



Coral Reef Survey
Vava'u, Kingdom of Tonga

South Pacific Regional Environment Programme

**Coral Reef Survey
Vava'u, Kingdom of Tonga**

by

Paul Holthus

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Data compilation and cartography
Dr Christopher Dahl
University of Hawaii

Editor
Roslyn Sharp

Production
Peter Evans

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Director	Sue Mitchell
Marine Biologist	Peter Raines
Diving Coordinator	Anthony Dobinson
Doctors	Chris Edge (23/12/89 – 06/01/90) Philip Porterfield (06/01/90 – end)
Volunteer Leaders	Peter McDowell Sarah Perryman
Support Team	Lucy Anne Bishop Alex Radway
Members	Alexandra D'Arcy Irvine Natalie Langley Juliet Larcombe Michelle McMackin Adrian Moore Anna Richards Phillippa Smith Tom Williams

Executive Summary

In October 1989, the South Pacific Regional Environment Programme (SPREP) was requested by the Government of Tonga, via the Department of Lands and Survey, to undertake a survey of the coral reefs of the Vava'u Group in northern Tonga. The general purpose of the survey was to describe the coral reefs of Vava'u and make recommendations regarding the management of coral harvesting. The coral reef survey was conducted from 20 January to 9 February 1990, with an interruption due to the near passage of Cyclone Ofa. The objectives of the survey were to:

- (1) document the condition of the coral reef communities of Vava'u;
- (2) assess the impacts from the coral harvesting which had already occurred;
- (3) determine whether there were sufficient amounts of *Goniopora* and *Porites* to support the commercial harvest and export of these corals; and
- (4) indicate whether the commercial harvest and export of corals were appropriate to the quality, condition, uses and values of the coral reefs of Vava'u. However, only one possible harvest area was identified specifically enough to be added to the survey. The field survey was thus unable to specifically inventory harvest areas for

environmental impact assessment and comparison with unharvested areas.

For each selected site, two-person teams surveyed the shallow and deep portions of the reef. Snorkelling gear was used for the former, and SCUBA gear for the latter. During the survey between one and four teams covered both shallow and deep portions of each site. A total of 36 sites was surveyed. These have been grouped into 18 categories based on descriptive characteristics.

It was found that the coral reefs of Vava'u support a mix of healthy, degraded and recovering coral communities. Sources of reef degradation include both human-induced and natural factors, although there may be some synergistic interaction between them. Recognising the many uses and benefits of coral reefs, the removal of coral colonies for the short-term economic benefits of a commercial enterprise owned by a few individuals is not recommended. If harvesting of live coral is proposed for any reef areas in Tonga, the proposal should be subject to an Environmental Impact Assessment and should be evaluated using the Environmental Guidelines for Coral Harvesting in preparation by SPREP. It is also recommended that a comprehensive coastal management plan for Vava'u be developed, with provision for the designation of suitable marine parks and coral reef reserves.

1. Background

In October 1989, the South Pacific Regional Environment Programme (SPREP) was requested by the Government of Tonga, via the Department of Lands and Survey, to undertake a survey of the coral reefs of the Vava'u Group in northern Tonga. The general purpose of the survey was to describe the coral reefs of Vava'u and make recommendations regarding the management of coral harvesting. *Goniopora* and *Porites* corals had been harvested from the coral reefs of Vava'u for export to a medical technology firm for use in the research and development of bone replacement material. The harvesting was conducted under a marine products export licence in 1988, apparently with little or no control or monitoring of the amounts and methods of coral removal, cleaning, sorting, shipping and refuse disposal. The licence was not renewed in 1989 pending a resource survey of the coral communities and the development of management recommendations.

The SPREP Project Officer (Scientist), Mr Paul Holthus, had been informally contacted in late 1988 by the Tonga Fisheries Division due to concerns over the coral harvesting activities. Information was provided to Tonga on the life history and field identification of *Goniopora* and *Porites* corals, reef survey methods and possible management alternatives. Efforts to undertake the coral reef survey of Vava'u using personnel from within Tongan government departments were not successful. SPREP was subsequently contacted to conduct the survey and agreed to make available the coral reef survey and management planning expertise of Mr Holthus.

