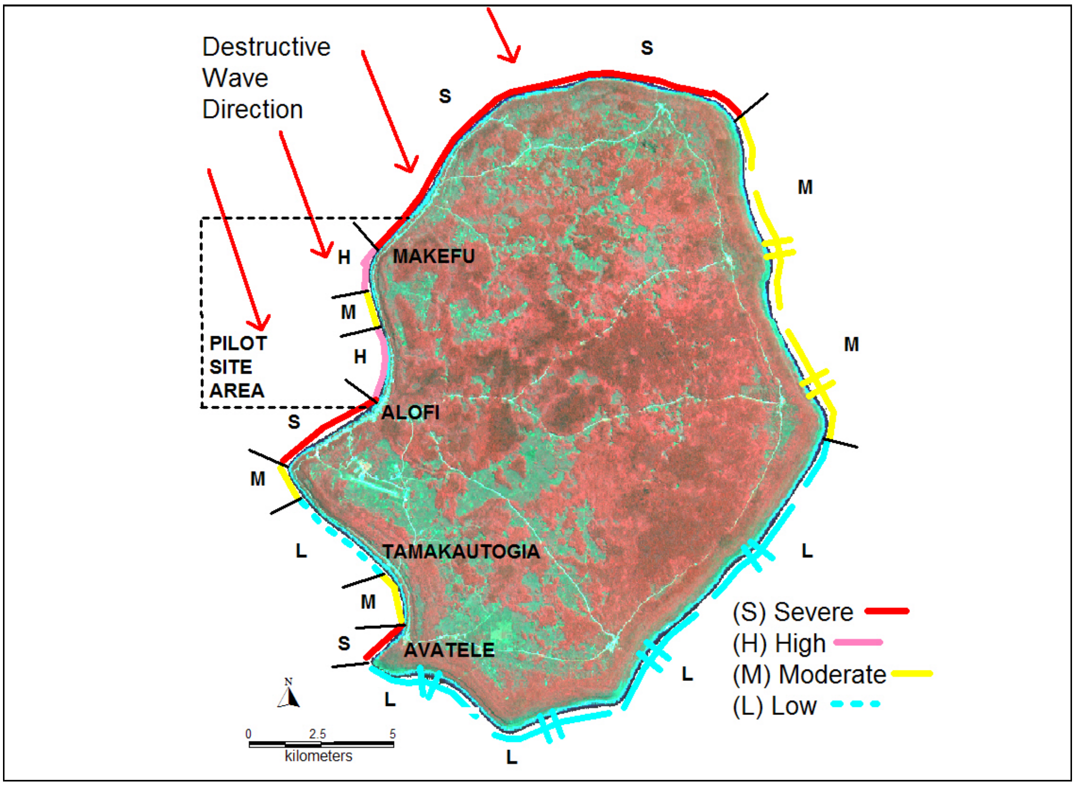

Figure 4. Map showing extent of cyclone-related reef damage experienced along the Niue coastline (from quantitative and qualitative data sources).

The east and south coast sections were not surveyed so the status of these areas was inferred from the strong directional pattern of damage (indicated with appropriate shaded lines and double strokes). Note the presence of at least one coastal section on the west coast where low to minimal damage occurred (small dotted line opposite Tamakautoga). Survey area refers to section of west coast surveyed using manta tows. For damage category explanations, see Table 3 below.

Table 3. Reef damage categories

Category	Characteristics
severe	All surface layers, algae, and reef flat invertebrates removed, smooth clean reef surface
high	Fragile corals, most large invertebrates, and algae removed, scars on most remaining corals
medium	Fragile corals, some large invertebrates, and algae removed, scars on most remaining corals
low	Negligible impacts evident; fragile corals remain; reduction in reef flat invertebrates

It is noteworthy that a section of subtidal slope on the western coastline was virtually untouched from the cyclone and is in very good condition with high diversity overall. This small section of marine coastal habitat stretches from south of the Matavai Resort to north of the Anaana lookout point (centrally located opposite Tamakautoga village).

No **crown of thorns starfish** (COTS) signs of feeding scars were observed in any of the tows. Some feeding scars were observed but they were typically characteristic of the **coral eating gastropod** *Drupella* species. *Drupella* spp. were also present along this section of the coast in December 2003 and they were predominantly feeding on table corals (*Acropora paniculata*) but the cyclone removed most of these colonies from the slope, except for a small area in the mid-Namoui Marine Reserve where some colonies remain.

The same mid-Namoui Marine Reserve section of coast where some table corals (*A. paniculata*) remain, is also where a low incidence of **coral disease** was observed in this species. The presence of diseased corals of this species was noted in the December 2003 pilot survey, when it was assumed that this was a secondary effect of stress caused by a severe coral bleaching event the previous summer. Coral disease is causing colony mortality in this species and is independent of the impact of the effects of the cyclone.

The incidence of coral bleaching in the remaining live corals was particularly high (approximately 30–75% of colonies had white to very pale colouration) in the southern section of the survey area. The incidence of bleaching generally decreased towards the north, although some species (e.g. *Montastrea curta*, *Porites* spp., and *Millepora* spp.) were consistently displaying paler than normal colours. The incidence of bleaching in the remnant coral population is significant, as it indicates stress which may be unrelated to the recent cyclone conditions, and is more likely due to other processes that commonly induce bleaching, (i.e. elevated sea surface temperatures and high levels of irradiation from an extended period of low or no cloud cover).

The presence, in April 2004, of some normal, conspicuous species common to Niue's coral reef system indicates that conditions are gradually returning to normal for certain components of the reef. Some of the indicators observed include the Niuean banded sea snake (*Laticauda colubrina*), which were relatively abundant and were displaying mating behaviour.[6] Sea snakes were observed particularly in the southern section of the survey area, but were generally widely distributed throughout. A moderate sized green turtle (*Chelonia mydas*) was also observed in the survey area during the manta tows, and schools of squid were observed off the reef slope at the Omahi Sea Track as well. When these observations are included with the status of relevant groups above, it indicates that marine resources will probably gradually recover, but it will be at different rates for different organisms; recovery will also be affected by external factors such as harvesting pressure.

3.2. Selected reef slope site surveys

Timed surveys consist of detailed snorkel swims and SCUBA dives in selected locations, as well as reef flat observations that were carried out at low tide. The main features of the data from these sites include a general site description using the same protocols as the manta tows, as well as details of species lists and other physical features of note. Sites are described in this report from south to north. These sites generally refer to the most relevant village or area where they are located (Figure 1). Specific descriptions and characteristics of communities are included here for corals and macro algae. Other relevant groups (e.g. macro invertebrates) are reported in the broad scale manta tow surveys and reef flat belt transect data.

Sites were selected so as include the same range of habitats (as well as conditions within those habitats) as was surveyed using the rapid manta tow method. Surveyed sites also included representative adjacent similar coastal habitats that were not in the pilot sites. Undertaking more detailed surveys at these sites ensured that information that might have been missed by the rapid manta tow surveys would be included in the overall assessment of resource status.

3.2.1 Site descriptions

Site descriptions for the timed survey sites (an average of 30 min each) are presented below and refer to sites surveyed in December 2003 and March 2004. Figure 1 shows the location of

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[6] Mating behaviour in sea snakes included pairing off and groupings of small numbers of individuals, but no "snake balls" were observed (tight entangled groups of snakes where actual mating takes place). The timing of mating behaviour in late summer is normal for this reptile.

these sites in addition to other place names referred to in the text.

Village: Tamakautoga #1	**Village: Tamakautoga #2 (approx. 200m north of #1)**
Date: March 2004	**Date: March 2004**
Habitat: Slope	**Habitat: Slope**
Location: South of Togulu Sea Track and north of Matavai Resort	**Location: Opposite Togulu Sea Track.**

These two sites were classified in the cyclone damage assessment as having low disturbance from the cyclone. The profile of this area is similar at both sites with a steep drop from the crest to the lower slope at 15 m depth (approx. 65°), and with deep spur and groove formations cutting into the slope. Coral diversity is high with a wide range of growth forms present, and high cover at an average of 50% live coral. Coral diversity is the highest observed from any of the western coast sites with 71 species identified, with a number of uncertain identifications in addition to this number, which may increase the total confirmed species count. Three genera of soft coral (*Lobophyton*, *Sarcophyton*, and *Sinularia*) are present, each of which may represent a number of species, making these sites the most diverse soft coral area observed on the west coast. There are a wide range of macro invertebrates present on the reef flat as well. This also is the case for the slope; in particular *Tridacna maxima* is present in a range of sizes. The calcareous macro algae *Halimeda opuntia* is also common among corals, indicating that this section of coast does not receive wave action strong enough to dislodge this large algae, unlike other more exposed sections of the coast.

The base of the slope extends into deeper water to form a terrace approximately 100–150 m wide with a gentle slope to 30 m depth, after which the depth rapidly increases with a steep drop off to unknown depths (hundreds of meters deep); coral cover is lower (10–15%) on the inner section close to shore but live coral cover increases towards the terrace edge to 80–90%, of which the tabulate coral *Acropora paniculate* is the dominant species. A number of coral species not present in shallower water are abundant in these areas, including more delicate foliose and branching species. Fish diversity and sizes are relatively higher on the lower terrace outer edge, particularly in the vicinity of complex substrate and coral formations. The reef along this small section of the coast represents the most diverse communities that have been observed to date for any part of the west coast.

Village: Alofi South
Date: March 2004
Habitat: Slope
Location: Opposite former land site of the national hospital; at a dive site known as Bubbles Cave and opposite the Tafalalo area (southwest of Alofi North).

This area was classified as a severely disturbed area from the cyclone. There is no reef flat formation but a labyrinth of relatively shallow channels that occasionally lead up into caves at the base of the cliff face. Deep grooves cut through the upper slope area and lead to lower scree slopes at a depth of 20–25 m. A terrace extends seaward for approximately 60–100 m length, to a depth of approximately 40 m, where the pavement descends into water hundred of meters deep. This area was severely affected by Cyclone Heta and corresponds to the most significantly damaged adjacent land areas. Sections of the slope habitat were devoid of any living benthos, other than the ubiquitous macro algae, *Liagora* spp., which was dominant on most slope surfaces. In contrast to the Omahii Sea Track slope site, there was only minor colonisation of bare surfaces by turf and blue-green algae mats. Very little land-based rubbish was observed in the gutters or on the base of the inner terrace, though extensive areas with rubbish were observed in deeper water on the outer terrace (I. Gray, pers.comm.).

Coral cover was very low (estimated at <1% cover) and consisted of a small number of massive coral species which exhibited extensive scaring and damage from impacts from material that moved around during the height of the cyclone. Small colonies of *Sarcophyton* spp., a low encrusting soft coral, were observed in some of the inner portions of the shallow gutters. As well, small patches of the macro algae, *Padina cf australis*, was present in the shallow gutters. This alga was previously very abundant in the harbour area to the north of this site. A few soft bodied and mobile invertebrates (anemone with anemone fish, and banded coral shrimp, *Stenopus hispidus*, respectively) surprisingly survived the extreme cyclone conditions, probably by using holes in the slope as refuges. Fish present in March 2004 were primarily represented by a small suite of herbivors from the families Acanthuridae (surgeon fish) and Scaridae (parrot fish).

Due to the almost total absence of corals and the extreme nature of the physical damage to

Village: Alofi South

the slope surface, regeneration of a coral reef-dominated benthos will be expected to take a relatively long time compared to some other areas, e.g. in comparison to the northern end of Alofi North and the Namoui Marine Reserve area. Further input from land based sources of pollution (and nutrients) could hinder the recovery of the reef system in this area by maintaining a benthos dominated by fleshy and turf algae.

Village: Alofi North
Date: December 2003 and March 2004
Habitat: Reef Flat
Location: Entrance from Tongalahi Sea Track and opposite Tomb Point

The reef flat habitat was classified as having medium disturbance from the cyclone. This area of reef flat leads to additional reef flat habitat to the south (into Alofi South village area) and extends to the excavated section of Alofi harbour to the north. Shallow pools are defined by algal ridges that tend to pond water at low tide, although none are deeper than approximately 15 cm. The inner reef flat has low numbers of most typical reef flat organisms with some notable absences. Commonly occurring species that are absent include a range of gastropod molluscs, with the exception of *Morula uva* and *Drupa ricinus*, and a low number of vermetid tube worms (*Serpulorbis colubrinus*). Very low numbers of *Holothuria leucospiota* and *H.atra* can be found in the few inner reef flat pools. Two species of prostrate encrusting coral forms of *Acropora monticulosa* and *Goniastrea retiformis* are present on the outer flat. The outer flat is dominated by the tough wave resistant macro algae, *Sargassum cf cristaefolium*, which is short branched and partially encrusting in this location. This macro algae can also be associated with relatively high nutrient environments. Numerous small burrows of a black pencil urchin (*Heterocentrotus cf trigonarius*) also inhabit the outer flat areas. This species is only found in this area, in contrast to the remainder of the reef flat in Alofi North and Makefu, where the dominant burrowing urchin is *Echinometra mathaei*. There appears to have been little change as a result of the cyclone, other than the elimination of a former small beach and adjacent coastal vegetation, despite this area receiving very severe ocean conditions.

Overall, the reef flat has low abundance and low diversity of most common reef flat organisms and is densely covered with turf algae, with most of the normal crustose coralline algae of other similar outer flat and crest positions being absent. The indications are that this site is receiving high nutrient inputs from adjacent land based activities. The location is directly below some storm drains that receive water from the main commercial area of Alofi, and is also the main receiving point for waste water from a commercial clothes laundry situated at the beginning of the sea track down to the reef flat. As part of an overall strategy to improve coastal fisheries, such nutrient sources will have to be addressed.

Village: Alofi N. Harbour
Date: December 2003 and March 2004
Habitat: Reef Flat
Location: North of wharf and harbour 2003.

The reef flat was classified as having high disturbance from the cyclone. Moderately deep pools (average 50 cm) are present on the inner and mid flat, but no deep channels that connect to the open sea are present. Prior to the cyclone this area received runoff from the main commercial district through a number of storm drains, as well as from the main bulk fuel depot immediately above the reef flat adjacent to the wharf. The cyclone destroyed most of the retaining walls, roads, and structures that supported the fuel depot and many of the large cement slabs from these structures are now resting on the reef flat. Large quantities of diesel fuel were released as a result of wave damage to the fuel storage tanks above the harbour. In December 2003, the reef flat supported a relatively diverse invertebrate fauna and flora, including high cover of a complex macro algae suite of species that was dominated by a calcareous branching red algae (*Jania* spp.). A repeat survey was not completed in 2004.

Village: Alofi North
Date: December 2003 and March 2004
Habitat: Reef Flat
Location: Inside Namoui Marine Reserve, South of Vailoapu (family) Sea Track.

This area was classified as having moderate disturbance from the cyclone. There was low abundance of the more common macro invertebrates that were present in March 2004, with some species significantly less abundant compared to December 2003 (see the discussion for belt transect quantitative data below). High cover of blue-green algal mats and turf algae clumps was more prevalent in 2004 compared to December 2003, though the two algae were also present in restricted areas prior to the cyclone. This probably represents an opportunistic expansion of cover for these two algae due to the greater exposure of bare substrate as a result of the removal by the cyclone of a sediment layer that was widespread prior to the cyclone. This sediment layer was held in place by short turf algae that occupied the majority of the bare substrata. This was a common impact from the cyclone on much of the reef flat habitats and its significance is not fully understood. One affect of the removal of this sediment layer and presumably the underlying turf algal layer is a reduction in this habitat feature that may be important for a range of surface feeding macro invertebrates such as holothurians.

Village: Alofi North
Date: December 2003 and March 2004
Habitat: Reef Flat
Location: Namoui Marine Reserve

This area was classified as having moderate disturbance from the cyclone. Very similar observations and effects were observed at this location as have been described for the northern sector of the Namoui Marine Reserve reef flat. Data from belt transects have been analysed and trends described for selected macro invertebrates in the relevant belt transect data section below. An impressive example of the force of cyclone waves was demonstrated at this site with the movement of a very large boulder approximately 4 m diameter into the path of one of the transects from its original position approximately 30 m away.

Village: Makefu
Date: March 2004
Habitat: Slope
Location: Opposite Makefu Sea Track

This area was classified as having moderate disturbance from the cyclone. The slope is steep throughout this section of the coast with very little reef flat development. Some short length spur and groove formations are present along the slope, with sand and land vegetation pieces found at the base of grooves in deeper water. The northern sides of the spurs and grooves were more severely damaged by the cyclone as the most destructive waves came principally from this direction.

There are minimal deeper terrace formations present in this section of the coast as the profile tends to fall away into deeper water more abruptly than in the northern Makefu and southern sectors of Alofi North. This results in a relatively smaller area of slope habitat that is available for reef development, but the relatively lower disturbance of slope communities in this area makes it very important as a refuge and source of regeneration of species for a wide range of reef species along this highly disturbed coastal area.

The remnant coral community is dominated by a diverse range of massive and encrusting species, with lower abundance of *Acropora* spp., which are generally absent from the slope communities due to the impact of the cyclone.

Village: Makefu	
Date: March 2004	
Habitat: Slope	
Location: Opposite Makefu Sea Track	

This area was classified as suffering severe disturbance from the cyclone. There is extensive reef flat development and a moderate to steep slope habitat that extends into a deeper terrace formation. A number of deep and steep sided grooves are present along the slopes that provide some heterogeneity in slope characteristics that may be important for larger fish as a minor refuge during low tides when access to the reef flat is restricted.

As with similar areas in the southern parts of the pilot village areas, this section of coast exhibited extreme cyclone-related disturbance, which will require a relatively longer time period for regeneration of the reef community to occur. Macro algae (particularly *Liagora* spp.) and turf algae (clumping as well as blue-green algae mats) dominate the slope community to depths of at least 25 m along this section of the coast. Very few remnant corals are present and much of the slope surface has been reduced to a very low relief or to smooth surfaces that will enhance herbivorous species in maintaining this condition for some time.

3.2.2 Coral communities and species

A total of 43 genera and an unspecified number of coral species have been recorded as being present on Niue's reefs (Wells and Jenkins 1988; from work quoted from Yaldwyn 1973). The present study has recorded fewer taxa with 32 genera and 85 species (Appendix 3). Although a significant revision of coral taxonomy has been carried out since the 1970s (most recently by Veron 2000), there have been very few new genera proposed, and probably fewer species, compared to the situation prior to the revision. Therefore it may be possible that the current total of coral genera and species present indicates that a reduction in species diversity may have occurred since the earliest studies in the 1970s. It is more likely that this conclusion may be premature, as it only includes surveys of the west coast, which is the more sheltered coastal section.

Coral communities on the west coast reef flat and slope habitats are subject to seasonally strong wave action that varies from low to extreme. As a result, coral colonies are highly adapted to the prevailing strong wave action conditions, but this adaptation is limited to a tolerance level that was obviously exceeded by Cyclone Heta. Even prior to Cyclone Heta, coral communities on the reef flat were very sparse in terms of both cover and number of species. The reef flat represents an extreme environment for corals as it experiences strong wave breaks, relatively high sedimentation, high light and fluctuating temperature regimes, periodic low salinity variations, and very shallow water at low tide.[7] In many sections of Niue's reef flats, deep pools as well as crevices connected to the open sea provide very good optimal conditions for corals, but in the village areas of Alofi North and Makefu, these features are not present. Only small shallow pools, less than a meter deep, are found in the pilot village areas, along with irregular shallow channels that are sealed off from the open ocean at low tide. Under these conditions, corals struggle to survive. The main types of coral to be found on the reef flat are massive and encrusting growth forms typically highly resistant to the extreme reef flat conditions mentioned above. For example, a few species of *Porites* spp. and *Platygyra* spp. can be found, along with small colonies of encrusting Faviidae species (e.g. *Leptastrea* spp.). In addition, a few *Acropora* spp. can be found on the reef flat, but they demonstrate extreme colony modifications to become encrusting forms in comparison to the normal colonial

[7] Corals require sunlight and good water flushing to grow optimally. In addition, corals cannot withstand extended periods of time exposed to air. Sedimentation here refers to the movement of coarse sand and fragments over coral colonies, which can be a very abrasive process for corals.

branching growth form.

The slope habitat is where the majority species can be found, and include most of the species also found on the reef flat. The highest diversity of corals (71 species) was recorded at Tamakautoga slope habitat, which is outside the study area, but was included in the extended survey area in March 2004, to assess the significance and extent of cyclone damage on the west coast. This coral community extends from the shallow crest zone down to more than 30 m depth, where the lower terrace begins to descend into very deep water. The structure of coral communities on the slope in the village area of Alofi North and Makefu prior to Cyclone Heta was very similar to the current coral community structure found at Tamakautoga. However, some sites in Alofi North had less developed coral communities than did Tamakautoga, with a predominance of medium sized colonies, particularly from the genus *Acropora* (Fisk 2007b). As well, all communities along the west coast were exhibiting variable degrees of impact from coral bleaching-related mortality prior to Cyclone Heta. The impact of cyclonic waves on coral communities in Alofi North and Makefu has been described above; the main features are as follows:

- The almost total elimination of branching coral forms (both alive and dead) from all slope habitats.
- A severe reduction in the presence of other coral growth forms including encrusting and massive forms.
- Serious physical damage to the remnant corals in the high impact sites, which coincides with severe coral bleaching conditions in March 2004. The probability that these remnants will survive is not high.
- Small sections of slope communities (in the Namoui Marine Reserve) where the impacts were intermediate (somewhere between the pre-cyclone situation and the extreme impacts described above), resulting in the dominance of non-branching coral growth forms.