Coincident with this request, an expedition sponsored by the Royal Geographic Society of Great

Britain ('Earthquest Expedition') was finalising plans to visit Tonga to undertake marine research activities, including an extended stay in Vava'u. SPREP arranged with the expedition leader, Ms Sue Mitchell, to have Mr Holthus train the expedition members in coral reef survey methods in order that the expedition could participate in, and assist with, the coral reef survey. The expedition arrived in Tonga in November 1989 and Ms Mitchell and other members of the expedition finalised arrangements and organised the logistics for the coral reef survey to take place in January 1990. In particular, the expedition arranged and was responsible for boat transport, fuel, SCUBA tanks, tank refills and shore facilities, which enabled SPREP's assistance to Tonga to be especially cost- and time-efficient.

The coral reef survey was conducted from 20 January to 9 February 1990, with an interruption due to the near passage of Cyclone Ofa. The objectives of the survey were to:

- (1) document the condition of the coral reef communities of Vava'u;
- (2) assess the impacts from the coral harvesting which had already occurred;
- (3) determine whether there were sufficient amounts of *Goniopora* and *Porites* to support the commercial harvest and export of these corals; and
- (4) indicate whether the commercial harvest and export of corals were appropriate to the quality, condition, uses and values of the coral reefs of Vava'u.

2. Methods

Interviews were held with Mr Ikani Prescott (District Surveyor, Vava'u) and Mr Aisea Taipulotu (Chief Fisheries Officer, Vava'u) to gather information on the history of the coral harvesting operations. Mr Etuati Afiaki, apparently the main proponent of the coral harvesting and export operation, was also interviewed in an attempt to determine where, when and how much coral was harvested, how it was processed, and how much was exported. However, only one possible harvest area was identified specifically enough to be added to the survey. The field survey was thus unable to specifically inventory harvest areas for environmental impact assessment and comparison with unharvested areas.

The selection of reef survey sites was therefore based on an analysis of charts and maps. Sites were chosen to represent major reef sectors, achieve as even a geographic coverage over as wide an area of the Vava'u reefs as possible, and include those areas which were potentially to be harvested due to their location, accessibility, etc. Unfortunately, selection of sites could not be further refined because air photos of the Vava'u area were not available for perusal prior to or during the survey. In addition, the number of sites that could be visited was constrained by the weather, sea conditions, the condition of the boat's motor and gearbox, and the limits of boat travel time available each day.

For each selected site, two-person teams surveyed the shallow and deep portions of the reef. Snorkelling gear was used for the former, and SCUBA gear for the latter. During the survey, between one and four teams covered both shallow and deep portions

of each site. The amount of time spent at each site varied according to the complexity of the reef community and time constraints, but all sites were observed for at least 20–30 minutes. Information was recorded on plastic slates or underwater paper. Following each site survey, a debriefing was held to compare and verify observations and compile a single information sheet for the site.

The following information was recorded at each of the sites: reef structure, geomorphology and substrate type; the presence and relative abundance of hard corals, macro-algae, soft corals and macro-invertebrates (e.g. starfish, sea cucumbers, clams, molluscs); estimated per cent coverage of the substrate by live coral; and other notable organisms or features. Corals were recorded to species level whenever possible, or to genera level with a description of growth form, with reference to Veron (1986) and Randall and Myers (1983). Relative abundance was assigned on a scale of 1 to 5 (1 = rare, 2 = occasional, 3 = common, 4 = abundant, 5 = dominant). Macro-algae and macro-invertebrates were generally described to genus level and soft corals to family level.

The information recorded at each site is summarised in Section 3.3 of this report. The complex mix of reef and islands in the Vava'u Group did not lend itself easily to a descriptive synthesis. Where reef structure and community characteristics were similar, sites were grouped for the descriptive summaries. Site groupings are tentative, are sometimes based mainly on geographic proximity, and thus should not be considered a definitive classification of reef types in the Vava'u Group.

3. Results

3.1 Interviews

Interviews with Vava'u Lands and Survey and Fisheries officers and with the coral export proponent, Mr Afiaki, indicated only in general terms the location, amount and timing of coral harvesting. The interview with the harvest proponent only revealed the location of one harvested area in enough detail to allow it to be added as a survey site (Site 25). During the interviews, samples of the types of corals harvested were inspected, making it possible to verify that *Goniopora* and massive *Porites* were the target corals. Site information on specific harvesting operations would have enabled the team to assess the environmental impacts of the coral harvesting and compare harvested and non-harvested coral communities. Without the harvest site information, the results of this survey are necessarily more of a description of reef community conditions and components which can then be analysed to advise on the appropriateness, sustainability and future prospects for coral harvesting.

3.2 General description of study area

The Vava'u Group is dominated by the main island of Vava'u which is indented on the southern coast by long narrow embayments (Figure 2). Much of the shoreline is composed of steep or cliffed coasts with narrow fringing reefs. South of Vava'u Island there is a reef and island complex covering an area somewhat larger than Vava'u Island itself. Pangaimotu, Kapa, Nuapapu and Hunga are the largest islands, although there are many more, including smaller high islands and small motus (sand cay islands) (Figure 3).

Fringing reefs are common around most of the islands in the reef and island complex except along island shorelines where cliffs descend directly into the sheltered waters. However, even these often support well-developed coral communities. Many of the islands reefs are joined together by reef development and others have additional patch reefs and shoals, resulting in a complex assemblage of reef configurations and habitats.

The reef and island complex is bounded in the south by a reef barrier platform between Ovaka and 'Euakafa Islands. Another reef platform forms the southeast corner of the reef and island complex. Thus, a parallel line of islands and reefs extends in a north-south direction along the eastern side of the reef and island complex. South of the reef and island complex is a scattering of small high islands and motus with fringing reefs and patch reefs.

Thirty-seven coral reef sites were surveyed during the field work (Figures 4a-d). These are described below either individually or in groups where similar characteristics or location made it logical to describe numerous sites together.

A note on the figures and tables

Figures

Figure 1 provides a key for the maps that follow (Figures 2-4). Site symbols in Figures 4a-d summarise information on the descriptive groupings of the sites, which follows Section 3.3; indicators of reef disturbance, including occurrence of *Acanthaster planci*, *Diadema setosum* and dead coral; and a ranking based on coral abundance and diversity. Spelling of place names on the maps and in the text follows Kingdom of Tonga topographic maps for the area.

Tables

Scleractinia have been organised systematically by family in an order that follows their appearance in Veron (1986). Other organisms are grouped by phylum and the specificity of identification varies. Numbers in the far left column are identifiers from the initial data collation and are not sequential in all cases. Individual cells in the table are shaded according to the abundance value accorded them. In cases where a range is given, the shading corresponds to the higher value. In the table head SH indicates a shallow water survey and DP a deep water survey. Both deep- and shallow-water surveys were not made at all sites, as indicated in the tables.