The Namoui Marine Reserve slope communities represent a significant foundation the regeneration of coral communities on the most damaged sections of the slope, if they are combined with the very important coral communities in the bay to the south at Tamakautoga.

3.2.3 Macro algae

Macro algae were not a significant component of reef flat and slope communities prior to Cyclone Heta, nor were they dominant in terms of cover or occupation of substrate. The number of species recorded for Niue during this survey is very preliminary, as algae were not specifically targeted during fieldwork but were opportunistically recorded during other activities. To date, nine species of macro algae have been recorded: *Halimeda opuntia*, *Turbinaria conoides*, *Halimeda opuntia*, *Dictyosphaera versluysii*, *Valonia fastigata*, *Jania* cf *adhaerens*, *Liagora* spp., *Padina* cf *australis,* and *Sargassum* spp. All except three species have been recorded on the reef flat with *H. opuntia*, *P.* cf *australis*, and *Liagora* spp. found on the slope. The latter species is currently dominant on the slopes and in certain places on the reef flat, especially in pools. No species that are important in subsistence fisheries were observed on reef flats in Alofi North and Makefu in March 2004. These include *Caulerpa* spp. and one other species that has not been positively identified.

3.3 Belt transects

Belt transects were used to assess the distribution and relative abundance of a selected set of macro invertebrates. A list of macro invertebrates recorded during all types of surveys is shown in Appendix 4. Full details of comparative belt transect data collected during the 2003 and 2004 surveys are presented in Appendix 5; all data from the 2004 baseline surveys are shown in Appendix 6. Some of the target species assessed for the baseline are of importance to coastal fisheries (these include the purple jewel oyster (*papahua)*, vermetid molluscs (*ugako*), false limpets (*matapihu*), giant clams (*gege*), and subsistence as well as potentially commercial holothurians (*loli tea*). The presence of other common reef flat species that occur in association with the fisheries species was also recorded (Table 4).

The non-fishery species were assessed as to their potential for future monitoring, particularly in relation to their changes in abundance over time, which could indicate the influence of variable settlement events that cannot be attributed to harvest impacts.[8] A reduction in abundance and presence of many species has occurred due to the impact of Cyclone Heta. It is possible that the remaining species survived by escaping the most extreme wave conditions in the numerous holes and shallow channels in the inner reef flat. Nonetheless, there was a significant difference in ability to withstand the cyclonic conditions among the surviving species (see below).

Table 4. Macro invertebrates recorded on the reef flats of Alofi North and Makefu.

Scientific Name	Common Name	Niuean Name	Village
Actinopyga mauritiana	Surf redfish holothurian		M
Chama isostoma	Jewel box oyster	Papahua	AN, M
*Conus capitaneus**	Captain cone		AN
*Conus virgo**	Virgin cone		
*Cypraea caputserpentis**	Serpent's head cowrie		AN
*Cypraea mauritiana**	Humpback cowrie		
*Cypraea talpa**	Mole cowrie		AN
*?G. Neothyonidium**	Filter feeding holothurian		
Serpulorbis colubrinus	Great worm shell (Vermetid)	Ugako	AN, M
*Drupa morum**	Purple pacific drupe		AN
*Drupa ricinus**	Prickly pacific drupe		AN
*Echinometra mathaei**	Burrowing sea urchin		AN
Holothuria atra	Lollyfish holothurian	Loli	AN, M
Holothuria leucospilota	White threads fish holothurian	Loli	AN
Lithophaga spp*	Boring date mussel		AN, M
*Morula uva**	Grape drupe		AN
Siphonaria sirius	False limpet	Matapihu	
Thais armiger	Belligerent rock shell		AN
Thais tuberosa	Tuberose rock shell		
Tridacna maxima	Elongate giant clam	Gege	AN
Turbo argyrostomus	Silver mouth turban	Alili	?AN, ?M
Turbo setosus	Rough turban	Alili	?AN, ?M
Vasum cf *turbinellus*	Common pacific vase		

Records from December 2003 and/or March 2004. Only those recorded in 2004 are registered with that village. * = non-fishery species. AN = Alofi North; M = Makefu

[8] Under natural conditions, with no harvesting occurring, the distribution pattern and abundance of a wide range of invertebrates would vary significantly (spatially and temporally) due to the stochastic nature of recruitment of organisms that have a larval stage in their life cycle. Hence the natural or background influence on replenishment characteristics of invertebrate populations is a factor that should be understood when considering the impact and management of harvest pressures. An indication of these patterns can be obtained by monitoring the trends in non-fishery species that co-exist with, and have similar ecological requirements to, the fishery species of concern.

3.3.1 Impact of Cyclone Heta on selected macro invertebrates

*Holothuria spp. (*holothurians*, loli tea)*

Three holothurian species were recorded in belt transects in December 2003 (*Holothuria leucospilota*, *Holothuria atra*, and *Actinopyga mauritiana*), but the latter species was not observed in the March 2004 surveys. *A. mauritiana* is virtually absent from reef flats at present; it was relatively rare in 2003 and was not capable of surviving in the cyclonic conditions in January 2004. Figure 5 shows the relative densities and distribution of the two holothurian species present in 2004. Both tend to occupy the inner reef flat habitat, particularly in the shallow holes and gutters close to the cliff face. *H. atra* is currently the most common holothurian on these reef flats while *H. leucospilota* rarely occurs here now, compared to 2003 when its abundance was approximately equally to that of *H. atra*. Both *Holothuria* species were less abundant in 2004 following Cyclone Heta, compared to December 2003.

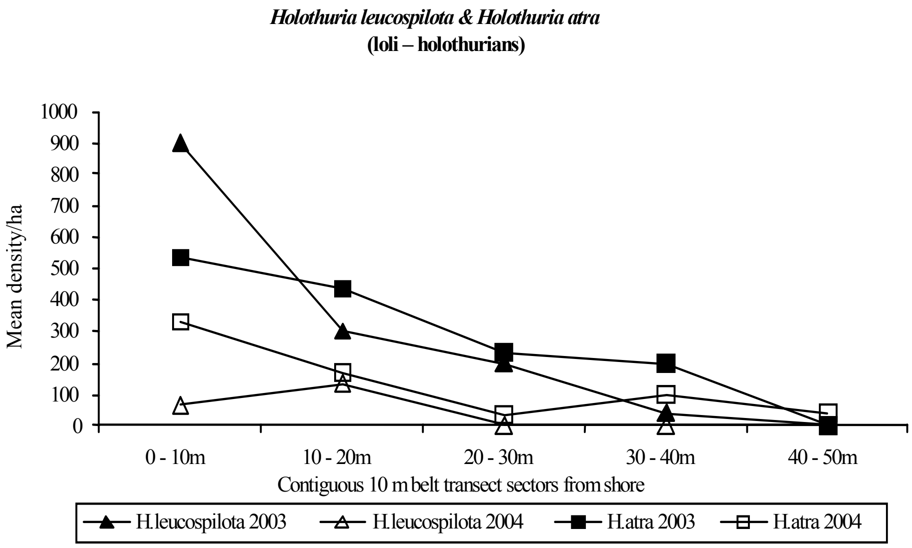

Figure 5. Mean density (per ha) of two common holothurian species (*Holothuria leucospilota* and *H.atra*).

Data from transects across the reef flat north and south of the boundary of the Namoui Marine Reserve (Namoui Sea Track (4 transects) and Vailoapu (family) Sea Track (2 transects), respectively).

*Serpulorbis colubrinus (*Vermetid molluscs*, ugako)*

The vermetid tube molluscs appeared to have survived reasonably well overall and there is a higher density of live vermetids in 2004 compared to 2003 (Figure 6). The proportion of live to dead vermetids was similar during both surveys, but in some locations, where there was probably high freshwater outflow due to the presence of caves and freshwater seepage points, there appears to have been substantial mortality. This conclusion is drawn from the fact that many of the dead shell records included complete tubes without the animal present (i.e. mortality was not due to recent harvesting, which is evidenced by the presence of clean tube portions with the upper tube section removed). There also appears to have been recent recruitment in the period between the surveys, which could have occurred either pre- or post-cyclone. This is concluded from the observation by local villagers of rapid colonisation by vermetids (and oysters) of reef flats at certain times (C. Tohovaka, pers. comm.).

*Chama isostoma (*purple jewel box oyster*, papahua)*

The jewel box oyster is a common oyster that is regularly harvested on the reef flat. It appears to have survived the cyclonic conditions very well (Figure 7), particularly on the mid to outer reef flat, but possibly suffered higher mortality on the outer reef flat as well. In addition, there appears to have been greater recruitment on the outer flat after the 2003 survey as shown by the cross flat distribution pattern in 2004.

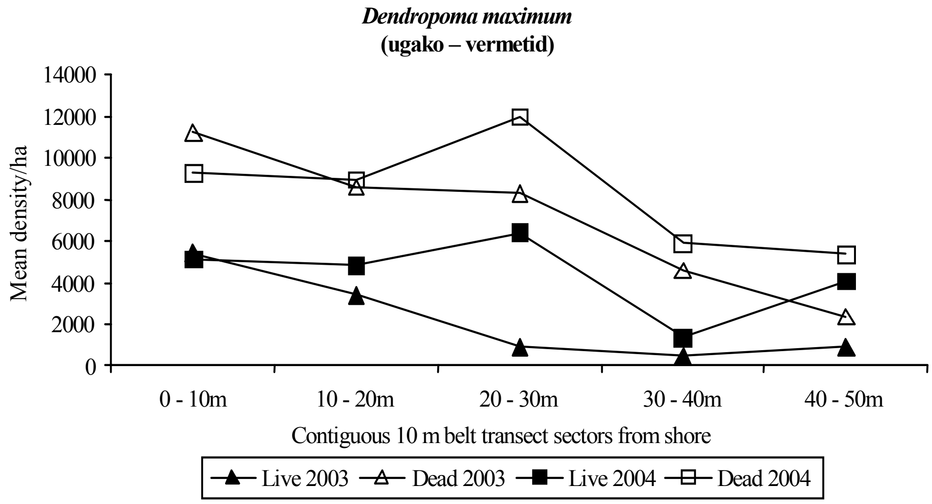

Figure 6. Mean density of live and dead vermetid tube worms (*Serpulorbis colubrinus*).

Data from transects across the reef flat north and south of the boundary of the Namoui Marine Reserve (Namoui Sea Track (4 transects) and Vailoapu (family) Sea Track (2 transects), respectively).

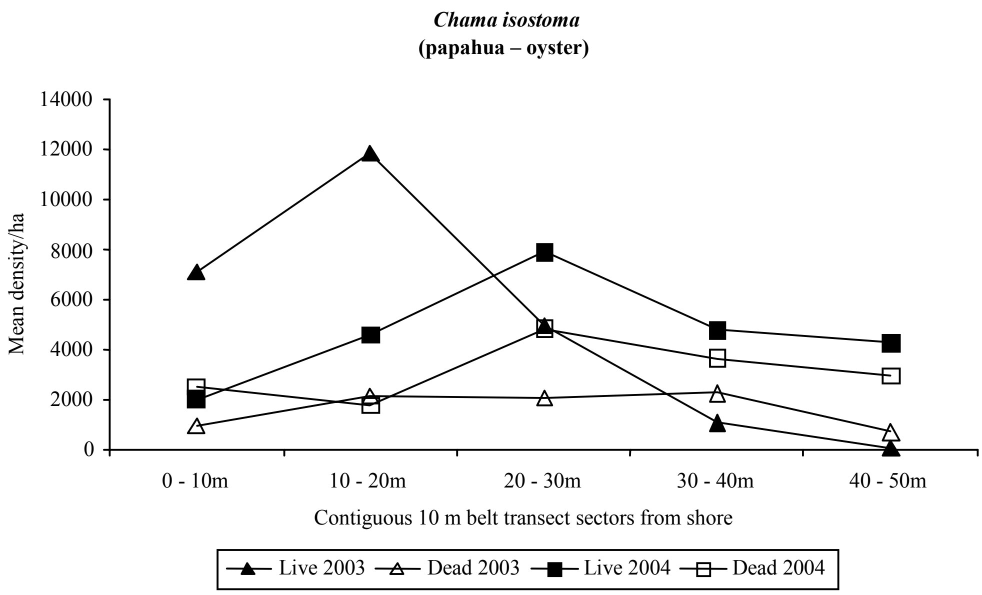

Figure 7. Mean density of live and dead purple jewel box oysters (*Chama isostoma*).

Transects are across the reef flat north and south of the boundary of the Namoui marine reserve (Namoui Sea Track (4 transects) and Vailoapu (family) Sea Track (2 transects), respectively).

This is clear from the densities of oysters across the reef flat where the inner flat had higher densities in 2003 compared to 2004, whereas higher densities were recorded on the outer flat in 2004 compared to 2003. In contrast, the corresponding densities of dead oysters appear to inversely follow the trend in live oysters. No recent evidence of harvesting was noticed though many of the remaining shell halves (evidence of harvesting) could have been present prior to the cyclone. There were very few dead oysters with both shell valves present, which indicates low mortality from natural causes.

*Siphonaria sirius (*false limpet*, matapihu)*

The complete absence of false limpets in the survey areas following the cyclone is a significant result; although false limpets were not abundant in December 2003, they were conspicuous in certain sites in the reconnaissance work conducted at that time. There is no direct method of observing if harvesting of this species has taken place, but the conclusion that other species (vermetids and oysters) have not been recently harvested seems to suggest that harvesting has not been occurring on the reef flats in the months preceding the survey. The false limpet tends to be found on the outer reef flat regions of Alofi North and Makefu, which is its preferred habitat. It appears the cyclone has had a significant impact on the presence of this species by physically removing most individuals.

3.3.2 Other macro invertebrates

Up to 8 species of macro invertebrates that were observed in 2003 were not recorded as present in 2004 (Table 4), which probably indicates that they have suffered significant impact from the cyclone. Although no targeted surveys were conducted in 2004 of *Turbo* spp. (*alili*), an important fisheries species, there were virtually no incidental records of their presence on the reef crest area, which was not the case in 2003. These species were present in very low numbers throughout Alofi North and Makefu prior to the cyclone, so the removal of the remaining individuals will significantly impact these species.

3.3.3 Distribution patterns of macro invertebrates in reef flat pilot sites

The distribution patterns of selected macro invertebrates are described below for both cross-reef flat and south–north coastal distributions under each of the individual species. Data are from reef flat belt transect surveys conducted between March and May 2004. Distribution patterns for both live and dead *ugako* (vermetid worms) and *papahua* (oysters) are also described to obtain an explanation for the current status and recent usage of these resources. The data collected here did not discriminate between very recent mortality[9] due to harvesting activity and longer-term cumulative mortality rates from both natural and harvest mortality pressures.

The conclusions are drawn from data that was collected in daylight and during low tide periods, which may be a biased observation with respect to distribution patterns across the reef flat but not along the coast. The possible bias arises from the fact that of the mobile invertebrates present on the reef flat, holothurians are generally more active at night. Also, deeper water over the reef flat at high tides reduces dislodgment of animals by wave action, and so allows for more dispersion during daylight hours.

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[9] **Mortality** refers to the death of an individual, which in the case of *ugako* and *papahua*, means that tube worm or the valve (respectively) remains attached on the substrate surface. Harvested *ugako* tubes can be concluded from the exposure of most of the full tube during the harvest process. In comparison, the death of the mollusc in the tube from other means can be assumed by the presence of the complete tube without a mollusc.

Holothuria leucospilota (loli)

The soft black holothurian *H. leucospilota* is not an important fisheries species but was very common and relatively abundant on the reef flats in the pilot village areas prior to Cyclone Heta. This may have been due to its low harvest value, which would selectively advantage this species. However, it could also be due to biology of this species. Both *H. leucospilota* and *H. atra* (discussed below) have the ability to asexually reproduce by transverse fission, or division of the body, thereby rapidly producing multiple clones.[10]

H. leucospilota appears to prefer the inner reef flat habitat which is where the majority of permanent pools are located, particularly the deeper pools with sand deposits at the base of the cliffs or opposite small sand/rubble beaches (Figure 8). As with all species of holothurian included in this survey, *H. leucospilota* feeds by ingesting sand to process detrital matter and micro organisms in the sand. *H. leucospilota* is apparently vulnerable to high wave action, as shown by the significant reduction in abundance following Cyclone Heta, and possibly by the distribution pattern across the reef flat, though this may be an artefact of the sampling period (see introduction to this section above).

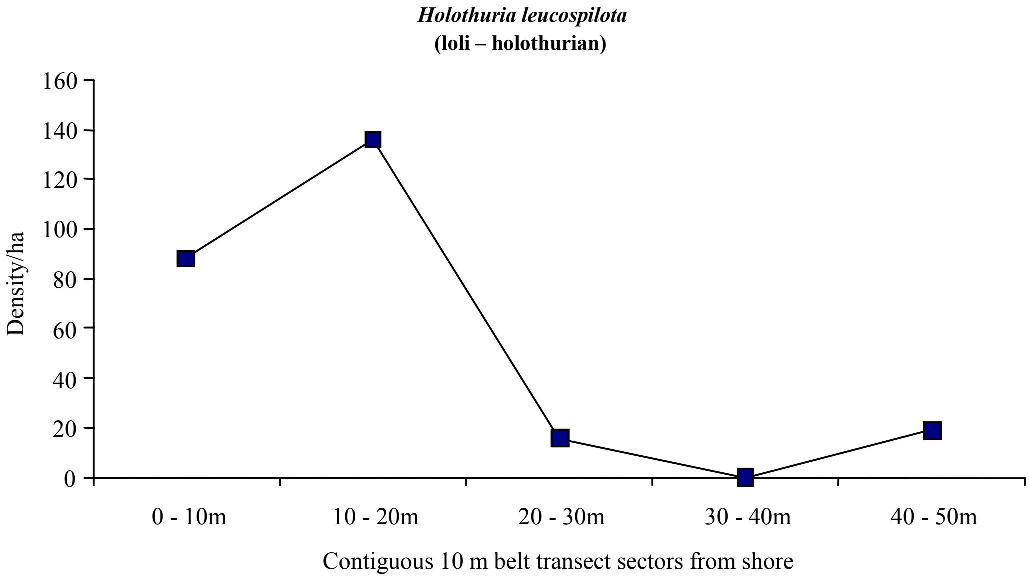

Figure 8. Density (per ha) of *Holothuria leucospilota* across the reef flat from shore to crest.

Mean density for each 10m x 5m wide belt is pooled from all 8 survey sites and a total of 25 transects.

Although low in abundance at all sites, there was a relatively uniform distribution pattern of *H. leucospilota* from south to north along the pilot villages coast (Figure 9), with a few locations where it was rare or absent. These low abundance locations included sites north of Alofi North, Vailoapu Sea Track, and Makefu Sea Track.

Holothuria atra (loli)

H. atra has low value as a fishery species, although the internal reproductive organs are seasonally harvested for food.[11] *H.atra* occupies a similar niche[12] on the reef to *H.*

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[10] By having the ability to **asexually reproduce**, these holothurian species can exploit favourable habitat and conditions by multiplying rapidly in number without the requirement of undergoing sexual reproduction and the high-risk larval development stages. Transverse fission is most common in reef flat individuals compared to the more common sexual reproduction of individuals in slope habitats.

[11] *H,leucospilota* may also be intermittently harvested in Niue for the consumption of internal organs in a

leucospilota and both have a similar black colour and size. Although the body shape and fine details of each species are very distinctive, it is likely that there have been mis-identifications of the two in earlier surveys on Niue (Fisk 2007b). *H. atra* shows a decline in abundance across the reef flat (Figure 10) which is somewhat similar to that of *H. leucospilota*, but the cross flat pattern is not as pronounced. The apparent ability of *H. atra* to withstand greater wave action than *H.leucospilota* is demonstrated by the higher survival rate from Cyclone Heta, and also by its wider distribution across the reef flat close to the more turbulent water of the outer flat.

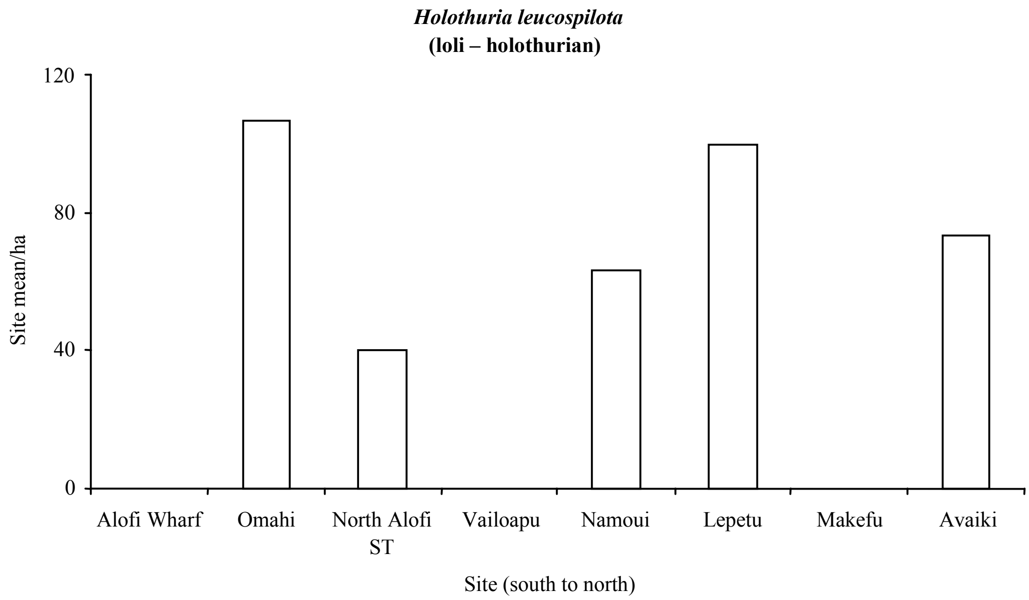

Figure 9. Density (per ha) of *Holothuria leucospilota* along the coast from south to north.

Mean density for each site is pooled from 2 to 4 transects surveyed at each site.

H. atra is relatively more abundant than *H. leucospilota* in all but two locations along the coast (Figs. 9 and 11), but is relatively more abundant in the Vailoapu and Avaiki locations. Alofi Wharf and Makefu, where *H .atra* is very rare, correspond to positions along the coast where cyclone impacts were most severe. These locations are also adjacent to human population centres where both harvest pressure and potential pollution sources would be expected to be relatively greater as well. No positive conclusion could be reached regarding the presence or sources of pollution entering the coastal habitat (Fisk 2007b), although it was a common concern of local residents (SPRP 2004). *H. leucospilota* is also relatively low or absent at these two sites, which appears to support the conclusion that there is a strong correlation between low abundance and multiple factors associated with these locations.

similar manner to *H.atra,* although the greater tendency of this species to evict white sticky cuverian tubules when disturbed makes it less attractive for harvesting.

[12] **Niche** refers to the full ecological description of a species' habitat and biological requirements to successfully maintain a presence on a reef. A species' niche on a reef can often be described in terms of its preferred habitat location, and feeding behaviour (e.g. a detritus-feeding reef flat species).

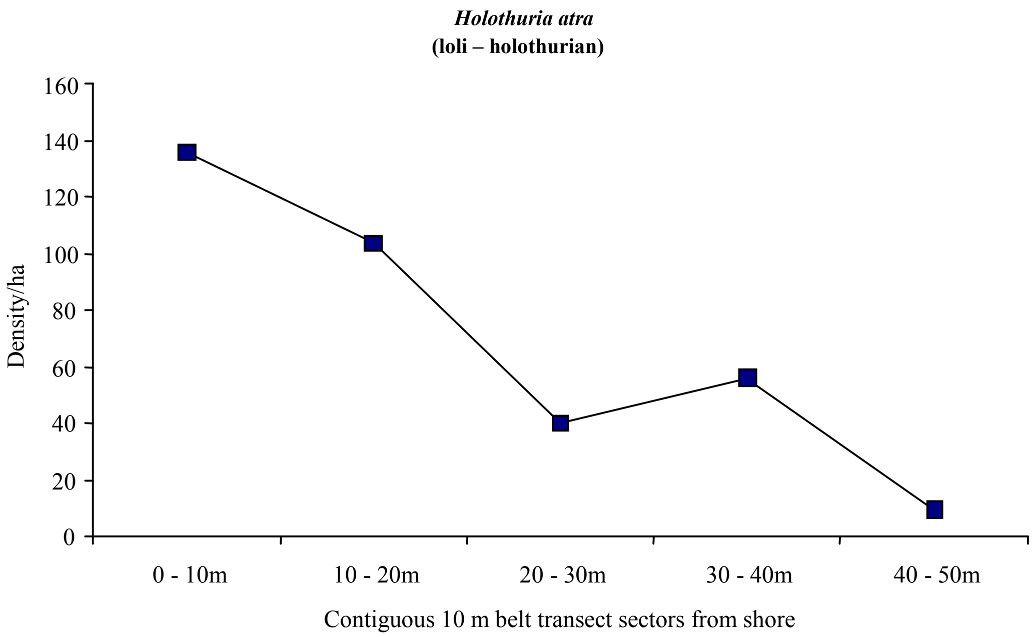

Figure 10. Density (per ha) of *Holothuria atra* across the reef flat from the shore to the crest.

Mean density for each 10m x 5m wide belt is pooled from all 8 survey sites and a total of 25 transects.

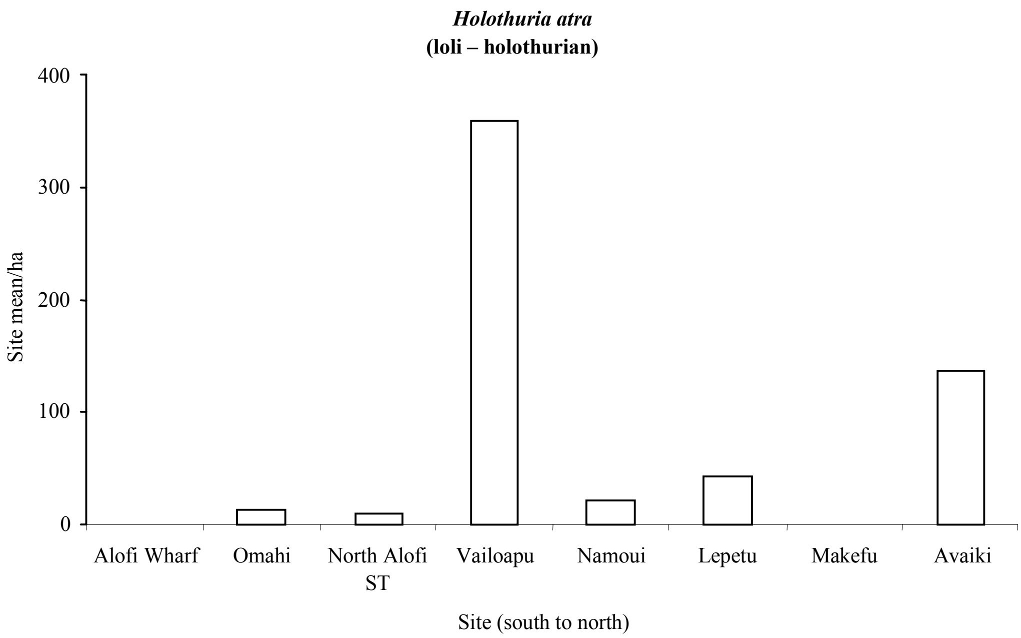

Figure 11. Density (per ha) of *Holothuria atra* along the coast from south to north.

Mean density for each site is pooled from 2 to 4 transects surveyed at each site.

Actinopyga mauritiana (surf redfish, holothurian)

A.mauritiana is a large robust holothurian of moderate fishery value. It was extremely rare on the reef flat and slopes following Cyclone Heta, which was surprising, as this species is usually found in high numbers in surf zones. The species has high reproductive potential with a summer spawning season and an early age of sexual maturity. It therefore has the potential to expand its population size under favourable conditions, but sufficient numbers of male and female individuals have to be present in one location for this potential to be realised.

The distribution patterns from the baseline survey are based on a small sample size, and conclusions are thus tentative at this stage. This species appears to be present on the inner and mid reef flats (Figure 12), and the few individuals observed were sparsely distributed over the pilot site coastal area (Figure 13). The low numbers present prior to Cyclone Heta have clearly been further reduced by the cyclone.

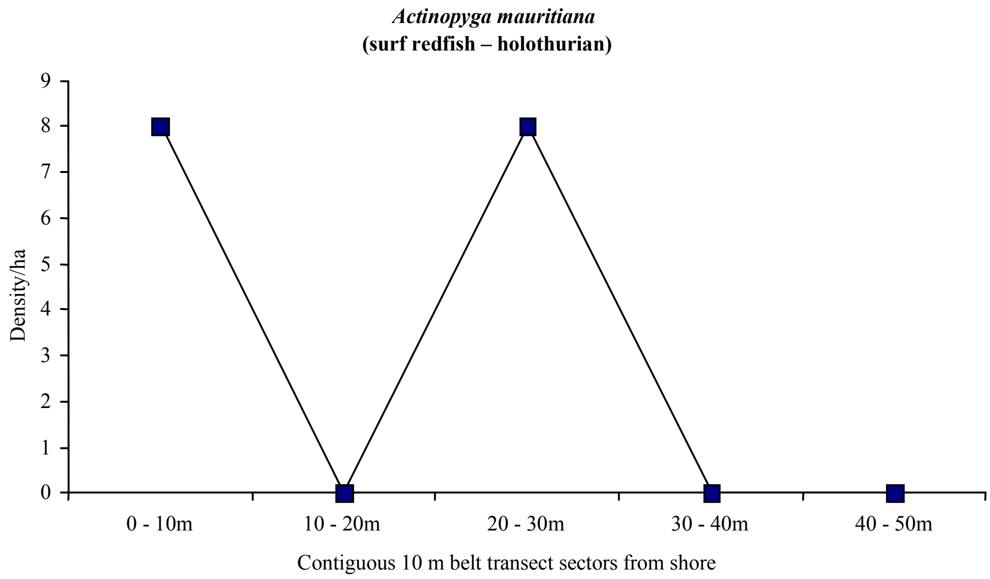

Figure 12. Density (per ha) of *Actinopyga mauritiana* across the reef flat from the shore to the crest.

Mean density for each 10m x 5m wide belt is pooled from all 8 survey sites and a total of 25 transects.

Serpulorbis colubrinus (ugako) — live and dead

The *ugako* or vermetid mollusc worm (*Serpulorbis colubrinus*) is an important subsistence fishery species on Niue and can be present in very high numbers in some reef flat locations, with an estimated overall mean density for the pilot site sections of the coast of 5084 individuals/ha.[13] These tube-dwelling molluscs are always located on the upper portions of the reef flat substrate, close to or just above the shallowest water level on the flat. This is a very similar microhabitat characteristic that is shared with the co-occurring jewel box oyster (see below). This habitat position on the reef flat may be related to the mollusc's filter feeding methods for planktonic and detrital food.[14] Both feeding methods require an elevated position for capturing water borne food, and a requirement that they avoid smothering and abrasion from sand and rubble in the depressions.

[13] The **ugako** harvested in Niue are small in size (less than 10 cm length), requiring high numbers of individuals to be collected for a small total volume of food.

[14] **Vermetids** have two ways of capturing food: a ciliary feeding method, whereby food is filtered from water by the gill filaments as it is swept into the mantle cavity during respiration; and by extruding sticky mucous, allowing detritus to adhere to it, then drawing the mucous back into the mouth.

Vermetids have separate male and female sexes and fertilisation occurs inside the female tube, where the young are brooded until large enough to crawl out on to the substrate, where they usually settle and start producing a permanent tube. In this way, vermetids tend to rapidly occupy favourable substrate, resulting in a locally clumped distribution pattern. They can also produce larvae with a short free-swimming stage that results in dispersion to different locations.

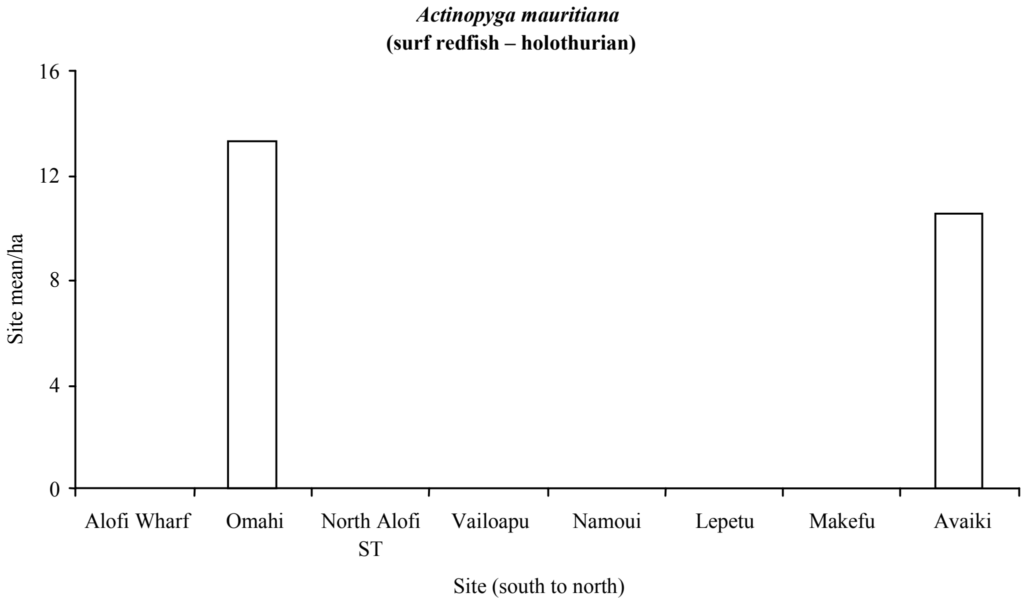

Figure 13. Density (per ha) of *Actinopyga mauritiana* (surf redfish, holothurian) along the coast from south to north.
Mean density for each site is pooled from 2 to 4 transects surveyed at each site.

Photo 11. Harvesting vermetid worms with an axe.

Photo 12. Live vermetid worm tubes (*Serpulorbis colubrinus*).
Ugako are a keenly sought-after reef flat invertebrate in Niue. They can occur in high densities in certain locations.

Photo 13. Freshly harvested vermetid worm tubes.
The freshly harvested worm tubes are easily observed on the reef flat (compare to the live tube worms immediately below these opened tubes), and offer a good indication of the level of harvesting of this species.

Photo 14. Freshly harvested oysters (*Charma isostoma*).
Oysters are highly prized reef flat molluscs in Niue. Here freshly harvested oysters are shown alongside smaller live specimens.

Photo 15. False limpet (*Siphonaria sirius*).
Matapihu is a commonly harvested reef flat mollusc that appears to have been significantly affected by the high seas associated with Cyclone Heta.

Photo 16. Turban shell (*Turbo setosus*).
Alili are heavily harvested along the reef crest habitat throughout Niue. Three or four species of turban shell are present in Niue, and all are harvested.

Vermetid worm tubes tend to be most abundant on the inner to mid reef flat (Fig. 14), which may be due to the crest being slightly more elevated and therefore exposed at low tide in most locations. The inner flat probably accumulates greater detrital biomass from crest and outer flat wave action, and from land based sources, so it is possible this location provides a better food supply.

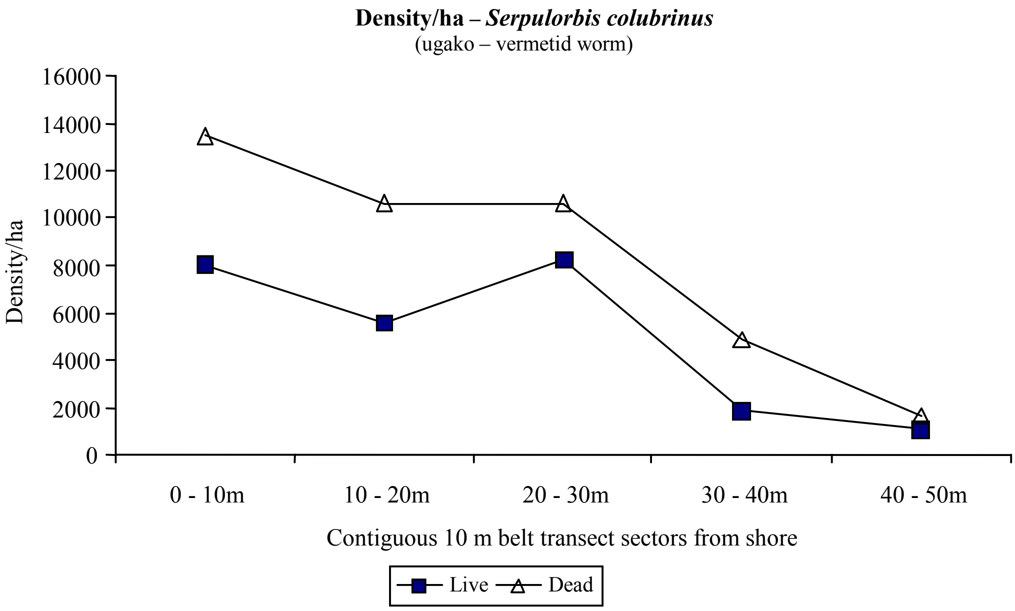

Figure 14. Density (per ha) of *Serpulorbis colubrinus* (*ugako* – vermetid worm) across the reef flat from the shore to the crest.

Mean density for each 10 m x 5 m wide belt is pooled from all 8 survey sites, and 2 to 4 transects per site.

Mortality rates are presented below using the percentage of dead vs. live + dead vermetids and oysters from the baseline surveys. The number of dead individuals represents an accumulated mortality estimate that could have occurred over an extended period of time. This limitation is recognized for the data presented below, but it is included as this estimate will act as a baseline against which future trends in the mortality rates can be monitored.

Total mean mortality estimates for the pilot sites are higher than for live vermetids (8467 indiv./ha compared to 5084 indiv./ha, respectively). The mortality pattern of vermetids varies across the reef flat (Fig. 15), with a gradual increase in the rate towards the outer flat and crest. One explanation for the mortality was presented in the comparison of pre- and post-Cyclone Heta results (above). That is, excess freshwater runoff may have occurred during the cyclone period and this would be expected to be most pronounced on the inner flat. However, the overall mortality pattern suggests that this may not be the case, as the highest mortality was found at reef flat locations most distant from the land. A supporting explanation may be that the outer flat is relatively shallower and more exposed than the inner and mid-flat, thereby exposing vermetids to increased amounts of freshwater during low tides (freshwater floats on top of sea water).

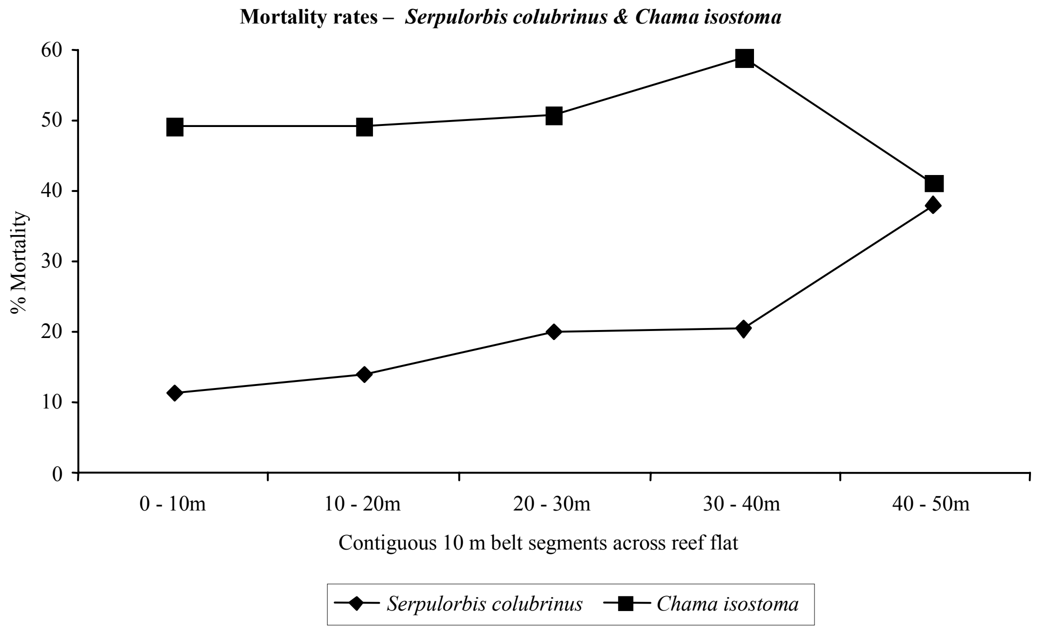

Figure 15. Pooled mortality rates of vermetid molluscs (*Serpulorbis colubrinus*) and oysters (*Chama isostoma*).

Data from belt segments taken across the reef flat in 10m length segments and a total of 25 transects along the coast.

The mortality pattern for vermetids does not vary along the coast (Figure 16), with the rate fairly constant except at the Omahi Sea Track site. The overall mean mortality rate was 62.5% with a range between sites of 42.9% to 84.4%.

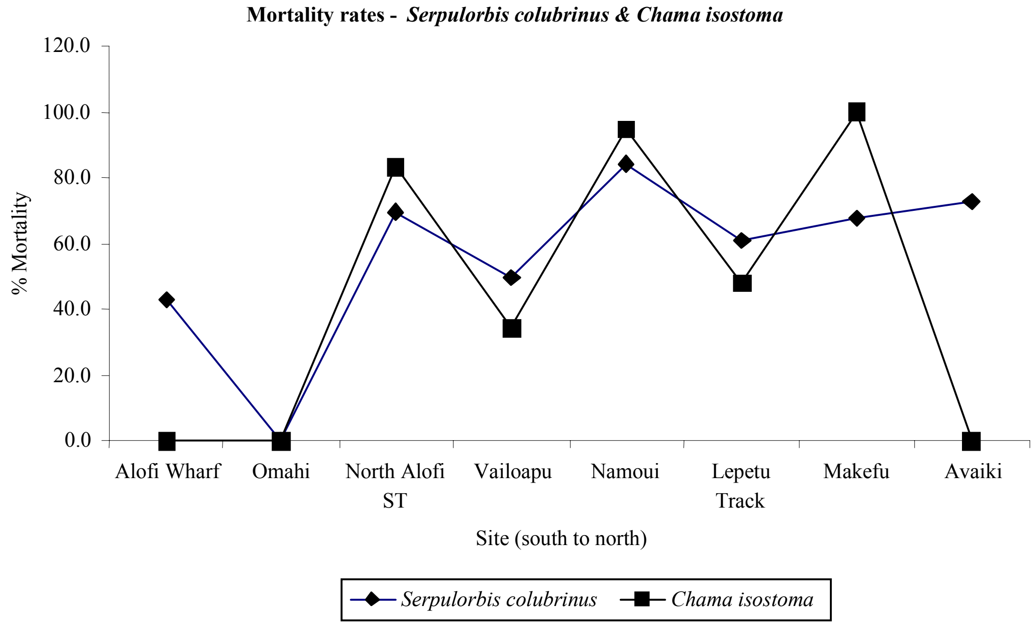

Figure 16. Pooled mortality rates of vermetid molluscs (*Serpulorbis colubrinus*) and oysters (*Chama isostoma*).