Figure 1 Legend for Figures

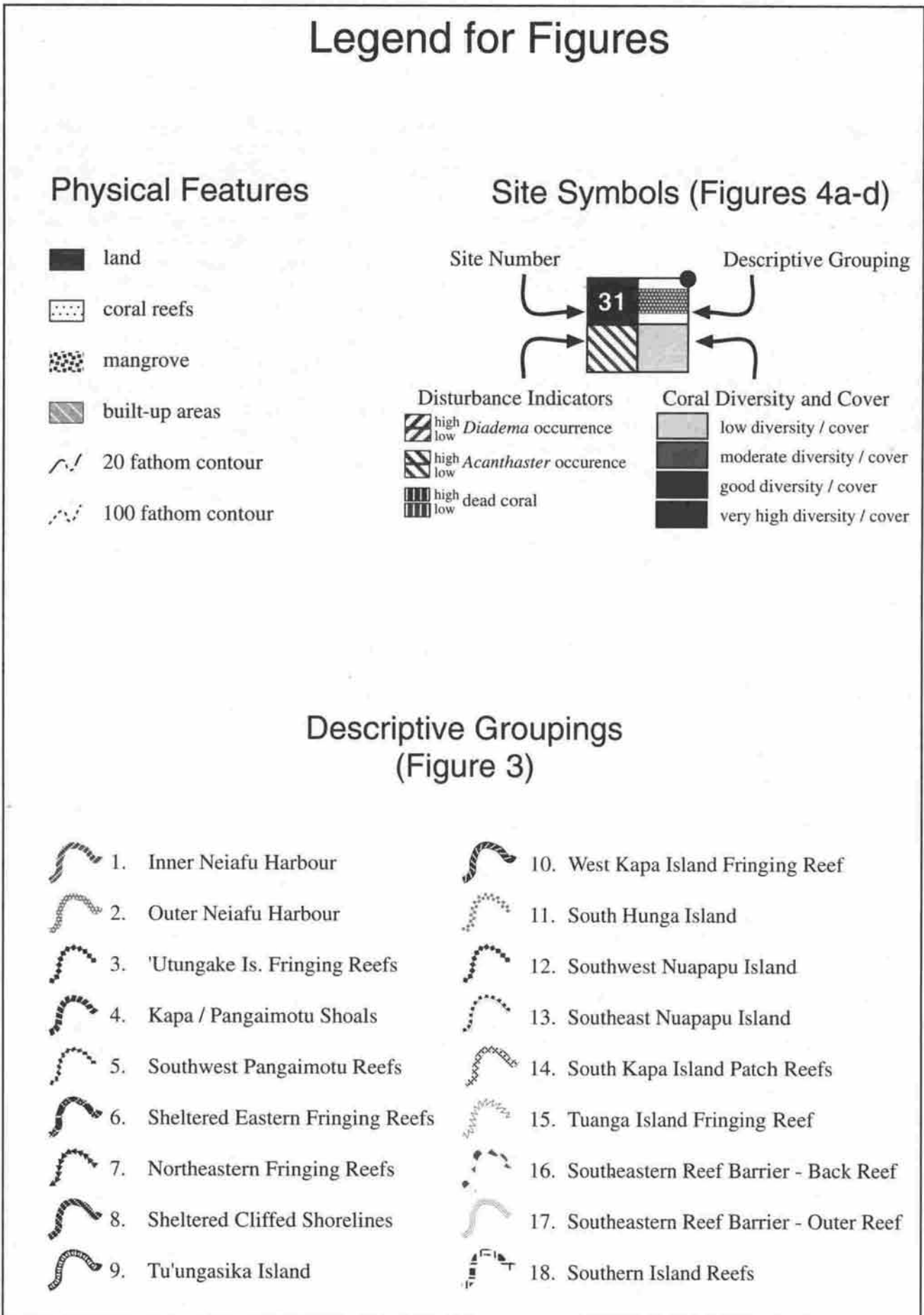
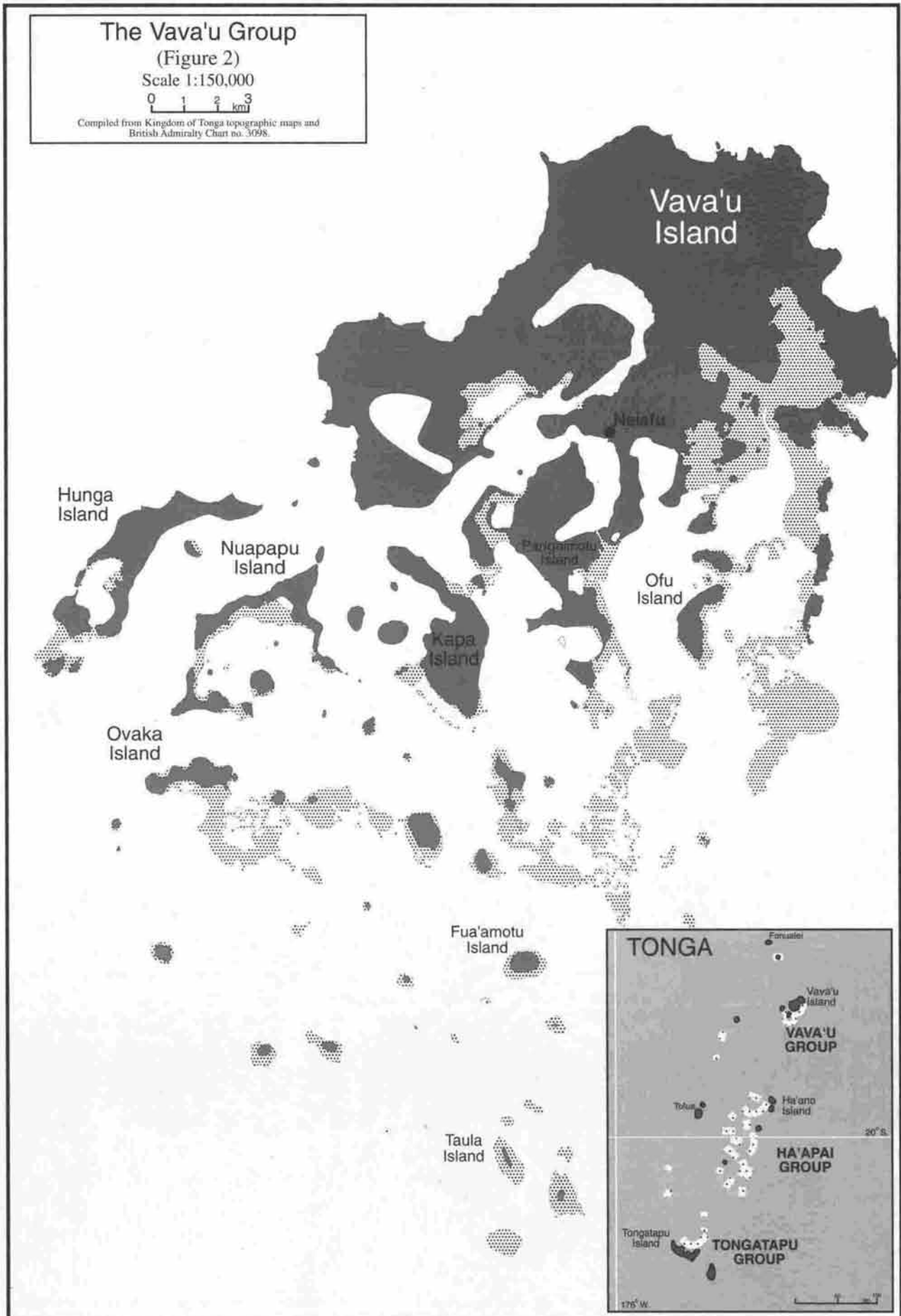