Data from coast survey sites, plotted from south to north (left to right); 2 to 4 transects per site.

The distribution of live vermetids along the coast (from south to north) was highly variable with the highest densities recorded at Lepetu (and generally around the central section), with none recorded at Alofi Wharf and Omahi (Fig. 17). At most sites, dead vermetids equalled or outnumbered live individuals (see discussion above).

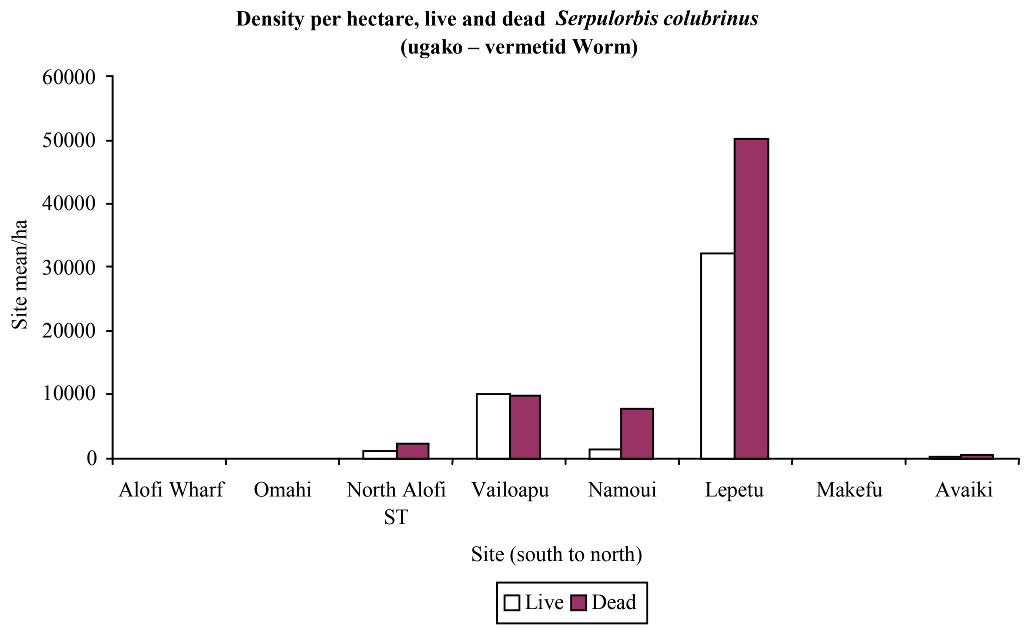

Figure 17. Density (per ha) of live and dead *Serpulorbis colubrinus*.

Data plotted from coast survey sites, plotted from south to north (left to right). Mean density estimates are calculated from 2 to 4 transects surveyed at each site.

Chama isostoma (Papahua — live and dead*)*

The distribution pattern of live oysters is relatively similar across the reef flat, with peak densities in the mid-reef flat and a reduction in densities towards the outer crest area (Fig. 18). The numbers of dead oysters closely follows the live oyster pattern across the reef flat, indicating a similar mechanism for mortality at all parts of the flat. It is quite likely that harvesting is the main cause of mortality, as most remnant shells are broken in a manner similar to the harvest method of using an axe or a strong metal object.

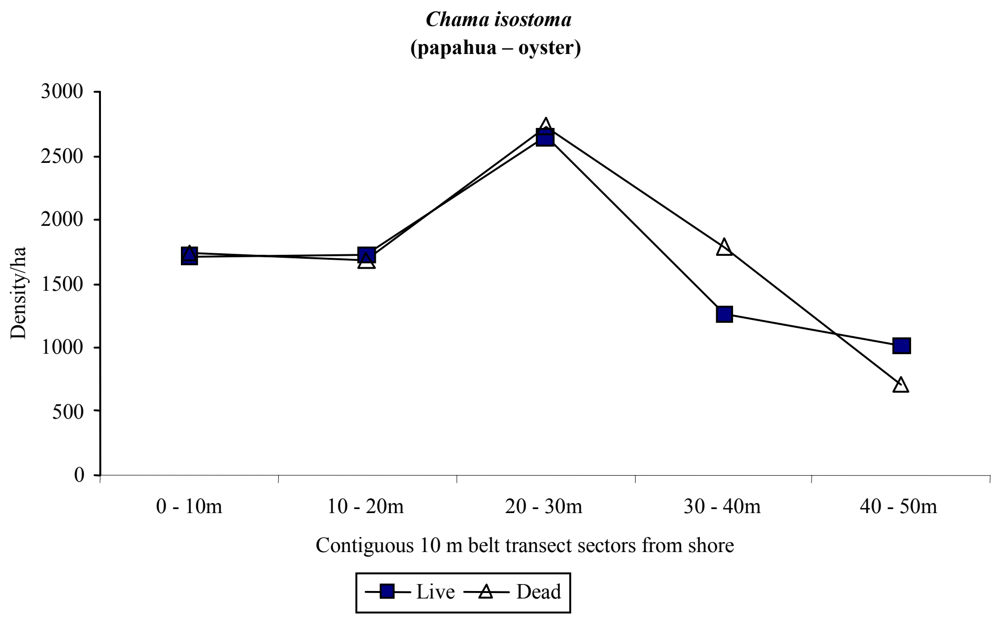

Figure 18. Density (per ha) of oysters (*Chama isostoma*) across the reef flat from the shore to crest.

Mean density for each 10m x 5m wide belt is pooled from all 8 survey sites and a total of 25 transects.

Patterns in oyster densities along the coast show strong variability, with peak densities just south of Namoui Marine Reserve at the Vailoapu Sea Track site. Relatively lower oyster densities were recorded at Lepetu and North Alofi Sea Track sites with very low numbers at Omahi, Namoui and Avaiki sites. No live oysters were observed at Alofi Wharf and Makefu.

The mean mortality rate for oysters in the pilot sites is 50.5% with a range of 41.2% to 58.8%; rates for oysters across the reef flat are similar (Fig. 18). The mortality pattern for oysters varies along the coast (ranging from 34.1% to 94.6%, Fig. 19) with high rates at Alofi North Sea Track, Namoui, and Makefu, and moderate rates at Vailoapu and Lepetu. Very few live or dead individuals were recorded at Alofi Wharf, Omahi Sea Track, and Avaiki sites. The variable pattern in the presence and mortality rates are quite likely due to harvest pressure and accessibility of sites. It also illustrates the extreme variability in current availability of live oysters within the pilot site coastal areas.

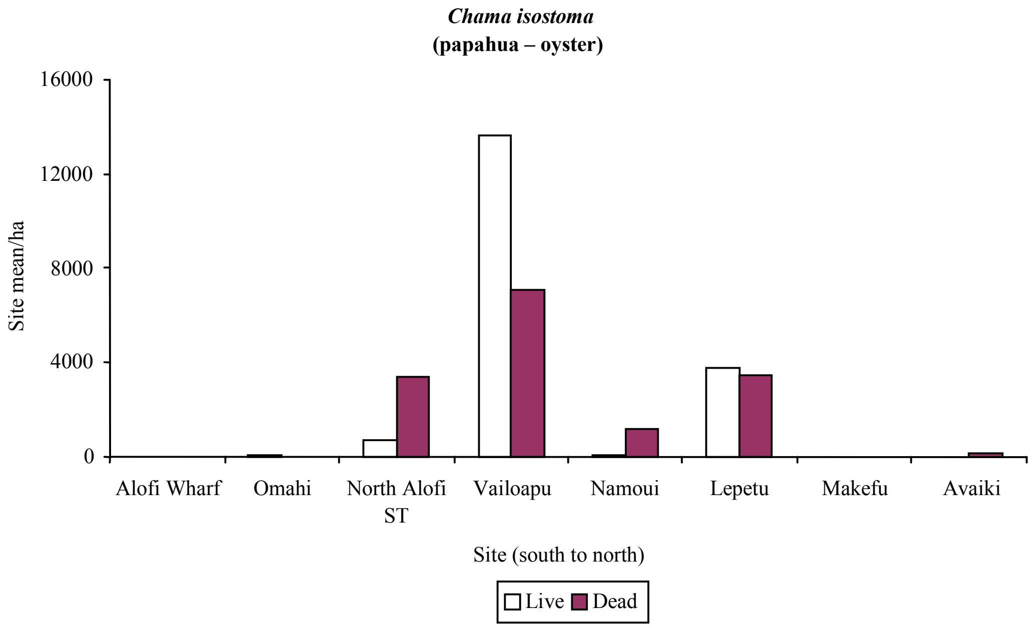

Figure 19. Density (per ha) of live and dead oysters (*Chama isostoma*) along the coast from south to north.

Mean density for each site is pooled from 2 to 4 transects surveyed at each site.

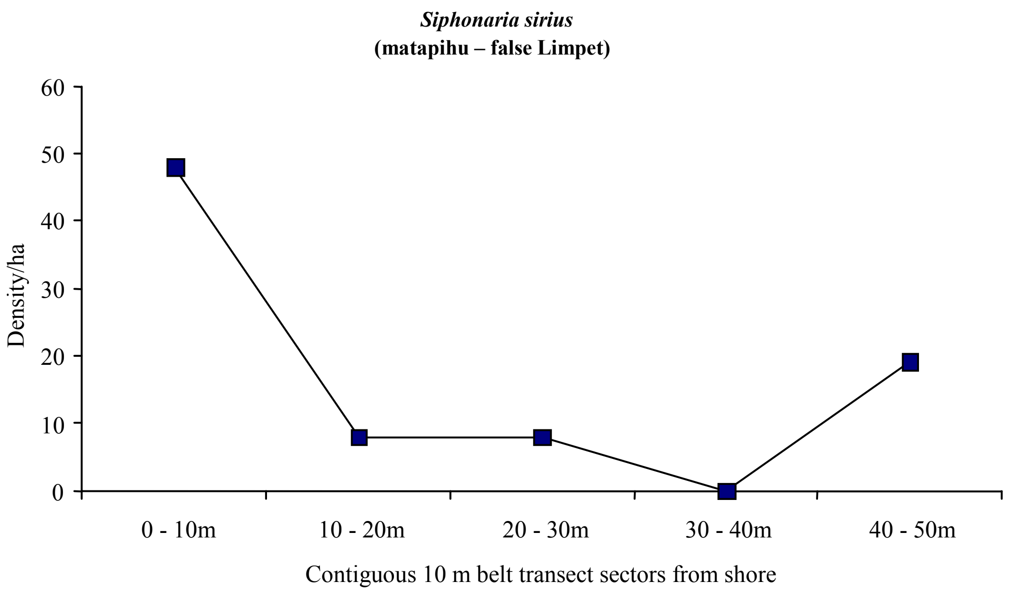

Figure 20. Density (per ha) of false limpets (*Siphonaria Sirius*) across the reef flat from shore to crest.

Mean density for each 10m x 5m wide belt is pooled from all 8 survey sites and a total of 25 transects.

*Siphonaria sirius (*false limpet*, matapihu)*

The false limpet showed a strong cross-reef flat pattern, with the highest densities at the extreme inner and outer flat positions (Fig. 20). The distribution of limpets along the coast was variable, with a few individuals observed at North Alofi Sea Track, Namoui, and Avaiki (Fig. 21). The former and latter sites are in the severe impact zones; the Namoui site was in a moderate impact zone (see Fig. 4).

Note that these densities are converted to numbers/ha, and that the actual recorded numbers are quite low (a total of 10 individuals were recorded from all sites in 2004). There was a significant reduction in numbers of individuals, which correlated with the passing of Cyclone Heta (see section above); the current numbers of individuals is too low to draw firm conclusions.

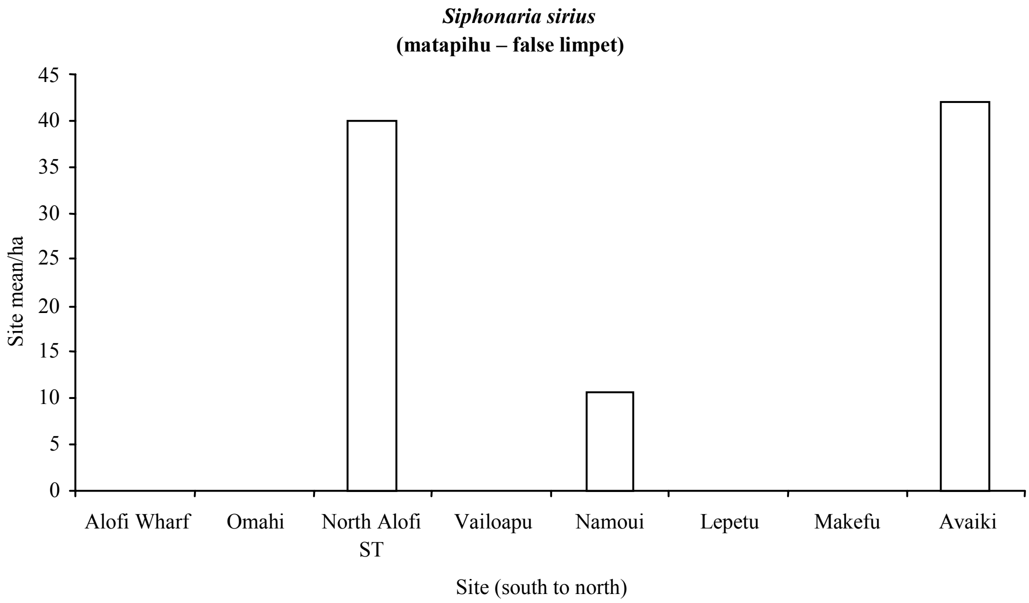

Figure 21. Density (per ha) of false limpets (*Siphonaria sirius*) along the coast from south to north.

Mean density for each site is pooled from 2 to 4 transects surveyed at each site.

*Tridacna maxima*_(giant clam, *gege)*

Clams of the species *Tridacna maxima* were extremely rare on the reef flat, with a total of four individuals observed. Clams were all very small in size (less than 10 cm length) and probably represented very recent recruitment to the reef flat. As there are low numbers in the current data set no firm conclusions can be drawn regarding distribution patterns.

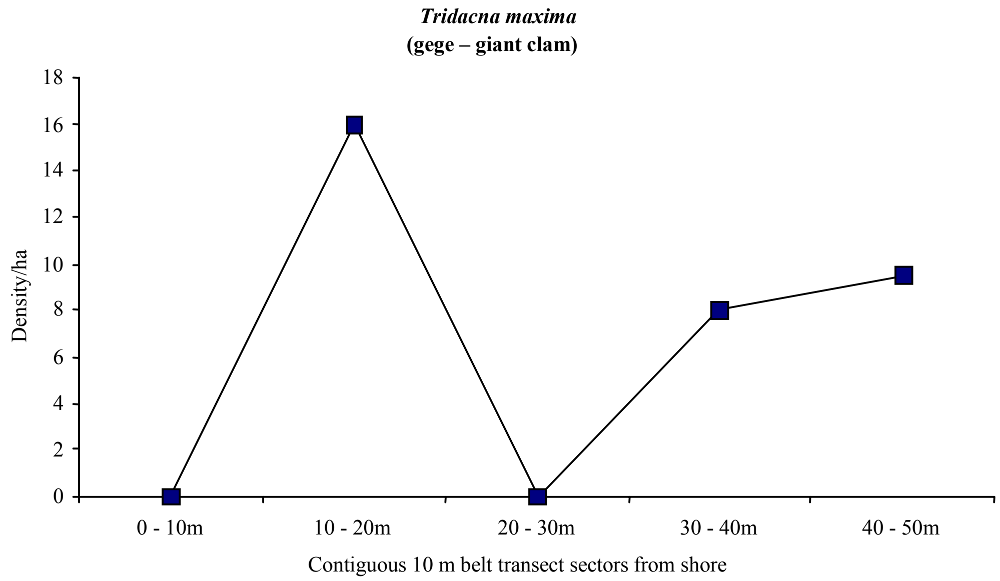

Figure 22. Density (per ha) of *Tridacna maxima* across the reef flat from shore to crest.

Mean density for each 10m x 5m wide belt is pooled from all 8 survey sites and a total of 25 transects.

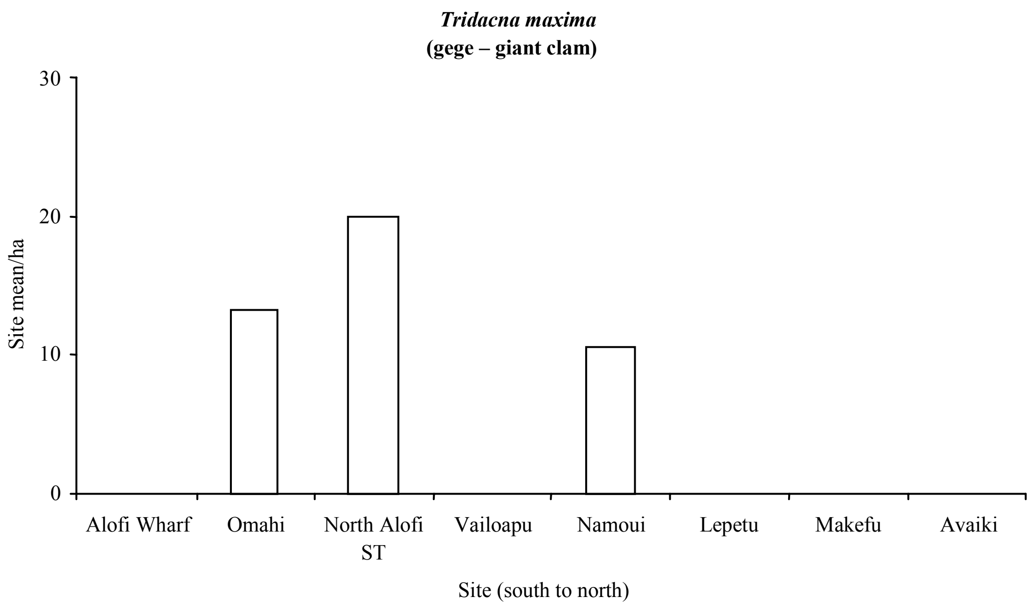

Figure 23. Density (per ha) of *Tridacna maxima* along the coast from south to north.

Mean density for each site is pooled from 2 to 4 transects surveyed at each site.

4 Discussion

4.1 Status and health of coastal resources

4.1.1 Reef structure

The spur and groove formations are usually rounded or curved in response to the dominant wave direction and force, as these shapes offers the least resistance to the water's force under average wave conditions. Corals and other hard skeleton-forming benthos are primarily responsible for creating this shape, as they grow in a manner to maintain least resistance to the prevailing wave conditions. Limited shelter for mobile reef organisms (like fish and crustaceans of fishery value) is provided by features such as holes and crevices under this average (exposed) condition. Also, the presence of branching and tabulate coral colonies can provide additional shelter when present. Prior to Cyclone Heta, the "average" condition had obviously been dominant for some time, resulting in a combination of tightly branched and encrusting corals along with rounded massive coral forms with tabular coral forms common in deeper water. However, the post-Heta living coral reef structure that provides shelter for reef organisms was seriously reduced by Cyclone Heta in January 2004.

Following the cyclone, the dominant substrate took the form of a low-relief calcareous platform, which will result in a slow recovery phase for the coral communities. The presence (or absence) of features that provide shelter has a significant influence on the rapidity with which many reef components in the cyclone damaged coastal sections recover. Shelter that can be utilised by small to moderate sized fish as well as many larger crustaceans was frequently absent from the most severely affected slope areas, particularly in the northern section of the survey area (north of Makapu Point), and in the more exposed sections of Alofi North. A living coral reef can provide shelter for many fishery species, but the removal of the reef component by the cyclone is expected to result in lower fisheries yields for a number of years into the future.

Coral recruits require micro shelter in the form of small crevices that allow light penetration but at the same time protect the juvenile corals from herbivorous fish and invertebrate feeding activity, which can accidentally remove the very small recruits. In predominantly smooth substrate areas with high herbivore densities (e.g. in Alofi North and Makefu), this situation can severely inhibit coral recruitment.[15] At present, there are moderate levels of herbivores present in the pilot site areas in the form of algal feeding fish, but this is not expected to impact on reef recovery potential, as there are relatively smaller areas of smooth platform (usually less than 500 m^2) with minimal micro-topography. The smooth platform areas are generally in the upper slope habitat and are less frequent in the lower slope sections. Of equal importance are areas that contain unattached rubble where there was previously attached coral. There are reports that coastal areas from north of Makefu included impact zones with mostly rubble on the slope (B.Pasisi, pers. comm.). In such situations the presence of mobile material will inhibit recruitment of corals through abrasion and constant turnover of material.