Figure 2 The Vava'u Group



Vava'u Coral Reef Survey

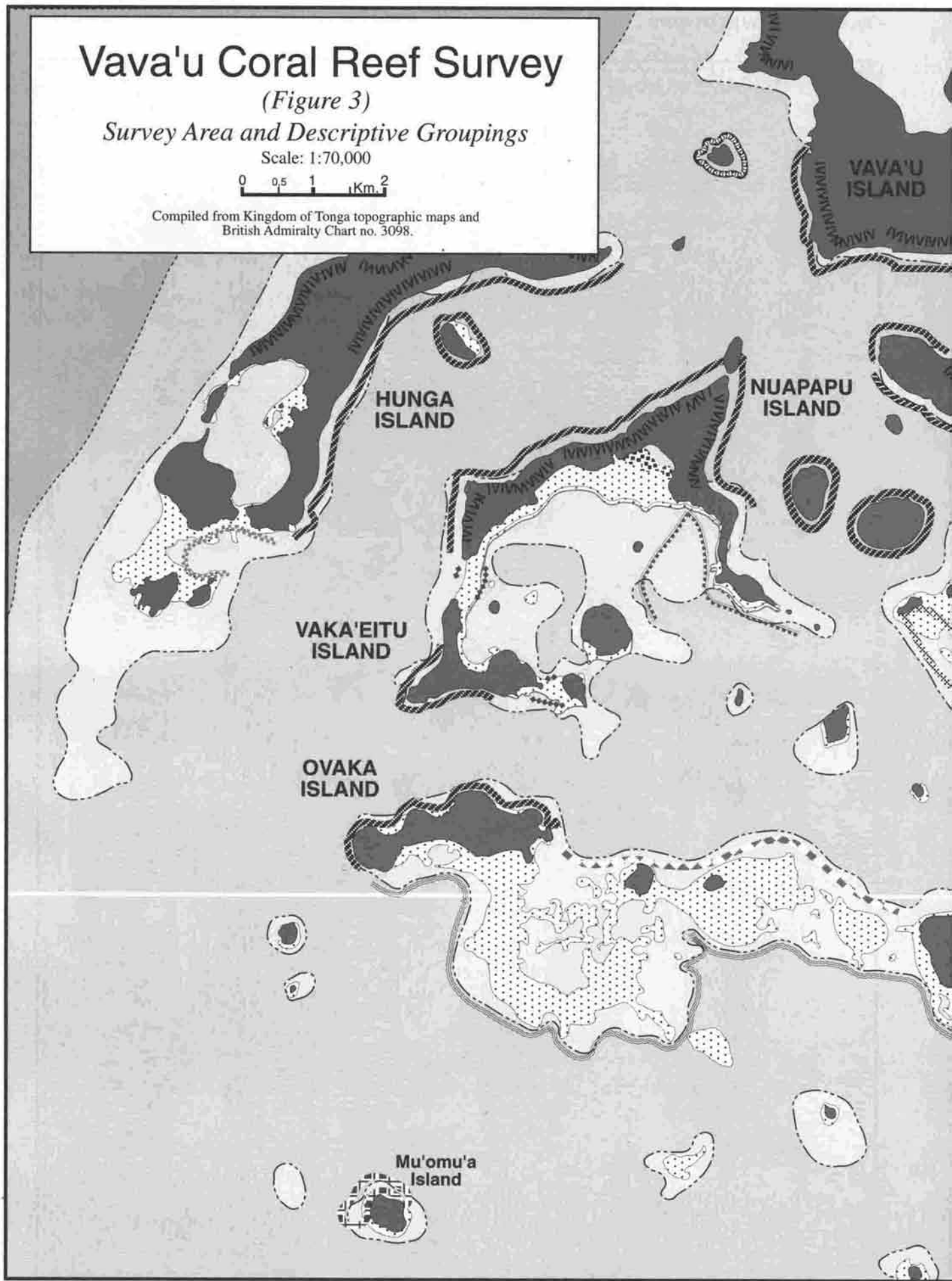
(Figure 3)

Survey Area and Descriptive Groupings

Scale: 1:70,000



Compiled from Kingdom of Tonga topographic maps and
British Admiralty Chart no. 3098.





3.3 Survey sites

3.3.1 Inner Neiafu Harbour (Site 9) (Refer to Figure 4b and Table 1)

Overview

The inner portion of Neiafu Harbour is a semi-enclosed basin surrounded by the fairly steep slopes of Vava'u Island, including Mount Talau in the northwest and the steep northeast coast of Pangi Motu. The main harbour entrance at the northwest end is constricted by shoals and reef areas extending from Pangaimotu to Vava'u. Water exchange through the very narrow, shallow Akahanga Passage at the southeast end of the harbour has been reduced by the construction of a causeway with a small bridged opening. Sediment accumulation is evident on the harbour side of the passage and some mangroves are becoming established.

The town of Neiafu borders the central northern side of the harbour. The waterfront includes numerous wharves and small landfills at the base of the steep, sometimes cliffed, shoreline. A large landfill extends into the harbour for the main wharf, fisheries dock and related facilities.

Coral reefs

The reefs of inner Neiafu Harbour are sediment-dominated with scattered coral patches on the submerged reef terrace. In the area investigated (Site 9), a sandy terrace extends out from the shoreline, increasing in depth from 2–3 m in the inshore portion to 10 m depths where the broad reef crest dropped off into the deeper harbour. The gradually sloping terrace has only 0–10% live coral cover. This is primarily on 1 m high patches of hard substrate that support coral colonies. Massive *Porites* mounds and large, free-standing *Lobophyllia* colonies are predominant within the depauperate coral community. Other corals which are common or occasional included *Porites cylindrica*, *P. rus* and *Psammocora contigua* (Table 1).

Hard substrate coverage is greater at the reef crest, although most of this is dead reef rock. Live coral cover is still only a patchy 0–30%. *Porites* mounds and *P. cylindrica* are most common. The sea urchin *Diadema setosum* was commonly found in small aggregations in this area, especially in the inshore portion of the site. Sea cucumbers (*Holothuria*) and the blue *Linckia* starfish were occasionally seen on the sandy terrace.

3.3.2 Outer Neiafu Harbour (Sites 24, 31, 33) (Refer to Figure 4b and Table 1)

Overview

The outer Neiafu Harbour area opens towards the south into the reef and island complex south of Vava'u Island. The nearly land-locked lagoon of Vaipua drains into the north end of the outer

harbour. At the time of the survey a causeway was under construction across the narrow opening of Vaipua, partly blocking the already constricted flow and creating a very strong current. Along the northwest side of the outer harbour is a wide embayment with shallow reefs which appear to receive significant input of terrigenous material from the surrounding watersheds. The embayment is cut off from the rest of the outer harbour by a reef front which connects across between the headlands and the two small islands (Muitatau, Kolotahi). Wire mesh fish traps occupy much of the reef front between these islands.

Coral reefs

As with the reefs of inner Neiafu Harbour, the outer harbour reefs are dominated by sediment. However, live coral coverage is sometimes higher and coral community diversity much greater in the outer harbour.

The shallow reef areas are typically composed of nearly 100% sand, silt or coral rubble sediment substrate, with very little live coral cover. The inshore portion of the reef along the west coast of Pangaimotu (Site 33) has a zone of algal turf. The outer edge of the fringing reef flat at this site had increased hard substrate cover, with a variable 10–30% live coral coverage. This live coral cover is generally made up of *Porites* micro-atolls, *P. cylindrica*, *P. rus* and bushes of *Millepora tenella*. Elsewhere in this area (Sites 24, 31), the outer fringing reef is primarily sand, silt and rubble with little hard substrate or live coral cover except in small clumps. These patches contain colonies of corymbose and branching *Acropora*, *Pocillopora meandrina*, *Astreopora*, small massive *Porites*, *Galaxea fascicularis* and a number of Faviid corals. *Diadema setosum* urchins and sea cucumbers are also common on the sediment substrate.