4.1.2 Corals and coral communities

Niue is located in a relatively isolated position in the central South Pacific. The distance between Niue and its closest neighbours (Tonga to the south, Cook Islands to the east, the

[15] The persistence of a smooth turf algal-dominated substrate suitable for high grazing levels but devoid of other benthic organisms has been observed in many highly disturbed reef systems around the world, particularly when disturbance is in areas that have been very heavily exploited by the use of destructive fishing methods.

Samoan Archipelago to the north, and Tokelau to the north of [Western] Samoa) is significant. Niue's coral communities are geographically isolated from other central Pacific reefs because of Niue's small size and the distance between reef systems. On a previous trip to Niue in August 2003, the author kept a record of coral species observed at popular swimming places on the north and east coasts, and from this list a possible further 10 coral species were noted that were not recorded during the current project activities on the west coast. The combination of data from all visits by the author to Niue results in a preliminary species list of 34 genera (two genera more than were recorded in the present study), and 96 species (11 additional species than the present study). This diversity estimate is less than what is most likely present in the islands of (Western) Samoa, where probably twice as many species are present (unpublished records by the author), and less than American Samoa, with 42 genera and 164 species recorded from very extensive coral surveys (Fisk and Birkeland 2002). Coral diversity on Niue is higher than that recorded for three Tokelauan atolls (Fisk in prep), where a preliminary coral diversity estimate suggests there are 20 genera and 60 species present.

These data indicate that Niue's small, isolated reef system is relatively less diverse than the Samoan Islands but probably more diverse than Tokelau, with respect to coral species. The lack of species diversity in Niue may be due in part to the lack of certain habitats: deep lagoons, extensive reef flats, and protected shorelines are absent. Conversely, Tokelau features both deep lagoons and extensive reef flats, but has a species diversity closer to that of Niue than to the Samoan Islands. Therefore, the more likely explanation is that the small size of the reef systems in Niue and Tokealu, in combination with the lack of habitat diversity, results in a reduced capacity to receive reef larvae from the region, in comparison with islands in Samoa.[16]

There are a natural long term fluctuation in reef species diversity on all reefs, due to larval supply fluctuations and natural perturbations. The pattern in coral species diversity described above for Niue and the other regional reef systems would suggest that Niue has a reduced capacity to be replenished by reef larvae from other regional systems. This reduced replenishment capacity means that if Niue loses species — through either natural or human induced disturbance — the long term impact will be greater than for reefs that are more easily replenished. The only other reef system close to Niue is the distant Beveridge Reef, which is within Niue's territorial jurisdiction. It is a relatively small emergent reef located to the southeast of Niue. Periodic surface wind-driven water currents (from the predominant southeast trade winds) could feasibly reach Niue Island from this reef, but the dilution factor would be high by the time larvae arrive; the chance that water currents that contain larvae could miss Niue altogether is also high.

4.1.3 Macro invertebrates: molluscs

A reduction in the abundance of most invertebrates occurred on reef flats after Cyclone Heta, with some species reduced to single individuals or possibly becoming locally extinct over wide areas of the Alofi North and Makefu coastline. Sections of reef flat in the Tamakautoga region were minimally affected with respect to macro invertebrates significant for fisheries, making this small section of the west coast reef system extremely important as a nursery for natural replenishment of cyclone-affected and heavily harvested sections of the west coast. It should be noted that the Tamakautoga coastal section is not included in the IWP project at present, and that this coastline is subject to harvesting pressure, as are other coastal areas.

A total of 32 species of **molluscs** were recorded as present on reef flats in the Alofi North

[16] The general understanding of the **larval transport** in this region is that the slow drift of the equatorial currents move from east to west (i.e. not in a north–south direction), and therefore it is unlikely that reef larvae will be transported from reef systems lying to the north. The closest systems to the east are the distant and individually isolated Cook Island group, so larval transport would be expected to be infrequent and in small numbers.

and Makefu village areas in December 2003, with only a few of the same suite of species present in the slope habitat. Surveys conducted in March 2004, over approximately the same length of time and area as in 2003, recorded only 14. This difference can be attributed to the impacts of Cyclone Heta. The mollusc fauna present on reef slopes and in deeper water is very different, so the lower number of species recorded on slopes compared to reef flats was expected. The exceptions are giant clams (*Tridacna maxima*) and certain holothurian species (*Thelenota anas, Holothuria nobilis*), which are generally more prevalent in slope habitats because of their specific life cycle requirements and because of the limitations of physical conditions found on the reef flat. Mollusc reproduction usually involves a planktonic larval stage,[17] meaning that settlement and recruitment[18] is dependent on favourable ocean currents, and the presence of suitable settlement conditions. The variability of ocean currents and water column conditions results in highly variable and unpredictable annual recruitment of marine coastal species. If fisheries management is to be sustainable, it must take into account the natural variability that occurs within individual fisheries, and in specific locations. In addition, management rules should be conservative (i.e. use the precautionary principle) in establishing allowable annual harvest levels.

Individual *Tridacna maxima* were present on shallow to mid-slope positions in most areas that were assessed by timed surveys, including sections of the coast that were severely damaged by cyclonic waves. This result was in contrast to the manta surveys, where no clams were recorded, and included areas that were surveyed by both manta tow and timed swim methods. Only small individuals appear to have remained after the cyclone and these were typically found in small indentations on the slope (i.e. in partially cryptic locations). A few small individuals were also recorded in belt transects on the reef flat in the pilot sites.

The finding that some clams are still present on the slopes in Alofi North and Makefu is a positive result. Some of the smaller individuals observed in the baseline surveys may have been a result of recent recruitment from unaffected parts of the coast. Significant time should be allowed for stock recovery prior to allowing low-level harvest, as the individuals present must be first allowed to reach maturity, and to then reseed this section of the coast. Further recruitment from other parts of the coast may also be expected to occur, but the recruitment rates from these sources appear to be quite low. Clams were present in low numbers even prior to Cyclone Heta, but now an additional protective period (during which no harvesting takes place) is needed to allow clams to grow to maturity, if a sustainable subsistence fishery is to be established. The estimated time for growth to maturity to occur is difficult to judge accurately, but is expected to be at least 3–5 years, given the growth rates that have been recorded for clams in other parts of the world. An additional 5 to 10 years of uninterrupted population growth would probably be required for adult stocks to be sufficiently abundant for controlled harvesting to occur. At that point, a management strategy of retaining a large breeding stock of adults will be required for a sustainable fishery. Transplanting specimens from elsewhere on Niue or from overseas will have to be carefully considered, as the requirement of having a firmly attached base is obviously necessary, and damage to the byssal threads used for attachment will undoubtedly occur during transplantation. If major disturbances such as cyclones or large storms occur during this replenishment time, the period for allowing sustainable harvesting may have to be delayed once again, depending on the extent and nature of the disturbance.

[17] The planktonic larval stage in many invertebrates refers to an independent swimming stage. The planktonic larvae develop in the surface water layer after hatching from eggs, where they persist for days or weeks, and undergo a number of distinct form changes. They then sink to the bottom and metamorphose into the juvenile form of the typical adult.

[18] Recruitment refers to the addition of juvenile forms of an invertebrate into a population.

The physical removal by waves of many of the unattached mobile mollusc species (including limpets, and possibly turban shells or *alili*) was expected, but a small number of individuals apparently survived the cyclonic conditions, and these will be the breeding stock for the west coast mollusc fishery in the next 3 to 5 years at a minimum, particularly in the pilot village sites. The same reasoning and management approach as outlined for giant clams should be considered for the other mobile gastropod species, except that it should be noted that the remnant stock of most gastropods are quite likely mature or close to maturity, and so are available as breeding stock. The breeding success and replenishment potential of many of these species may be hampered by their extremely low densities, which negatively impacts sexual reproduction. Given the low densities, the removal, for example, of one or a few individuals from the reef flat in Alofi North or Makefu could necessitate that protective harvest restrictions be extended for a much longer period to ensure sustainability of these stocks. The overall time frame will probably be similar to that needed for clam stock replenishment and management.

Turban shell species were not systematically surveyed in the baseline assessment because of the lack of appropriate conditions to access the crest habitat where they are located. Three species of *Turbo* were observed to be present in the pilot site reef flats and in adjacent reef flat locations in December 2003, with *T. argyrostomus* the most relatively abundant (they were observed during other survey work and in midden shell piles left from recent harvesting activity). A fourth turbo shell species, *T. petholatus*, was not observed on the west coast though it is harvested on the east coast (Dave Fisk, pers. obs.). It is suggested that turbo shell surveys be included in recommendations for community based monitoring activities, because of their high value to subsistence fishers, their role in the coconut crab life cycle (see below), and because of the specific concerns expressed during initial village consultations (Niue IWP National Programme 2004) of a reduction in abundance of *alili*.

An additional factor relating to turbo shells, as well as all larger gastropod species, is the importance of maintaining a sufficiently large population of healthy breeding stocks of large shell-forming molluscs. Vacant gastropod shells are used by hermit crabs, and in particular, by the young coconut crabs or *uga*.[19] Large turbo shells seem to be especially favoured by coconut crabs, who use them until they are large enough to live independently of the shell. As with all shells used by coconut crabs, the discarded shells are usually left inland from the sea in the forest, so a continual replenishment of vacant shells is required at the coast for the long term sustainability of this extremely valuable species.

The vermetid mollusc species, *Serpulorbis colubrinus* (*ugako*), was commonly recorded along most reef flat habitats in Alofi North and Makefu, although densities varied greatly. Small reef flat sections in the vicinity of the main harbour (both immediately north and south of the jetty opposite the Centennial Hall and former fuel tanks and Tomb Point, respectively) supported very low numbers of vermetid worm tubes, both before and after the cyclone. The very low abundance could be caused by high harvesting pressure, and pollution may also play a role. Belt transect surveys before and after the cyclone demonstrated that survival of vermetids has been good in many sites, but not necessarily in areas with freshwater outlet caves nearby. In these locations (e.g. at the north end of Namoui Marine Reserve), high mortality was recorded in March 2004 on transects that in December 2003 recorded very high densities. There was no evidence of harvesting being the cause of death, as the worm tubes were intact and unbroken and with no animals remaining inside. There were also signs of recent recruitment, which occurred in the period between the 2003 and 2004 surveys. The life cycle of vermetid worms includes a planktonic larval stage, but this species can also produce highly developed young,

[19] The coconut crab (*uga*) life cycle includes a stage at the beginning of the terrestrial phase where young crabs utilize a vacant gastropod shell for protection, exhibiting behaviour similar to that of hermit crabs. However, in contrast to hermit crabs, after approximately one year the *uga* moves inland to forested areas and discards the shell.

which have undergone their larval development phase inside the adult tube. These emerge as fully formed juvenile vermetids that can crawl a short distance from the adult and commence producing a permanent calcareous tube. In this way, vermetids can maximise the use of favourable living conditions and rapidly increase in number within a site.

A management strategy involving setting aside clearly marked reef flat refuges in areas that are highly favourable to vermetids would aid in sustaining a subsistence fishery in Alofi North and Makefu. Obvious areas that are favourable for vermetids can be determined from current observations and from local knowledge of former high abundance locations. Direct observations can be made by noticing where aggregations of live vermetids are currently located, which is generally in the inner to mid reef flat, in locations that include relatively higher ridges or platform areas. They are not found in deeper pools on the reef flat, possibly due to a low tolerance for sediment and abrasion from resuspended rubble. The remaining broken tubes where harvesting has occurred can also indicate former productive areas where remediation may be possible (providing that at least low densities of adults are still present in the area). The current distribution of vermetids along the pilot project coastline is possibly strongly influenced by prior harvest pressure, especially in areas that are accessible by sea tracks and where there is relative safety with respect to surf on the reef flat. All these factors can be taken into consideration when refuge areas for vermetids are under discussion.

Densities of oysters (*Chama isostoma*) were relatively variable along the coast and similar across the reef flat with the exception of the outer flat. There was a clear indication that the reduction in oyster densities occurred predominantly in areas adjacent to reef flat access points, especially near to Sea Tracks. Mortality rates were relatively more variable along the coast for *papahua* compared to *ugako*. Mortality due to harvest effort was thought to be the major contributor to the densities of dead oysters. Harvesting of both *ugako* and *papahua* may occur at the same time, as both tend to be present in the same location. There may be some harvest behaviour and preference differences in each of the villages, but this does not appear to have caused differences in distribution patterns. The oyster tends to favour the higher sections of the reef flat, as does the ugako. Their preference for this microhabitat is related to the fact they are filter feeders, and is required to avoid their being smothered by sediment. It is possible that *ugako* can more rapidly settle and occupy favourable reef flat space in comparison with *papahua*, which may explain the greater densities and lower mortality of the former.

Hihi vao (a yellow terrestrial gastropod snail) lives on the shoreline amongst coastal vegetation, but since the cyclone there has been a significant reduction or elimination of these species from Alofi North and Makefu shoreline areas. Little is known of the ecology of these molluscs but the presence of vegetation may be an important factor for their living requirements. It is likely that waves have physically removed most individuals as well (Makefu village members, pers. com.) and that these molluscs will not return to the pilot site shoreline for some time. No specific surveys of these molluscs were carried out during the baseline work.

4.1.4 Macro invertebrates: holothurians

Holothurian species are restricted to suitable habitat, which includes grazing substrate that does not contain high live coral cover, but rather sand or an algal platform. A total of five holothurian species have been recorded on west coast habitats during the survey period of this project, with one species possibly becoming locally extinct as a result of Cyclone Heta. *Holothuria leucospilota* was common in December 2003 before Cyclone Heta, but was very rare afterwards in March 2004. In general, a few individuals remain in deeper pools at the base of cliff faces and in shoreline caves. The current distribution of *H. leucospilota* tends to be sporadic and probably reflects the presence of relatively deeper pools adjacent to cliff edges. Similarly, *Actinopgya mauritiana* was rare to uncommon prior to the cyclone but in March 2004 it was absent from most of the reef flat. The other previously abundant species, *Holothuria atra*, was common and relatively the most abundant of all holothurians in

December 2003; although it remains the relatively most abundant holothurian in March 2004, it has been reduced in abundance in all surveyed locations. A fourth holothurian, an unidentified filter feeding species (belonging to the order Dendrochirotida, family Phyllophuriidae, and possibly genus *Neothyonidium*) was common in December 2003 in pools at the base of cliff faces where there was also reef flat development, but was absent at all sites visited in March 2004. *Thelenota anas* (prickly redfish) was rarely observed in 2003 and 2004; during both surveys individuals were found in slope habitats at depths of greater than 10 m. A single individual of *Holothuria nobilis* (black teatfish), was observed in March 2003 at 15m depth on the slope base at Namoui Marine Reserve.

4.1.5 Algae (macro, turf, blue-green)

A dramatic successional process appears to be under way in most severely damaged coastal habitats due to Cyclone Heta. The early stages of succession have been dominated by a green turf algae, while at present the macro algae *Liagora* spp. appears dominant. *Liagora* spp. was present in very low abundance at a number of slope sites along the west coast prior to Cyclone Heta, but in March 2004, it was dominant on many of the severely affected slope and reef flat pools that were surveyed. In areas relatively less affected by the cyclone (e.g. the mid Namoui Marine reserve slopes), it was patchy and often restricted to shallow areas (less than 6 m depth). In other highly affected areas it was very uncommon (e.g. the slope areas south of Namoui Marine Reserve and the northern part of Alofi North coastal area).

In December 2003, a very abundant brown macro algae, *Padina* cf *australis*, was present in the main harbour area (north and south sides) and was associated with ciguatera fish poisoning,[20] which was first noticed in late 2001 (Yeeting 2003). The cyclone appeared to have removed all traces of this alga from the harbour area, though small patches were observed in shallow reaches of channels in the upper slope south of the harbour. *Liagora* spp. appears to have replaced *Padina* spp. as the dominant macro algae in most areas including the harbour area.

In addition to dominance of macro algae, abundance of turf algae and blue-green algae mats is very high, as these are thriving on the abundance of open space resulting from the removal of most coral. The high biomass of turf and mat algae may also be a consequence of land based and re-suspended nutrient loads from the cyclone and associated rainfall runoff from land. The high nutrient load was first evident within weeks of the cyclone, when very high cover of opportunistic green turf algae (possibly *Enteromorpha* spp.) occupied the majority of reef substrata (Vieux 2004). The green turf algae was not strongly attached to the substrate but had probably persisted due to the lack of wind and turbulent water in the weeks following the cyclone. The presence of loosely attached blue-green algae mats on reef flats as well as slopes in March 2004 may indicate that nutrient and water turbulence conditions are changing and that the mats are part of an algal succession process.[21] These mats do not appear to be grazed by herbivorous fish or urchins, unlike the strongly attached turf algae.

4.1.6 Fish

Fish communities were not specifically targeted in the baseline assessment as there had been other specialists undertaking surveys in two locations prior to the author's visit in March 2004.

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[20] Ciguatera is associated with the presence of high populations of a microscopic dinoflagellate, *Gambierdiscus* spp., which contains a toxin that is concentrated by organisms in the food chain. The dinoflagellates are indirectly ingested by algae-eating fish (predominantly turf algae) and the toxin persists as algae eating fish are in turn consumed by larger fish, which are often then consumed by people. Little is known of the ecology of the dinoflagellate but it can be correlated with the presence of dissolved iron (for example from metal debris).

[21] Succession processes refer to the replacement of the dominant algal species at a site over time due to natural cycles of changing environmental conditions and species availability.

However, the broad assessment protocols of the manta tow method were used to gauge gross patterns of fish abundance and dominance. In general, herbivours dominated slope fish communities in all survey tows and timed surveys, with the most dominant family being the Acanthuridae (surgeon fish) and relatively less abundant Scaridae (parrot fish) family. Low numbers of other families were often observed, especially, species of Serranidae (groupers), but these were never relatively abundant. In some locations, the damsel fish were most abundant, but these are not recorded in the surveys as they are commonly the most numerically abundant fish group on reefs and are of little commercial value, although they are major food sources for many larger predators. Total numbers of fish were very low in all tows and timed surveys from Alofi North and Makefu. A school of chevron or dark fin barracuda, in association with a few great barracuda (*Sphyraena qenie*, and *S. barracuda*, respectively), were present in the Namoui Marine Reserve, which is a well known local phenomenon, indicating that certain elements of the reef fish community were returning to previously established locations. Very few sharks were observed along the pilot village coastal areas, and there were no other larger fish observed such as the humphead wrass (*Cheilinus undulatus*). Both of these indicator fish groups were commonly observed in December 2003.

Sea snakes were abundant and were displaying mating behaviour along slope habitats in both Alofi North and Makefu in March 2004. In addition, occasional observations of small **green sea turtles** (*Chelonia mydas*) were recorded from slope areas. These observations are a further indication of the return of some elements of the normal reef-associated fauna after the disruption from Cyclone Heta.

4.1.7 Health and disturbance indicators

Crown of thorns starfish (COTS, *Acanthaster planci*) are not commercially important macro invertebrates but they can be significant disturbance agents with respect to reef health, so it is important to monitor the status of this species as part of a holistic management regime for fisheries management. No COTS were observed at any sites in 2003 and 2004. Another reef health indicator is the **corallivour mollusc,** *Drupella* spp**.**, which was observed on a range of *Acropora* coral species in 2003 and 2004. *Drupella* spp. are not found at densities that are of concern for the health of reef corals, but monitoring priorities should include observations of *Drupella* spp. distribution and abundance in the future, as these molluscs can slowly increase in number and become a threat to coral communities. They leave feeding scars on live corals that are superficially similar to COTS feeding scars; the scars also bear some resemblance to patterns of coral disease present on Niue corals. These three reef disturbance and health-related signs need to be clearly distinguished. Both COTS and *Drupella* spp. feeding impacts usually lead to partial or total death of coral colonies, and both organisms tend to favour *Acropora* species, particularly, plate or table growth forms.[22] The result of disturbance from coral eating invertebrates is the presence of dead attached coral colonies colonised by algae.

The incidence of **coral disease** is a useful indicator that can be used to assess coral reef health. Disease can be caused by a number of factors but is commonly observed in coral communities that have been stressed, and in Niue this most likely has been due to bleaching stress. Coral disease was observed to be present on plate *Acropora paniculata* colonies where this species was still present on the west coast in March 2004. The same pattern of coral disease was observed on Niue in December 2003. The lower incidence of disease recorded in the 2004 manta tow surveys is related to the removal by the cyclone of most of this coral form from slope communities. There may be a depth restriction to the incidence of coral disease, as large populations of *A.paniculata* in depths of approximately 30 m (e.g. near Tamakautoga) were not observed to have any signs of disease. This is in contrast to colonies in shallower slope areas

[22] In the case of COTS feeding behaviour, other coral species groups and growth forms are also eaten when *Acropora* spp. is absent or present in low numbers, or in situations where juvenile COTS are present.

(depth range of 12–20 m), where the incidence of disease was relatively high with 5–10% of colonies affected. Corals are eventually killed by this disease and the skeletons remain attached to the substrate for a long time after the death of the colony, leaving a medium-term indicator of the extent of bleaching impact. Most sites in March 2004 that retained table *Acropora* were showing a similar incidence of disease and similar percentages of dead tables to the estimates made in December 2003. However, in areas like the Namoui Marine Reserve, the effects of cyclonic waves were to remove both live and dead *Acropora* spp. colonies. This is an important observation, as future assessments of coral communities in this area will not contain indicators of past disturbance events prior to January 2004 such as coral disease, but only events that have occurred after January 2004.