The fringing reef slope in the northern portion of outer Neiafu Harbour is generally a continuation of the sand, silt and rubble material of the shallow reef. The gradual sand slope is punctuated by rocky outcrops and coral mounds. Coral cover is low overall, but coral diversity is moderate. Massive *Porites*, *P. rus*, *Lobophyllia* and *Symphyllia* are generally dominant or abundant and many other corals were occasionally seen. Along the Pangaimotu reef slope (Site 33), coral cover reaches 10–30%. The clams *Tridacna crocea* and *T. maxima*, the urchins *Diadema setosum*, *Culcita* and *Linckia*, sea cucumbers, sponges and soft corals were occasionally seen. An *Acanthaster planci* was recorded at each of two of the sites (Sites 24, 33), and occasional feeding scars were seen at the latter site.

In contrast, the reef slope at Site 24 has only very little live coral cover on a sand and rubble slope, which supported the calcareous green algae

Halimeda in scattered beds. Periodic outcrops of reef rock are primarily composed of dead substrate, often covered with sponges. Massive *Porites*, *Lobophyllia*, *Astreopora* and *Plerogyra* are the only common corals.

3.3.3 'Utungake Island Fringing Reefs (Sites 29, 32) (Refer to Figure 4b and Table 1)

Overview

Located due east of Pangaimotu Island, 'Utungake Island has a steep western shore with a cliff which drops down to the relatively sheltered waters of this area. A fringing reef borders the western side of the island.

Coral reefs

A narrow fringing reef flat extends out from the shoreline with little live coral cover. The substrate is primarily bare reef, rubble or dead standing *Acropora*, often with algal cover. A large number of *Acanthaster planci* were seen in the area: 50-60 at Site 29 and 13 at Site 32. Only some of the starfish were observed to be feeding and there were only a

few fresh feeding scars. Coral cover increases at the edge of the reef flat, although sand and rubble areas are common as well. Sections of the reef edge are dominated by 100% coverage of *Millepora tenella* bushes. Elsewhere, hard substrate supports numerous corymbose *Acropora* colonies.

The upper reef slope has areas with only 0-5% coral cover and is dominated by bare reef rock substrate, dead standing coral and rubble patches. However, coral cover of 20-40% is found on other portions of the upper slope where hard substrate and reef rock promontories occur. These are interspersed with open sand slopes and isolated reef rock and coral outcrops, especially towards the south (i.e. Site 32). Much of the hard substrate reef slope is fairly steep and irregular and composed of dead reef rock with algal growth. The limited and variable live coral cover is composed primarily of *Millepora*, *Acrhelia*, *Seriatopora*, small massive *Porites* colonies, *Pocillopora damicornis*, *Pavona varians* and a host of other corals, which occur only occasionally or rarely. The water is fairly turbid in this area and sponges are common.