The incidence of and impacts from **coral bleaching** constitute a second very useful reef health indicator. Bleaching was observed in December 2003 and also present in March 2004 (in remnant colonies, particularly in the north and south of the Alofi harbour area). Local divers and Niue Fisheries personnel had reported bleaching along most parts of the west coast in the previous summers (2002 and 2003), with variable mortality from the bleaching in a number of locations. One such location was the Alofi harbour area (I. Gray and A. Franklin, pers. comm.), where corals were severely bleached and suffered relatively high mortality. This pattern appears to be repeated in March 2004, suggesting the bleaching is not related to the after effects of the cyclone. Some coral species appear to be more susceptible to bleaching mortality than others, particularly *Acropora* spp., *Stylophora* spp., and *Millepora* spp., and the dead attached forms observed in December 2003 were mostly from these genera.

In addition, remnant corals in these areas have very high levels of **physical damage (**such as scars and broken portions of colonies) from debris abrasion due to cyclonic wave action. This has allowed turf and macro algae to colonise the exposed colony surfaces; the algae is competing in a number of cases with the live coral by inhibiting the regrowth of the damaged sections of colonies. The current high bleaching level is adding further stress to the remaining corals and is probably contributing to the persistence of algae on and around the live colonies. The survival rates of these remnant corals are not expected to be high if the bleaching continues for a prolonged period.

The ratio of dead to live coral (**mortality index**) is a useful means for assessing the status of a coral community, as it integrates the impact from a range of disturbance and health indices, and can thus be a very good monitoring tool.[23] The ratio of dead to live coral cover is not applicable where only subjective categories of coral cover are used during visual assessment, because the categories are too broad to provide accurate mortality indices. However, quantitative estimates of coral cover can be very useful to compare sites and survey times, and this index should be employed in a longer term monitoring program using appropriate methods.

The presence of metal and other persistent human **debris** (predominantly in the harbour area in December 2003) was expected to be compounded by the addition of large quantities of debris from the destroyed infrastructure in Alofi. However, the intensity of wave conditions from Cyclone Heta removed virtually all traces of metal and other material from the shallow slope habitat and most of the deeper terrace, including the metal objects formerly present in the harbour area. Debris was relatively common in some places towards the edge of the lower terrace drop off, at depths greater than 30 m (e.g. at the lower terrace edge 40 m out from Tafalalo). Because of the rapid transmission of freshwater from the land to the coastal areas, the long-term presence of metal material from infrastructure destruction in the main village

[23] It is difficult to determine why dead attached corals died if prior observations of disturbance phenomena are not available. Sometimes, the pattern in dead coral components of the reef will be depth and/or growth form related, which can help with the interpretation of possible causes of death, but interpretation is especially difficult when more than one form of disturbance has occurred over time.

areas could present a long-term threat to the coastal area, including the potential for further outbreaks of ciguatera. It is therefore imperative that as much of this material as possible be removed from the most vulnerable areas.[24]

The pilot site section of the coast can expect heavy impacts from most cyclones so a fishery management regime should take into account the nature of such natural disturbances. The limited Cyclone Heta-related impact data available from the pilot studies is valuable, as it serves as an indication of the maximum cyclone-related impact that could be expected to occur on the west coast. The variation in degree of impact along the very exposed sections of the coastline is noteworthy and should be incorporated into management decisions.

4.2. Capacity building for volunteers and national staff

The reef flat surveys succeeded in developing the skills of IWP Niue staff and some local volunteers in survey methods and species identification. It was hoped that a lecturer from the local University of South Pacific (USP) campus could accompany the team for the reef flat baseline surveys and become familiar with the methods being used, so that USP students could incorporate some of the IWP studies in their respective studies. Community involvement using students was seen as a significant awareness raising and value-adding exercise for the project. Unfortunately, it was not possible to introduce the lecturer to IWP's methods during the author's visit, but it was expected that IWP Niue will ensure USP staff do get involved in planned follow-up reef flat surveys by the national team. Further community involvement will be included in the third phase of the marine assessment, planned for later in 2004, when the establishment of permanent baseline sites and training of community based monitoring volunteers is expected to take place (see Fisk 2007a).

Niue's IWP staff are sufficiently experienced and trained at present to undertake reef flat surveys. The inclusion of a New Zealand Volunteer Service Abroad volunteer in training and undertaking fieldwork early in his two-year contract has added extra personnel to the IWP team. This is important as reef flat work is highly dependent on suitable tides and weather conditions, and it is necessary to have experienced locally-based staff who can take take advantage of suitable conditions when they are present.

A series of digital photos taken by the author were given to the IWP team at the end of the baseline visit. These photos include images of most currently present invertebrate and other habitat components currently found on the reef flat and slope. Photocopies of relevant sections of the most widely referenced identification books were also given to the team to support their monitoring efforts. An updated copy of relevant digital photos (which have been referenced and are accompanied by explanatory text and IDs) will hopefully form part of the training material for community based monitoring activities.[25]

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[24] Note that IWP is helping to fund removal of major metal accumulations from the villages of Alofi North and Makefu.

[25] Video footage was also taken on reef slope habitats during the baseline work. The transfer of useful footage along with explanations and descriptions would be a very useful awareness and education tool for Niue and other IWP countries. However, this will take time and resources to develop, which will not be possible under the current work program.

5 Recommendations

The area of coastline under the pilot village program is relatively small compared to the entire coastline of Niue. The types of habitat features present in the pilot village areas are typical of certain portions of the west coast, but not necessarily of all areas. Consequently, it is necessary to be mindful of habitat differences when applying lessons drawn from this project to other locations. Improvements in and support for national-level coastal fisheries sustainability will require a more detailed analysis of the relative importance of variations in habitats and conditions.

The pilot project sites will serve as a test case for implementation of parts of the National Coastal Fisheries Management Plan, because reef areas are in a very accessible section of the coast and adjacent to relatively high population centres. The pilot sites were also severely disturbed by Cyclone Heta, and extra consideration will need to be given to the effects of this disturbance.

On the basis of work performed to date, including (i) the literature review, (ii) status evaluations (past and present), and (iii) observations of the current coastal resource situation in Niue, including the recent cyclone impacts, the following five major factors with relevance to coastal fisheries management in Niue will be considered:

1. **Natural disturbances** from coral bleaching or cyclones vary in intensity along adjacent sections of coastal habitat. Areas that are more susceptible to these relatively common disturbances will require special management considerations, such as setting aside larger areas for recovery. In addition, such disturbances will require that longer-than-average recovery periods be allowed, in comparison with less affected areas. Consideration should be given to including less disturbed areas in replenishment strategies, as these areas will generally respond more quickly to a reduction in harvest pressure.
2. **Natural refuge areas** where reef communities can develop to maturity and serve as a source of propagules for other sections of the coast are very significant, even if they are relatively small. These refuge areas need to be carefully managed.
3. The **isolation** of Niue from other regional reef systems, which affects species replenishment.
4. **Harvest pressure** — in terms of the characteristics, timing and intensity of harvest effort — needs to be considered in relation to natural variations in target species abundance.
5. **Indicator species** should include species of particular concern, as identified by the local community, which will be good indicators of management success; these should include both reef flat invertebrates and slope-inhabiting fish.

These major factors are discussed separately in detail below.

5.1 Natural disturbances

Recent natural disturbances known to have significantly affected Niue coastal reef slopes include bleaching and cyclones. Crown of thorns starfish outbreaks as well as *Drupella* spp. infestations have not been recorded, though both have been present on Niue for long periods of time. Coral disease appears to be specific to tabulate coral species that are fast growing and of minor importance as reef building species, but form important micro refuges[26] for many fish

[26] **Micro refuge** coral species have branching and tabulate growth forms that are very three-dimensional in form and afford protection for small fish within and under the colony. These coral forms are usually primary colonizers of vacant reef substrata and are generally fast growing in comparison with other forms.

species. Coral disease is thought to be associated with bleaching stress and is therefore a secondary disturbance.

Bleaching events have resulted in selective coral mortality along the west coast but the general location of areas with high impacts is relatively predictable. These include the major embayments associated with Alofi township and Avatele. Current bleaching events have resulted in selective mortality of species that are relatively most abundant, namely, species of *Acropora.*

The behaviour of Cyclone Heta meant that the Namoui Marine Reserve area was relatively less affected than adjacent coastlines and that the coastal area around Tamakautoga was least affected. The characteristics of cyclone impacts also showed variations in the degree of damage due to the direction of the most destructive waves. The exact direction of destructive cyclonic waves will vary according to the path and behaviour of individual cyclones. However, the north and west coasts in general will probably be most affected, due to the paths that cyclones commonly follow in this region.

An appropriate management approach for sections of the west coast, which are expected to experience variable cyclone damage, would be to have multiple harvest protection zones spread along this coastline. It would be prudent to capitalise on the fact that some sections of the coast were less affected by strongly enforcing the no-fishing restrictions within the current Namoui Marine Reserve boundaries. Additional high protection zones should take into account the relatively more predictable bleaching impact patterns, by including harvest protection zones in major bleaching impact areas as well.

Extending the Namoui Marine Reserve boundaries is an important management option. By so doing, important reef flat habitat can be placed under protection from harvest, which will greatly enhance the replenishment potential of many reef flat fishery species. The northern boundary of Namoui Marine Reserve should be extended at least as far north as adjacent to the Coral Gardens motel and the Sails restaurant. Significant slope habitat would be included in such a boundary extension, in the form of a cave system and steep deep gutters present close to Sails restaurant. A cave and deep gutter system will potentially enhance crayfish and fish stocks through the predation protection given by such habitat.

Minor reef flat development occurs in the northern part of the Namoui Marine Reserve and a very small proportion of the first reef flat in the southern end of the Reserve is currently included in the Namoui Marine Reserve. It is therefore important to increase the protected reef flat area; the only way this can be achieved is by extending the southern boundary a minimum of several hundred meters from its current position. As there is a constant movement of organisms between the reef flat and slope habitats, this extension should also include the adjacent slope habitat.

Recommendation 1

Harvesting restrictions on reef slope habitats currently within the Namoui Marine Reserve should be strongly enforced with respect to harvesting of any species. In addition, consideration should be given to extension of the boundaries, to both the north and south, as described above.

5.2 Refuge areas

Refuge areas include those sites or locations that appear to be resistant to many natural disturbances over long-term time frames. These currently include pools and crevices in the reef flat that are deep and well flushed by wave and tidal flows, and support diverse reef communities that appear resistant to many natural disturbance factors that affect slope and exposed reef flat communities. Protection is afforded by a number of characteristics, including lower wave forces, high light and oxygenated water regimes,[27] rapid water replenishment within the pools, and cooler water temperatures due to freshwater outflows along the shoreline.[28]

Although to a lesser extent than deep pools and crevices, the shallow pools in many parts of the pilot site reef flats are also acting as micro refuges, as shown by the survival from Cyclone Heta of relatively large macro invertebrates. Unfortunately there are few pool or crevice formations in the pilot village areas except for the pools at Avaiki. Therefore, the degree of pool formation on the reef flat is an important factor to consider when assessing the best positions to locate replenishment or no-take areas.

Recommendation 2

Reef flat habitats under consideration for protective (harvest restriction) measures should be assessed for the presence of the most suitable habitat for mobile macro invertebrates. As a general rule, the more shallow pools and water retention areas (occurring at low tide) that are present, the more desirable the habitat as a refuge area, suitable for implementation of protective (harvest restriction) measures.

5.3 Regional isolation

The regional isolation of Niue's reef system is an important consideration on a national level, but because of the significance of cyclone impact on the west coast, it should be considered in the pilot village context at this time. The coastal habitat north and south of Tamakautoga is clearly the last remaining complex and diverse reef community (reef slope and probably reef flat) on the west coast at present. The nearshore water circulation patterns along the west coast are hypothesised to be in the form of large gyres, which rotate near to shore under the predominant southeast trade winds. These gyres would be expected to retain reef larvae for several days before they move offshore or break up. This is believed to be the main mechanism for larval distribution along the west coast, from adult species sources within the Niue reef system. This section of coast is therefore potentially critical to the rapid recovery of reef communities on those sections of the coast that suffered significant cyclone damage. It is imperative for the medium term sustainability of resources that a high level of protection be considered for a major portion of this section of the coast (i.e. a protected zone extending for several kilometres, and including both reef flat and slope habitat).

East and south coast locations constitute an additional potential source of replenishment larvae from within Niue. Though no surveys were conducted on these coastlines, it is assumed that a reasonable contribution of replenishment larvae could come from this location. However, Dalzell et al. (1993) reported that the reef slope was steep and adjacent areas quite deep compared to the west coast. Along with the relative lack of reef flat habitat along the east and south coast (particularly reef flat with pools and shallow water retention areas), it is not known if these locations could provide an adequate larval supply. Until surveys can be conducted to assess the extent and health of coastal resources in these locations, it should not be assumed that they can reasonably be expected to supply adequate numbers of larvae to the west coast. In addition, the conditions on the east and south coast are quite different to the west coast, as the former areas typically receive greater wave impacts than the west coast, and therefore normal

[27] **Oxygenation** refers to high turbulence caused by waves, resulting in oxygen enriched water flowing through the pools and crevices, but without high wave force impacts.

[28] **Cooler water temperatures** are created by the mixing of cool freshwater seeping from land with seawater in pools and crevices. Slightly lower water salinities may result, but most species are adapted to such salinity fluctuations in these pools. Where cooler water is not present, many species that are normally vulnerable to bleaching from high sea temperatures seem to be adapted to the elevated water temperatures regimes.

habitat conditions are expected to be different.

Recommendation 3

Significant portions of the slope and adjacent reef flat habitat north and south of Tamakautoga Sea Track should be considered as a significant refuge area and source of replenishment larvae for the remainder of the west coast, and should be afforded high protection from harvest activities.

Recommendation 4

The health and status of habitats and resources on the north, east and south coasts should be thoroughly assessed, as these locations may assist significantly in replenishing severely impacted populations of commonly harvested species.

5.4 Harvest pressure

Adequate assessments (in terms of the degree of resource impact) of human harvest pressure on coastal resources have not been made in Niue. However, the participatory situation analysis activities (SPREP 2004), conducted among villagers in 2003, revealed a strong perception that resources were being overharvested. As a precautionary measure, harvest pressure should be assumed to be unsustainably high until data can be produced that shows otherwise.

Cyclone Heta caused a significant reduction in most reef flat resources, and special consideration should be given to establishing a temporary (2–3 year) widespread ban on collection of certain macro invertebrates. This relatively extreme measure is suggested due to the assumed high harvest pressure, relative regional isolation of Niue, and the severity of the natural disturbance that recently impacted these resources.

Recommendation 5

Studies regarding coastal resource harvest levels should be initiated as a matter of urgency. In addition, current fisheries regulations should be enforced. It is also recommended that the current fisheries regulations be reviewed with the assumption that overharvesting is presently occurring.

Recommendation 6

Where harvesting is to be allowed within the pilot village sites, there should be a systematic rotation system of open and closed areas, which can be easily applied and understood with reference to coastal features. This will allow regular replenishment of species that can rapidly reestablish their numbers, given sufficient time.

5.5 Indicator species

Indicator species to be used for monitoring trends in reef communities and the success of specific management actions should have certain characteristics: they should (i) be commonly found in the target area, (ii) display a range of abundance, (iii) be responsive to management actions, (iv) be easily identified, and (v) be accessible for regular monitoring. Indicator species will preferably include target species that are of concern and that are the target of management actions; indicators may also include other parameters or species associated with the species of concern.

5.5.1 Reef flat indicators

The pilot studies and baseline surveys suggest a number of reef flat indicators that can be used to test the effectiveness of fisheries management actions, including a number of macro invertebrates that both fulfil the requirements of a "good indicator species" and are highly targeted by gleaners for food. These comprise the vermetid tube worm (*ugako*), purple jewel box oyster (*papahua*), and the false limpet (*matapihu*). All three species were extensively surveyed in the pilot and baseline surveys. In addition, the vermetid and oyster are useful as they can typically be used to indicate recent harvest activities, due to their permanent attachment to the substrate and the presence of the shell on the substrate after harvesting. In both cases the nature of the remaining shell can serve to indicate the cause of mortality (natural mortality is indicated if the shell is not cracked or broken but remains in situ). In contrast, the false limpet is completely removed by gleaners; if mortality is not due to harvesting, the shell will not remain in place. In this instance density or presence changes are the only indicator of harvest pressure, aside from opportunistic observations of discarded harvested shells that are processed and perhaps eaten ashore.

Additional useful indicator species include the turban shell (*alili*), giant clam (*gege*), and species of holothurian present on the reef flat. The turban shell is difficult to monitor as it naturally occurs in the crest surf zone and can only be accessed at low tides during relatively calm sea conditions. This should not be a problem for volunteers who are familiar with the distribution of *alili* and the conditions required for monitoring them.

The giant clam is very uncommon on reef flats and relatively more abundant on reef slopes, but at present, both habitats carry very low densities of giant clam, so large sample sizes will be required to monitor changes in the density of this species. This is a very important indicator species and may be included in the suite of indicators only if it is part of a multiple-indicator sampling program.

The species of holothurian currently present serve as another useful indicator group, in part because some species are targeted by gleaners, but also because the presence and abundance of holothurians on a reef flat can be used as an indicator of reef flat health. Most holothurian species in Niue are detritus feeders (feeding on the substrate surface) where pollutants may be expected to impact shoreline resources.

5.5.2 Slope indicators

The monitoring of reef slope habitat indicators is dependent on gaining access to the slope, as well as the aims underlying reef slope community enhancement activities. Fish target species and abundance are the most emphasised reef group of concern from the participatory situation analysis (SPREP 2004). Fortunately, some work by SPC staff (see Labrosse et al, 1999) on fish density and abundance has been carried out in 1998 and in 2004 for the Namoui marine reserve (within the pilot village sites), and at Avatele (which is not in the pilot site area). Certain reef flat and slope macro invertebrate fisheries species are also targeted as part of the SPC fish survey protocol. If the pilot villages adopt management options in an attempt to enhance fish stocks, a more specifically designed survey will have to be considered. Most likely this may take the form of a program that targets a few indicator fish species — such as the humphead wrass (*Cheilinus undulatus)*, trevally species, and some grouper species — rather than targeting a suite of species.

Macro invertebrates (such as giant clams), macro crustaceans (crayfish and crabs) and possibly commercial species of holothurian may be of specific interest to villagers as well. In these cases, slope-inhabiting species may have to be monitored at night, as that is when they are often most active and not in shelter or hiding.

One important indicator of reef slope health is the presence (expressed as per cent cover) and condition of hard coral. This will be of specific interest, as Cyclone Heta has reduced coral cover to very low levels.

Associated reef slope health indicators could include the abundance of sea urchins (*kina, vana*), cover of macro algae (*limu*, possibly *Liagora* spp.), and the density of juvenile coral recruits. The relative densities of the former two indicators can be inversely related, as the urchins tend to feed on the macro algae.

Recommendation 7

It is recommended that some of the following reef flat species be considered as good indicators of management success: the vermetid tube worm (*ugako*), purple jewel box oyster (*papahua*), false limpet (*matapihu*), as well as the turban shell (*alili*), giant clam (*gege*), and species of holothurian (*sepulupulu, loli*). Reef slope species that would be good indicators include a few indicator fish species, giant clams (*gege*), macro crustaceans, hard coral cover and coral recruit densities, sea urchins (*kina*, *vana*), and macro algae (*limu*) cover.

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Appendix 1. Manta tow data

Manta tow data from Alofi North and Makefu reef slopes, December 2003 and March 2004.

Sample ID = Unique ID number for each sample (WC = West Coast)

Coral Damage categories = S (severe, >75% all colonies), H (high, 30–75% all colonies), M (moderate, 10–30% all colonies), L (low, 10% all colonies), none (0))

Slope steepness categories = M (moderate angle <300), ST (steep angle, 30–600), V (tending to vertical angle, >60–900))

Edge categories = SPG (Spur and groove), CON (Continuous edge), BR (Broken edge to slope))

Substrate categories = PL (Platform),S (sand))

Benthos (Dominant life form) = LC (Live coral), MA (Macro algae))

Coral Form = ACC (Acropora corymbose), ACT (Acropora tabulate), ENC (Encrusting), MAS (Massive))

Coral Cover Categories = 0 (zero), 1 (1-10%), 2 (11-30%), 3 (31-50%), 4 (51-75%), 5 (76-100%);

Clams, Holothurians, and Urchins abundance = 0 (zero), L (<10 indiv.)

Fish abundance = M (Moderate numbers, >100 - <500), L (Low, <100);

Fish Dominance = SUR (Surgeon Fish, F. Acanthuridae), PAR (Parrot Fish, F. Scaridae)

COTS No. & Size = 0 (zero);

Disturbance = Coral Disease, Coral Bleaching;

Other (Mega fauna) = S (Sea snakes), T (Turtles).

Sample ID	Date	Tow #	Vis./Dep. (m)	Coral Damage.	Slope	Edge	Substrate	Benthos	Coral form	Live coral cover	Dead coral cover	Soft coral cover	Clams	Holothurians	Urchins	Fish Abundance	Fish Dominance	Cots No.	Cots Size	Disturbance	Other	Notes
WC001	Dec 03	1	G/12	O	ST	SPG	PL	LC	ACC	2	0	0	0	L	0	M	SUR	0	0	NIL		Holothurian = 1, Thelenota anas;
WC002	Dec 03	2	G/15	M	ST	CON	PL	LC	ACT	2	1	0	0	0	0	M	SUR	0	0	NIL		1x WT Shark; ACT = A.paniculata; ACT with colony damage (Storm?); ACT >12m depth; Dead coral from bleaching early 2003;
WC003	Dec 03	3	G/18	M	ST	CON	PL	LC	MAS	3	2	0	0	0	0	L	SUR	0	0	Disease (5% ACT)		1x Napoleon Wrass; ACT with colony damage (Storm?); ACT >12m depth; Dead coral from bleaching early 2003;
WC004	Dec 03	4	G/15	M	ST	CON	PL	LC	ACT	2	2	0	0	0	0	L	SUR	0	0	Disease (5% ACT)		ACT with colony damage (Storm?); ACT >12m depth; Dead coral from bleaching early 2003;
WC005	Dec 03	5	G/15	M	ST	SPG	PL	LC	ACT	2	2	0	0	0	0	L	SUR	0	0	Disease (2% ACT)		ACT with colony damage (Storm?); ACT >12m depth; Dead coral from bleaching early 2003;
WC006	Dec 03	6	G/15	M	M	BR	S	MA	ENC	1	1	0	0	0	0	L	SUR	0	0			Padina spp. macro algae dominant; coral damage (anchors?)
WC007	Mar 04	1	G/15	H	ST	SPG	PL	MA	MAS	1	1	0	0	0	0	M	SUR	0	0	Bleaching high	S=3	LC = <2%; TA high with MA
WC008	Mar 04	2	G/17	S	ST	SPG	PL	MA	MAS	1	1	1	0	0	0	M	SUR	0	0	Bleaching high	S=2	LC = <2%; TA high with MA
WC009	Mar 04	3	G/13	M	ST	CON	PL	MA	MAS	1	1	0	0	0	0	M	SUR	0	0	Bleaching High	S=3	LC = 2-3%; TA high with MA; patches of bare smooth substrate;

Sample ID	Date	Tow #	Vis./Dep. (m)	Coral Damage.	Slope	Edge	Substrate	Benthos	Coral form	Live coral cover	Dead coral cover	Soft coral cover	Clams	Holothurians	Urchins	Fish Abundance	Fish Dominance	Cots No.	Cots Size	Disturbance	Other	Notes
WC010	Mar 04	4	G/15	M	ST	CON	PL	MA	MAS	1	1	0	0	0	0	M	SUR	0	0	Bleaching High	S=3	LC = 5-6%; TA high with MA
WC011	Mar 04	5	G/18	S	ST	SPG	PL	MA	MAS	1	1	0	0	0	0	L	SUR	0	0	Bleaching High	S=1	LC = 1%; TA high with MA
WC012	Mar 04	6	G/20	M	ST	SPG	PL	MA	MAS	1	1	0	0	0	0	L	SUR	0	0	Bleaching High	S=3	LC = 8%; TA high with MA
WC024	Mar 04	1	G/18	L	ST	SPG	PL	TA	MAS	1	1	0	0	0	0	L	SUR	0	0			LC = 2%; No MA present, No bleaching; Massive = Porites spp. dom.;
WC025	Mar 04	2	G/17	L	ST	CON	PL	TA	MAS	1	1	0	0	0	0	L	PAR	0	0		S=2 T=1	LC = 4%; No MA; No bleaching; Massive = Porites spp. dom;
WC026	Mar 04	3	G/14	L	ST	CON	PL	TA	MAS	1	1	0	0	0	0	L	SUR	0	0			LC = 6%; No MA; No bleaching; Massive = Porites spp. dom;
WC027	Mar 04	4	G/13	L	ST	SPG	PL	LC	MAS	1	1	0	0	0	0	M	SUR	0	0			LC = 9%; MA in <6m; No bleaching; Massive = Porites dom;
WC028	Mar 04	5	G/12	M	ST	SPG	PL	LC	MAS	1	1	0	0	0	0	M	SUR	0	0			LC = 9%; MA <10% cover; No bleaching; Massive = Porites spp. dom; Start Vailoa ST;
WC029	Mar 04	6	G/12	L	V	SPG	PL	LC	MAS	1	2	1	0	0	0	M	SUR	0	0	Disease On Few ACT;	S=2	LC = <5%; Low MA in <5m; DC = ACC,ACT,ACB;
WC030	Mar 04	7	G/16	L	V	SPG	PL	LC	MAS	1	2	1	0	0	0	L	SUR	0	0	Disease On Few ACT; Bleaching On Shallower Corals < 10m;	S=2	LC = <2%; MAS = Favids;
WC031	Mar 04	8	G/15	M	ST	SPG	PL	LC	ACT	1	2	0	0	0	0	L	SUR	0	0	Disease On Few Act; Drupella Scars Act;		LC = <4%; DC = ACC, ACT;
WC032	Mar 04	9	G/12	M	ST	SPG	PL	MA	MAS	1	2	1	0	0	0	L	SUR	0	0	Disease On Few ACT;		LC = <3%; MA in <6m;
WC033	Mar 04	10	G/12	L	ST	SPG	PL	MA	MAS	1	1	0	0	0	0	L	SUR	0	0	Partial Bleaching;		LC = <2%; MAS = Porites spp. & Millepora spp.; Opp. Blowholes;
WC034	Mar 04	11	G/15	L	V	SPG	PL	MA	MAS	1	1	0	0	0	0	L	SUR	0	0		S=1	LC = <2%;
WC035	Mar 04	12	G/14	L	V	CON	PL	MA	MAS	1	1	0	0	0	0	L	PAR	0	0		S=1	LC = <2%;

Sample ID	Date	Tow #	Vis./Dep. (m)	Coral Damage.	Slope	Edge	Substrate	Benthos	Coral form	Live coral cover	Dead coral cover	Soft coral cover	Clams	Holothurians	Urchins	Fish Abundance	Fish Dominance	Cots No.	Cots Size	Disturbance	Other	Notes
WC036	Mar 04	13	G/12	M	V	CON	PL	MA	MAS	1	1	0	0	0	0	L	PAR	0	0	Disease On ACT;	S=1	LC = <2%; DC = Acropora spp. mainly; MAS = Millepora spp. mainly;
WC037	Mar 04	14	G/12	H	ST	SPG	PL	MA	MAS	1	0	0	0	0	0	L	SUR	0	0			LC = <2%; MAS = Millepora spp. mainly; Smooth substrate; Start at S reef flat on N Namoui;
WC038	Mar 04	15	G/13	H	ST	SPG	PL	MA	MAS	1	0	0	0	0	0	L	SUR	0	0		S=3	LC = <1%; Smooth substrate; Opp. Namoui pilot Tr #3;
WC039	Mar 04	16	G/13	H	ST	SPG	PL	MA	MAS	1	0	0	0	0	0	L	SUR	0	0			LC = <1%; Smooth substrate;
WC040	Mar 04	17	G/12	H	ST	SPG	PL	MA	MAS	1	0	0	0	0	0	L	SUR	0	0			LC = <1%; Smooth substrate; Caves on slope opp. cliff cave at Coral Gardens;
WC041	Mar 04	18	G/16	S	ST	SPG	PL	MA	MAS	1	1	0	0	L	0	L	PAR	0	0			LC = <1%; MAS = Porites spp.; Smooth substrate; Holothurian= 1, Thelenota anas;
WC042	Mar 04	19	G/16	S	ST	SPG	PL	MA	MAS	1	0	0	0	0	0	L	SUR	0	0			LC = <1%; MAS = Millepora spp.; Smooth substrate;
WC043	Mar 04	20	G/17	S	ST	SPG	PL	MA	MAS	1	0	0	0	0	0	L	SUR	0	0			LC = <1%; MAS =Millepora spp.; Smooth substrate;
WC044	Mar 04	21	G/18	S	ST	SPG	PL	MA	MAS	1	0	0	0	0	0	L	PAR	0	0			LC = <1%; MAS =Millepora spp.; Smooth substrate; Opp. former church at Makefu; cave opp. Makefu Sea Track;

Appendix 2. Manta tows: position and direction

Manta tow position, direction, and other relevant information recorded during the baseline assessment.

Village	Date	Site	Habitat	Sample ID	Tow #	Time	Recorder	Lat. (S)	Long. (W)	Direction	Notes
Alofi North	4-Dec-03	N of Wharf	Slope	WC001	1	PM	SL			S to N	No GPS Start N wharf (100m N of church)
Alofi North	4-Dec-03	N of Wharf	Slope	WC002	2	PM	SL	19 02.91	169 55.17	S to N	N Direction contiguous to #WC001; GPS for start of each tow only; Stop opp Omahii Sea Track
Alofi North	4-Dec-03	S Namoui MR	Slope	WC003	3	PM	SL	19 02.05	169 55.18	N to S	GPS for start of each tow only; Start S end Namoui MR, heading Sth;
Alofi North	4-Dec-03	S Namoui MR	Slope	WC004	4	PM	SL	19 02.13	169 55.16	N to S	GPS for start of each tow only; S direction contiguous with #WC003;
Alofi North	4-Dec-03	S Namoui MR	Slope	WC005	5	PM	SL	19 02.21	169 55.14	N to S	S direction contiguous to #WC004;
Alofi North	4-Dec-03	Opp Harbour	Slope	WC006	6	PM	SL	19 03.08	169 55.24	N to S	Start opp church going Sth across harbour opening to opposite Tomb Point;
Alofi North	23-Mar-04	N of Wharf	Slope	WC007	1	AM	SL	19 03.074	169 55.226	S to N	Start 200m N of wharf
Alofi North	23-Mar-04	N of Wharf	Slope	WC008	2	AM	SL	19 02.905	169 55.204	S to N	N Direction contiguous to #WC007; 2 min tows
Alofi North	23-Mar-04	N of Wharf	Slope	WC009	3	AM	SL	19 02.907	169 55.107	S to N	N Direction contiguous to #WC008; 2 min tows
Alofi North	23-Mar-04	N of Wharf	Slope	WC010	4	AM	SL	19 02.822	169 55.162	S to N	N Direction contiguous to #WC009; 2 min tows
Alofi North	23-Mar-04	N of Wharf	Slope	WC011	5	AM	SL	19 02.727	169 55.143	S to N	N Direction contiguous to #WC010; 2 min tows
Alofi North	23-Mar-04	N of Wharf	Slope	WC012	6	AM	SL	19 02.624	169 55.122	S to N	N Direction contigupous to #WC011; Finish 100m S of Catholic Church
Alofi North	26-Mar-04	Opp Catholic Church	Slope	WC024	1	AM	SL	19 02.451	169 55.129	S to N	Start 50m Sth of Catholic Church; N Direction;
Alofi North	26-Mar-04	Nth Catholic Church	Slope	WC025	2	AM	SL	19 02.359	169 55.134	S to N	N Direction contiguous to #WC024;
Alofi North	26-Mar-04	Nth Catholic Church	Slope	WC026	3	AM	SL	19 02.258	169 55.139	S to N	N Direction contiguous to #WC025;
Alofi	26-Mar-	Nth Catholic	Slope	WC027	4	AM	SL	19	169	S to N	N Direction contiguous to #WC026;

Village	Date	Site	Habitat	Sample ID	Tow #	Time	Recorder	Lat. (S)	Long. (W)	Direction	Notes
North	04	Church						02.167	55.149		
Alofi North	26-Mar-04	Nth Catholic Church	Slope	WC028	5	AM	SL	19 02.068	169 55.164	S to N	Start Vailoapu (Namoui MR); N Direction contiguous to #WC027;
Alofi North	26-Mar-04	Namoui MR	Slope	WC029	6	AM	SL	19 02.967	169 55.173	S to N	In Mar Reserve; N Direction contiguous to #WC028;
Alofi North	26-Mar-04	Namoui MR	Slope	WC030	7	AM	SL	19 01.877	169 55.201	S to N	In Mar Reserve; N Direction contiguous to #WC029;
Alofi North	26-Mar-04	Namoui MR	Slope	WC031	8	AM	SL	19 01.793	169 55.226	S to N	In Mar Reserve; N Direction contiguous to #WC030;
Makefu	26-Mar-04	Namoui MR	Slope	WC032	9	AM	SL	19 01.700	169 55.259	S to N	In Mar Reserve; N Direction contiguous to #WC031;
Makefu	26-Mar-04	Namoui MR	Slope	WC033	10	AM	SL	19 01.625	169 55.274	S to N	In Mar Reserve; N Direction contiguous to #WC0032;
Makefu	26-Mar-04	Namoui MR	Slope	WC034	11	AM	SL	19 01.558	169 55.291	S to N	In Mar Reserve; N Direction contiguous to #WC033;
Makefu	26-Mar-04	Namoui MR	Slope	WC035	12	AM	SL	19 01.486	169 55.343	S to N	In Mar Reserve; N Direction contiguous to #WC034;
Makefu	26-Mar-04	Namoui MR	Slope	WC036	13	AM	SL	19 01.429	169 55.343	S to N	In Mar Reserve; N Direction contiguous to #WC035;
Makefu	26-Mar-04	Makefu	Slope	WC037	14	AM	SL	19 01.356	169 55.360	S to N	N of Namoui MR; N Direction contiguous to #WC036;
Makefu	26-Mar-04	Makefu	Slope	WC038	15	AM	SL	19 01.249	169 55.397	S to N	N of Namoui ST; N Direction contiguous to #WC037;
Makefu	26-Mar-04	Makefu	Slope	WC039	16	AM	SL	19 01.158	169 55.426	S to N	N of Namoui MR; N Direction contiguous to #WC038;
Makefu	26-Mar-04	Makefu	Slope	WC040	17	AM	SL	19 01.069	169 55.443	S to N	N of Namoui MR; N Direction contiguous to #WC039;
Makefu	26-Mar-04	Makefu	Slope	WC041	18	AM	SL	19 00.982	169 55.453	S to N	N of Namoui MR; N Direction contiguous to #WC040;
Makefu	26-Mar-04	Makefu	Slope	WC042	19	AM	SL	19 00.904	169 55.470	S to N	Start opp Sails (Coral Gardens); N Direction contiguous to #WC041;
Makefu	26-Mar-04	Makefu	Slope	WC043	20	AM	SL	19 00.848	169 55.465	S to N	N Direction contiguous to #WC042;
Makefu	26-Mar-04	Makefu	Slope	WC044	21	AM	SL	19 00.778	169 55.464	S to N	Finish opp former church at Makefu (opp stairs of ST); N Direction contiguous to #WC043;

Appendix 3. Coral genera and species recorded

The list includes species recorded in locations elsewhere on the west coast as well as within the pilot village habitats (I.e. from all surveys to date).

P = present

The use of "cf" (as in *Acropora* cf. *loripes*) refers to species for which identification is tentative.

Year =	**2003**					**2004**					
Habitat =	**Reef Flat**				**Limu Rf Fl Pools**	**Reef Flat**		**Limu Rf Fl Pools**	**Slope**		
Village =	**Alofi N**	**Alofi S**	**Makefu**	**Tamakautoga**		**Alofi N**	**Makefu**	**Makefu**	**Alofi N**	**Makefu**	**Tamakautoga**
Acanthastrea brevis									P		P
Acanthastrea echinata	P										
Acanthastrea ishigakiensis											P
Acropora austera											P
Acropora cerealis											P
Acropora cf *loripes*				P							
Acropora cf *tenuis*					P						P
Acropora cf *valida*					P						P
Acropora chesterfieldensis					P						P
Acropora cytherea					P						P
Acropora digitifera	P										P
Acropora gemmifera	P	P	P								P
Acropora globiceps					P						P
Acropora humilis					P						P
Acropora hyacinthus					P						P
Acropora latistella											P
Acropora listeri					P						P
Acropora microclados											P
Acropora millepora					P						P
Acropora monticulosa						P					P
Acropora nasuta					P						P
Acropora palmerae		P									
Acropora paniculata					P					P	P
Acropora pulchra					P						P

Year =	2003					2004					
Habitat =	Reef Flat				Limu Rf Fl Pools	Reef Flat		Limu Rf Fl Pools	Slope		
Village =	Alofi N	Alofi S	Makefu	Tamakautoga		Alofi N	Makefu	Makefu	Alofi N	Makefu	Tamakautoga
Acropora retusa											P
Acropora robusta											P
Acropora verweyi					P						P
Alveopora cf *minuta*					P						P
Astreopora cucullata					P					P	P
Astreopora gracilis					P						
Astreopora myriopthalma					P			P	P	P	P
Astreopora scabra					P						P
Coscinaraea columna					P						P
Cyphastrea serailia	P				P				P		P
Echinophyllia aspera			P							P	P
Favia matthai	P				P				P	P	P
Favia pallida									P		P
Favia stelligera											P
Favites abdita			P						P		P
Favites cf *russelli*									P		
Favites halicora	P	P							P		
Fungia scutaria											P
Galaxea fascicularis					P			P			P
Goniastrea aspera										P	P
Goniastrea edwardsii											P
Goniastrea favulus					P						P
Goniastrea pectinata											P
Goniastrea retiformis	P	P	P	P	P	P	P		P		P
Hydnophora microconus	P				P				P		P
Leptastrea purpurea	P		P		P	P	P		P		P
Leptastrea transversa				P	P	P		P	P		P
Leptoria phrygia					P				P	P	P
Lithophyllon undulatum					P						
Lobophyllia cf *diminuta*									P		

Year =	2003					2004					
Habitat =	Reef Flat				Limu Rf Fl Pools	Reef Flat		Limu Rf Fl Pools	Slope		
Village =	Alofi N	Alofi S	Makefu	Tamakautoga		Alofi N	Makefu	Makefu	Alofi N	Makefu	Tamakautoga
Lobophyllia cf *flabelliformis*											P
Lobophyllia hemprichii											P
Millepora cf *exaesa*									P	P	P
Montastrea cf *valenciennesi*									P		P
Montastrea curta									P		P
Montipora caliculata											P
Montipora hoffmeisteri					P						
Montipora venosa											
Montipora verrucosa											P
Mycedium elephantotus											P
Oulophyllia bennetti										P	
Pachyseris gemmae									P		P
Pachyseris speciosa											P
Pavona explanulata											P
Pavona frondifera					P			P			P
Pavona varians					P				P		P
Pavona venosa			P	P	P						P
Platygyra pini			P			P	P		P		
Platygyra ryukyuensis					P						P
Platygyra sinensis									P		
Plesiastrea versipora	P								P		P
Pocillopora eydouxi										P	P
Pocillopora meandrina											P
Pocillopora verrucosa					P				P		P
Porites cf *australiensis*					P						P
Porites cf *lobata*				P	P	P	P	P			P
Porites cf *lutea*				P	P			P			P
Porites lichen					P			P			P
Porites solida									P		
Psammocora haimeana	P				P			P			P

Year =	2003					2004					
Habitat =	**Reef Flat**				**Limu Rf Fl Pools**	**Reef Flat**		**Limu Rf Fl Pools**	**Slope**		
Village =	**Alofi N**	**Alofi S**	**Makefu**	**Tamakautoga**		**Alofi N**	**Makefu**	**Makefu**	**Alofi N**	**Makefu**	**Tamakautoga**
Seriatopora hystrix											P
Stylophora pistillata					P					P	P
Turbinaria reniformis				P	P						P
Total No. Species (87)	**11**	**4**	**7**	**7**	**42**	**6**	**4**	**8**	**24**	**11**	**71**

Appendix 4. Macro invertebrate species in reef flat and slope habitats

Records of presence at a site were from both timed surveys and general observations. (C) = Crustacean; (E) = Echinoderm, (M) = Mollusc. P = Present.

Year	**2003**					**2004**					
Habitat	**Reef Flat**				**Limu Pools**	**Reef Flat**	**Limu Pools**	**Slope**			
Village	**Alofi N**	**Alofi S**	**Makefu**	**Tamakautoga**	**Makefu**	**Alofi N**	**Makefu**	**Alofi N**	**Alofi S**	**Makefu**	**Tamakautoga**
Actinopyga mauritiana (M)	P		P	P		P				P	
Australium calcar (M)	P					P					
Chama isostoma (M)	P		P			P					
Chlamys spp. (M)											P
Conus capitaneus (M)						P					
Conus cf eburneus (M)		P									
Conus frigidus (M)		P		P							
Conus virgo (M)	P										
Cypraea caputserpentis (M)	P					P					
Cypraea mauritiana (M)	P										
Cypraea talpa (M)	P					P					
Dardanus guttatus (C)	P		P			P					
Unidentif. Holothurian: *O .Dendrochirotida, F .Phyllophuriidae,? G. Neothyonidium* (E)	P		P								
Serpulorbis colubrinus (M)	P			P	P	P					P
Diadema setosum (E)					P		P				P
Drupa clathrata (M)				P							
Drupa morum (M)	P	P	P			P					
Drupa ricinus (M)		P		P		P					
Drupella spp. (M)											P
Echinometra mathaei (E)	P					P					
Echinometra spp. *(Black)* (E)		P									
Echinostrephus spp. (E)											P

Year	2003					2004					
Habitat	Reef Flat				Limu Pools	Reef Flat	Limu Pools	Slope			
Village	Alofi N	Alofi S	Makefu	Tamakautoga	Makefu	Alofi N	Makefu	Alofi N	Alofi S	Makefu	Tamakautoga
Echinothrix diadema (E)					P						P
Heterocentrotus cf *trigonarius*	P					P					
Holothuria atra (E)	P	P		P	P	P				P	P
Holothuria leucospilota (E)		P				P					
Holothuria nobilis (E)										P	
Latirus cf polygonus (M)				P							
Lithophaga spp. (M)	P	P		P		P					
Morula uva (M)		P		P		P					
Nassarius cf *horridus* (M)				P							
Oliva sp. (M)	P										
Oliva vidua (M)	P										
Ophiocoma spp. (E)		P									
Siphonaria Sirius (M)	P										
Stenopus hispidus (C)									P		
Thais armiger (M)	P					P					
Thais tuberosa (M)	P										
Thelenota ananas (E)									P	P	
Tridacna maxima (M)					P			P			P
Turbo setosus (M)	P	P		P	P						P
Turbo argyrostomus (M)	P										
Vasum cf turbinellus (M)	P										
Total Species Present per Village & Habitat=	22	11	3	11	6	16	1	1	2	4	9

Appendix 5. Comparative data from before and after Cyclone Heta

The data was recorded in contiguous belt transects across the reef flat (each 10 m long by 5 m wide, except those marked with an *, which were 2.5m wide) during pilot (2003) and baseline surveys (2004) of the reef flat habitat. Species recorded included all holothurians present (*Holothuria leucospilota*, *Holothuria atra*, *Actinopyga mauritiana*), live or dead mollusc tube worms (*Serpulorbis colubrinus*), the bivalve (*Chama isostoma*), and the false limpet *Siphonaria sirius*. GPS positions refer to the starting position of the belt, i.e. against the cliff face or at the base of a beach. Transects were placed perpendicular across the reef flat, starting from the base of a cliff or the base of a beach or rubble bank and extending out to the crest.

SITE		**VAILOAPU SEA TRACK**		**NAMOUI SEA TRACK**					
DATE		**Dec.2003/Mar. 2004**		**Dec.2003/Mar. 2004**					
GPS		**19^0 0202 S 169^0 5500 W**	**19^0 0227 S 169^0 5506 W**	**19^0 0128 S 169^0 5533 W**	**19^0 0120 S 169^0 5535 W**	**19^0 0113 S 169^0 5536 W**	**19^0 0107 S 169^0 5538 W**		
SPECIES	**BELT LENGTH.**	**TR#1/TR#1 (n=3)/(n=5)**	**TR#2/TR#2 (n=5)/(n=5)**	**TR #1/TR#1 (n=5)/(n=5)**	**TR #2/TR#2 (n=5)/(n=5)**	**TR #3/TR#3 (n=5)/(n=5)**	**TR#4/TR#4 (n=4)/(n=4)**	**TOTAL**	**DENSITY/HA**
Holothuria leucospilota	0 - 10m	9/0	9/0	2/0	7/0	0/0	0/2	27/2	900/66.7
	10 - 20m	0/0	1/0	4/0	4/0	0/0	0/4	9/4	200/133.3
(*Loli*: White threads fish)	20 - 30m	0/0	0/0	6/0	0/0	0/0	0/0	6/0	300/0
	30 - 40m	-/0	0/0	0/0	1/0	0/0	0/0	1/0	40/0
	40 - 50m	-/0	0/0	0/0	0/0	0/0		0/0	0/0
	Mean/m^2=	0.060/0.0	0.040/0.0	0.048/0.0	0.048/0.0	0.0/0.0	0.000/63.16	0.032/0.004	318.5/41.4
Holothuria atra	0 - 10m	3/6	7/4	3/0	1/0	0/0	2/0	16/10	533.3/335.3
	10 - 20m	1/0	7/4	1/1	0/0	1/0	3/0	13/5	433.3/166.7
(*Loli*: Lollyfish)	20 - 30m	0/0	3/9	3/0	0/0	1/1	0/0	7/1	233.3/33.3
	30 - 40m	-/2	0/1	2/0	1/0	1/0	1/0	5/3	200.0/100.0
	40 - 50m	-/0	0/1	0/0	0/0	0/0		0/1	0.0/40.0
	Mean/m^2=	0.027/0.032	0.068/0.04	0.036/0.004	0.008/0.0	0.012/0.004	0.030/0.0	0.030/0.013	303.7/131.0
Actinopyga mauritiana	0 - 10m	4/0	0/0	0/0	0/0	0/0	0/0	4/0	133.3/0.0
	10 - 20m	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0.0/0.0
	20 - 30m	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0.0/0.0
	30 - 40m	-/0	0/0	0/0	0/0	0/0	0/0	0/0	0.0/0.0
	40 - 50m	-/0	0/0	0/0	0/0	0/0		0/0	0.0/0.0
	Mean/m^2=	0.027/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.003/0.0	29.6/0.0
Serpulorbis colubrinus (Live)	0 - 10m	117/89	3/24	15/11	0/0	17/7	11/23	163/154	5433.3/5133.3
	10 - 20m	75/11	5/81	1/5	5/1	4/10	12/37	102/145	3400.0/4833.3
(*Ugako*: Vermetid mollusc tubes)	20 - 30m	15/30	0/136	0/4	7/3	3/5	2/14	27/192	900.0/6400.0
	30 - 40m	-/6	0/25	2/0	2/6	4/4	3/0	11/41	440.0/1366.7
	40 - 50m	-/69	0/30	8/3	9/0	1/0		18/102	900.0/4080.0

SITE		VAILOAPU SEA TRACK		NAMOUI SEA TRACK					
DATE		Dec.2003/Mar. 2004		Dec.2003/Mar. 2004					
GPS		19^0 0202 S 169^0 5500 W	19^0 0227 S 169^0 5506 W	19^0 0128 S 169^0 5533 W	19^0 0120 S 169^0 5535 W	19^0 0113 S 169^0 5536 W	19^0 0107 S 169^0 5538 W		
SPECIES	BELT LENGTH.	TR#1/TR#1 (n=3)/(n=5)	TR#2/TR#2 (n=5)/(n=5)	TR #1/TR#1 (n=5)/(n=5)	TR #2/TR#2 (n=5)/(n=5)	TR #3/TR#3 (n=5)/(n=5)	TR#4/TR#4 (n=4)/(n=4)	TOTAL	DENSITY/HA
	Mean/m^2=	1.380/0.820	0.064*/1.184	0.104/0.092	0.092/0.040	0.116/0.104	0.140/1400.0	0.262/0.367	2473.5/3669.0
Serpulorbis colubrinus (Dead) (*Ugako* : Vermetid mollusc tubes)	0 - 10m	59/118	28/11	10/20	5/0	184/69	50/59	336/277	11200.0/9233.3
	10 - 20m	79/41	20/23	5/12	8/14	109/90	37/88	258/268	8600.0/8933.3
	20 - 30m	21/61	30/105	1/32	6/36	121/82	69/42	248/358	8266.7 11933.3
	30 - 40m	-/0	23/62	5/24	1/35	81/55	4/0	114/176	4560.0/5866.7
	40 - 50m	-/16	4/53	11/17	5/15	27/32		47/133	2350.0/5320.0
	Mean/m^2=	1.060/0.944	0.84*/1.016	0.128/0.420	0.100/0.400	2.088/1.312	0.800/7600.0	0.819/0.744	7804.1/7441.4
Chama isostoma (Live) (*Papahua* : Purple edge jewel box oyster)	0 - 10m	144/10	35/47	32/2	2/0	0/0	0/1	213/60	7100.0/2000.0
	10 - 20m	303/56	53/80	0/1	0/0	0/0	0/0	356/137	11866.7/4566.7
	20 - 30m	50/104	97/132	1/0	0/0	0/2	0/0	148/238	4933.3/7933.3
	30 - 40m	-/85	27/58	0/0	0/0	0/0	0/0	27/143	1080.0/4766.7
	40 - 50m	-/43	1/64	0/0	0/0	0/0		1/107	50.0/4280.0
	Mean/m^2=	3.313/1.192	1.704*/1.524	0.132/0.012	0.008/0.0	0.0/0.008	0.0/63.158	0.608/0.436	6073.5/4362.3
C. isostoma (Dead) (*Papahua* : Purple edge jewel box oyster)	0 - 10m	9/36	3/20	3/3	6/3	8/7	0/7	29/76	966.7/2533.3
	10 - 20m	22/14	15/15	2/11	6/4	19/8	0/0	64/52	2133.3/1733.3
	20 - 30m	0/62	11/47	0/7	2/4	42/25	8/0	63/145	2100.0/4833.3
	30 - 40m	-/45	7/47	0/4	0/5	50/9	0/0	57/110	2280.0/3666.7
	40 - 50m	-/20	0/46	1/3	0/2	13/3		14/74	700.0/2960.0
	Mean/m^2=	0.207/0.708	0.288*/0.700	0.024/0.112	0.056/0.072	0.528/0.208	0.040/1105.263	0.185 /0.289	1738.8/2890.6
Siphonaria sirius (*Matapihu*: False limpet)	0 - 10m	0/0	1/0	-/0	-/0	-/0	-/0	1/0	100.0/0.0
	10 - 20m	0/0	5/0	-/0	-/0	-/0	-/0	5/0	500.0/0,0
	20 - 30m	1/0	5/0	-/0	-/0	-/0	-/0	6/0	600.0/0.0
	30 - 40m	-/0	0/0	-/0	-/0	-/0	-/0	0/0	0.0/0.0
	40 - 50m	-/0	0/0	-/0	-/1	-/0	-/0	-/1	0.0/50.0
	Mean/m^2=	0.007/0.0	0.088*/0.0	-/0.0	-/0.004	-/0.0	-/0.0	0.044/0.0	436.4/0.0

Appendix 6. Data from contiguous reef flat belt transects (2004)

Each belt transect 10m long by 5m wide, surveyed during baseline surveys (2004) of the reef flat habitat. Species recorded included all holothurians present (*Holothuria leucospilota*, *Holothuria atra*, *Actinopyga mauritiana*), live or dead mollusc tube worms (*Serpulorbis colubrinus*), the bivalve (*Chama isostoma*), and the false limpet *Siphonaria Sirius*. The transects were placed perpendicular across the reef flat, starting from the base of a cliff or the base of a beach or rubble bank and extending out to the crest. Site means were converted to standard hectare areas using a conversion factor with the belt transect area of 200 m^2 or 250 m^2. * Refers to transects with total length of 40m and not the standard 50m length.

Site		**Alofi Wharf**			**North Alofi ST**				**Omahi**			**Vailoapu**		**Namoui**			
		Belt transect #			**Belt transect #**				**Belt transect #**			**Belt transect #**		**Belt transect #**			
Species	**Segment**	**1**	**2**	**3**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**2**	**3**	**1**	**2**	**3**	**4 ***
Holothuria leucospilota (loli)	0 - 10m	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2
	10 - 20m	0	0	0	1	1	1	0	0	1	2	0	0	0	0	0	4
	20 - 30m	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	30 - 40m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	40 - 50m	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	
Site Mean/ha				**0.0**				**40.0**			**106.7**		**0**				**63.2**
Holothuria atra (loli)	0 - 10m	0	0	0	0	1	0	0	0	0	0	4	6	0	0	0	0
	10 - 20m	0	0	0	0	0	0	0	0	0	1	4	0	1	0	0	0
	20 - 30m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	30 - 40m	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0
	40 - 50m	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	
Site Mean/ha				**0.0**				**10.0**			**13.3**		**360**				**21.1**
Actinopyga mauritiana	0 - 10m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10 - 20m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	20 - 30m	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	30 - 40m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	40 - 50m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Site Mean/ha				**0.0**				**0.0**			**13.3**		**0**				**0**
Serpulorbis colubrinus (Live) (vermetid mollusc worm tube) (*ugako*)	0 - 10m	0	0	4	35	0	3	3	0	0	0	24	89	11	0	7	23
	10 - 20m	0	0	0	35	2	0	0	0	0	0	81	11	5	1	10	37
	20 - 30m	0	0	0	24	0	0	0	0	0	0	136	30	4	3	5	14
	30 - 40m	0	0	0	0	0	0	0	0	0	0	25	6	0	6	4	0
	40 - 50m	0	0	0	0	0	0	0	0	0	0	30	69	3	0	0	
Site Mean/ha				**53.3**				**1020.0**			**0.0**		**10020**				**1400.0**
Serpulorbis	0 - 10m	0	0	3	68	0	21	22	0	0	0	11	118	20	0	69	59

Site		Alofi Wharf			North Alofi ST				Omahi			Vailoapu		Namoui			
		Belt transect #			Belt transect #				Belt transect #			Belt transect #		Belt transect #			
Species	**Segment**	**1**	**2**	**3**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**2**	**3**	**1**	**2**	**3**	**4 ***
colubrinus (Dead) (vermetid mollusc worm tube) (*ugako*)	10 - 20m	0	0	0	68	0	7	0	0	0	0	23	41	12	14	90	88
	20 - 30m	0	0	0	45	0	0	0	0	0	0	105	61	32	36	82	42
	30 - 40m	0	0	0	0	0	0	0	0	0	0	62	0	24	35	55	0
	40 - 50m	0	0	0	0	0	0	0	0	0	0	53	16	17	15	32	
Site Mean/ha				**40.0**				**2310.0**			**0.0**		**9800**				**7600.0**
Chama isostoma (Live) (purple edge jewel box) (*papahua*)	0 - 10m	0	0	0	4	3	2	12	0	0	1	47	10	2	0	0	1
	10 - 20m	0	0	0	6	0	1	27	0	0	0	80	56	1	0	0	0
	20 - 30m	0	0	0	2	0	0	9	5	0	0	132	104	0	0	2	0
	30 - 40m	0	0	0	0	0	0	3	0	0	0	58	85	0	0	0	0
	40 - 50m	0	0	0	0	0	0	0	0	0	0	64	43	0	0	0	
Site Mean/ha				**0.0**				**690.0**			**80.0**		**13580**				**63.2**
Chama isostoma (Dead) (purple edge jewel box) (*papahua*)	0 - 10m	0	0	0	6		12	62	0	0	0	20	36	3	3	7	7
	10 - 20m	0	0	0	24	2	8	72	0	0	0	15	14	11	4	8	0
	20 - 30m	0	0	0	14	0	7	89	0	0	0	47	62	7	4	25	0
	30 - 40m	0	0	0	1	0	7	39	0	0	0	47	45	4	5	9	0
	40 - 50m	0	0	0	0	0	0	0	0	0	0	46	20	3	2	3	
Site Mean/ha =				**0.0**				**3430.0**			**0.0**		**7040**				**1105.3**
Siphonaria sirius (false limpet) (*matapitu*)	0 - 10m	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0
	10 - 20m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	20 - 30m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	30 - 40m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	40 - 50m	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	
Site Mean/ha =				**0.0**				**40.0**			**0.0**		**0**				**10.5**
Tridacna maxima giant clam (*gege*)	0 - 10m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10 - 20m	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
	20 - 30m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	30 - 40m	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	40 - 50m	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	
Site Mean/ha =				**0.00**				**20.0**			**13.3**		**0**				**10.5**

Appendix 6 (continued) — contiguous reef flat belt transects (2004)

Each belt transect 10m long by 5m wide, surveyed during baseline surveys (2004) of the reef flat habitat. Species recorded included all holothurians present (*Holothuria leucospilota*, *Holothuria atra*, *Actinopyga mauritiana*), live or dead mollusc tube worms (*Serpulorbis colubrinus*), the bivalve (*Chama isostoma*), and the false limpet *Siphonaria sirius*. The transects were placed perpendicular across the reef flat, starting from the base of a cliff or the base of a beach or rubble bank and extending out to the crest. Site means were converted to standard hectare areas using a conversion factor with the belt transect area of 200 m^2 or 250 m^2. * Refers to transects with total length of 40m and not the standard 50m length.

Site		Makefu		Lepetu			Avaiki				TOTAL	SUM ALL INDIV	TOT AREA (m^2)	TOT DENSITY/HA
		Belt transect #		Belt transect #			Belt transect #							
Species	**Segment**	**1**	**2 ***	**1**	**2**	**3 ***	**1**	**2**	**3 ***	**4**				
Holothuria leucospilota (*loli*)	0 - 10m	0	0	0	0	0	3	0	2	1	11		1250	88.0
	10 - 20m	0	0	6	0	1	0	0	0	0	17		1250	136.0
	20 - 30m	0	0	0	0	0	0	0	0	1	2		1250	16.0
	30 - 40m	0	0	0	0	0	0	0	0	0	0	32	1250	0.0
	40 - 50m	0		0	0		0	0		0	2		1050	19.1
Site Mean/ha =			**0.0**		**120**	**100**				**73.7**			**6050**	**52.9**
Holothuria atra (*loli*)	0 - 10m	3	0	0	2	0	0	1	0	0	17		1250	136.0
	10 - 20m	2	0	0	0	0	3	0	0	2	13		1250	104.0
	20 - 30m	0	0	1	0	0	1	0	0	2	5		1250	40.0
	30 - 40m	0	0	0	0	0	2	0	0	2	7	43	1250	56.0
	40 - 50m	0		0	0		0	0		0	1		1050	9.5
Site Mean/ha =			**0.03**		**60**	**42.9**				**136.8**			**6050**	**71.1**
Actinopyga mauritiana	0 - 10m	0	0	0	0	0	1	0	0	0	1		1250	8.0
	10 - 20m	0	0	0	0	0	0	0	0	0	0		1250	0.0
	20 - 30m	0	0	0	0	0	0	0	0	0	1		1250	8.0
	30 - 40m	0	0	0	0	0	0	0	0	0	0	2	1250	0.0
	40 - 50m	0			0	0	0	0		0	0		1050	0.0
Site Mean/ha =			**0.00**		**0**	**0**				**10.5**			**6050**	**3.3**
Serpulorbis colubrinus (Live) (vermetid mollusc worm tube) (*ugako*)	0 - 10m	47	0	107	88	548	11	0	1	0	1001		1250	8008.0
	10 - 20m	12	0	108	96	293	2	0	0	0	693		1250	5544.0
	20 - 30m	0	0	69	744	4	0	0	0	0	1033		1250	8264.0
	30 - 40m	0	0	27	107	60	0	0	0	0	235	3076	1250	1880.0
	40 - 50m	0		8	4		0	0		0	114		1050	1085.7
Site Mean/ha =			**0.3**		**27160**	**32328.6**				**147.4**			**6050**	**5084.3**
Serpulorbis colubrinus (Dead) (vermetid mollusc	0 - 10m	93	0	58	123	1000	15	0	6	0	1686		1250	13488.0
	10 - 20m	30	0	44	192	700	17	0	0	0	1326		1250	10608.0
	20 - 30m	0	0	72	850	4	0	0	0	0	1329		1250	10632.0

Site		Makefu		Lepetu			Avaiki				TOTAL	SUM ALL INDIV	TOT AREA (m^2)	TOT DENSITY/HA
		Belt transect #		Belt transect #			Belt transect #							
Species	**Segment**	**1**	**2 ***	**1**	**2**	**3 ***	**1**	**2**	**3 ***	**4**				
worm tube)	30 - 40m	0	0	93	312	27	0	0	0	0	608	5123	1250	4864.0
(*ugako*)	40 - 50m	0		11	30		0	0		0	174		1050	1657.1
Site Mean/ha =			**0.6**		**35700**	**50228.6**				**400**			**6050**	**8467.8**
Chama isostoma	0 - 10m	0	0	82	50	1	0	0	0	0	215		1250	1720.0
(Live)	10 - 20m	0	0	17	25	0	3	0	0	0	216		1250	1728.0
(purple edge	20 - 30m	0	0	3	74	0	0	0	0	0	331		1250	2648.0
jewel box)	30 - 40m	0	0	0	11	0	0	0	0	0	157	1026	1250	1256.0
(*papahua*)	40 - 50m	0		0	0		0	0		0	107		1050	1019.1
Site Mean/ha =			0.00		5240	3757.1				31.6			6050	1695.9
Chama isostoma	0 - 10m	0	0	31	20	1	0	0	0	0	208		1200	1733.3
(Dead)	10 - 20m	0	0	10	30	0	11	0	0	0	209		1250	1672.0
(purple edge	20 - 30m	3	0	5	78	0	0	0	0	0	341		1250	2728.0
jewel box) (*papahua*)	30 - 40m	0	0	0	67	0	0	0	0	0	224	1057	1250	1792.0
	40 - 50m	0		0	1		0	0		0	75		1050	714.3
Site Mean/ha =			**0.02**		**4840**	**3471.4**				**115.8**			**6000**	**1761.7**
Siphonaria sirius	0 - 10m	0	0	0	0	0	0	1	0	1	6		1250	48.0
(false limpet)	10 - 20m	0	0	0	0	0	0	0	0	1	1		1250	8.0
(*matapitu*)	20 - 30m	0	1	0	0	0	0	0	0	0	1		1250	8.0
	30 - 40m	0	0	0	0	0	0	0	0	0	0	10	1250	0.0
	40 - 50m	0		0	0		0	1		0	2		1050	19.1
Site Mean/ha =			**0.01**		**0**	**0**				**42.1**			**6050**	**16.5**
Tridacna maxima	0 - 10m	0	0	0	0	0	0	0	0	0	0		1250	0.0
Giant Clam	10 - 20m	0	0	0	0	0	0	0	0	0	2		1250	16.0
(*gege*)	20 - 30m	0	0	0	0	0	0	0	0	0	0		1250	0.0
	30 - 40m	0	0	0	0	0	0	0	0	0	1	4	1250	8.0
	40 - 50m	0		0	0		0	0		0	1		1050	9.5
Site Mean/ha =			**0**		**0**	**0**				**0**			**6050**	**6.6**