Table 1 Species Lists for Sites 9, 31, 24, 33, 29 and 32

		Inner Neiafu harbour		Outer Neiafu harbour						'Utungake I.			
		9	31		24		33		29		32		
		SH	SH	DP	SH	DP	SH	DP	SH	DP	SH	DP	
Scleractinian corals													
Family Pocilloporidae													
1	<i>Pocillopora damicornis</i>		2	2			1	1/2	1	2/3		3	
2	<i>Pocillopora verrucosa</i>								1		2	2	
3	<i>Pocillopora meandrina</i>		1		5				1				
4	<i>Pocillopora eydouxi</i>												
5	<i>Seriatopora hystrix</i>		1	1		1	1	1		2	1		
6	<i>Seriatopora caliendrum</i>		2			1	2	2		3	2/3	3	
7	<i>Stylophora pistillata</i>		1	1/2	1				2		2	2	
Family Acroporidae													
8	<i>Montipora</i> (encrusting)			2		2		1/2	1	2/3		2	
9	<i>Montipora</i> (submassive)												
10	<i>Montipora</i> (plate/foliaceous)												
11	<i>Montipora verrucosa</i>			1					1		1		
12	<i>Montipora hispida</i>						1		1/5				
13	<i>Montipora digitata</i>				1				4				
14	<i>Acropora</i> (plate)						1						
15	<i>Acropora</i> (corymbose)		2/3	2	4	1	2	2	3	1/2	3	2	
16	<i>Acropora</i> (digitate)												
17	<i>Acropora</i> (branching)			2	4	1	2	1	1/2	2			
18	<i>Acropora</i> (bottlebrush)			2								3	
19	<i>Acropora palifera</i>								1	1			
19a	<i>Acropora aspera</i>						2						
20	<i>Astreopora</i>			1	3	1/3		1		1		1	
Family Poritidae													
21	<i>Porites</i> (<i>synarea</i>) <i>rus</i>	3		5		1	4/5	2/3	3	2		2	
22	<i>Porites</i> (massive)	4	3/4	5	4	3	5	3	1/2	2/3	2	1	
23	<i>Porites cylindrica</i>	4	2	1			1	2				1	
24	<i>Goniopora</i>		2		1	1		2	1	1	1		
25	<i>Alveopora</i>					1		1	1	1			
Family Siderastreidae													
26	<i>Psammocora contigua</i>	2		1			1	1	1	1		1	
27	<i>Psammocora</i> (submassive)							1					
28	<i>Psammocora</i> (encrusting)			2								2	
29	<i>Coscinarea</i> (submassive)									2			
Family Agaricliidae													
30	<i>Pavona cactus</i>												
31	<i>Pavona decussata</i>												
32	<i>Pavona clavus</i>												
33	<i>Pavona minuta</i>									2			
34	<i>Pavona varians</i>			2			1	1/2	2			3	
35	<i>Leptoseris</i> (plates/encrusting)			1								3	
36	<i>Gardineroseris</i> (submassive)												
37	<i>Pachyseris rugosa</i>							2		2	2		
38	<i>Pachyseris speciosa</i>												

Table 1 (cont'd)

	Inner Nelafu harbour	Outer Nelafu harbour								'Utungake I.			
		9 SH	31 SH DP		24 SH DP		33 SH DP		29 SH DP		32 SH DP		
Family Fungiidae													
39	Fungiidae	1			1			1		1	1		1
41	<i>Herpolitha limax</i>												
42	<i>Halomitra pileus / Sandolitha robusta</i>												
40	Non-Fungiidae (free living)												
Family Oculinidae													
43	<i>Galaxea astreata</i>												
44	<i>Galaxea fascicularis</i>		1	1/2	3	1/2	1	1	1/2	2	1/2	1	
45	<i>Acrhelia horrescens</i>		1	1				1	2	4		2/4	
Family Pectiniidae													
46	<i>Echinophyllia</i> (plate/encr./fol.)												1
47	<i>Mycedium elephantotus</i>												
48	<i>Pectinia paeonia</i>												
Family Mussidae													
49	<i>Acanthastrea</i>												
50	<i>Lobophyllia</i> (massive)	5	3	4	1	1/3	1	3/4		1			1
51	<i>Symphyllia</i> (massive)		2	4		1	1	2/3		1			2
Family Merulinidae													
52	<i>Hydnophora rigida</i>												
53	<i>Hydnophora</i> (massive/submassive)					1							
54	<i>Merulina ampliata</i>					1		1					
Family Favitidae													
53a	<i>Caulastrea</i>												
55	<i>Favia</i> (submassive)		2	2	2	1/2	1	1	2	2	1		
55a	<i>Favia stelligera</i>												2
56	<i>Goniastrea</i> (submassive/encr.)						1	1		1			
57	<i>Platygyra / Leptoria</i>								1				1
58	<i>Oulophyllia</i>												
59	<i>Diploastrea heliopora</i>												
60	<i>Leptastrea</i> (submassive/encr.)					1				1			2
61	<i>Cyphastrea</i>									1			
62	<i>Echinopora</i>									1			1
Family Caryophyllidae													
63	<i>Euphyllia</i> (massive)												
64	<i>Euphyllia ancora</i>					1							
65	<i>Plerogyra sinuosa</i>			1		3		1					
66	<i>Physogyra lichtensteini</i>												
Family Dendrophyllidae													
67	<i>Turbinaria</i> (plate/foliaceous)					1		1					
68	<i>Turbinaria</i> (encr./submassive)												1

Table 1 (cont'd)

	Inner Neiafu harbour		Outer Neiafu harbour						'Utungake I.			
	9 SH	31		24		33		29		32		
		SH	DP	SH	DP	SH	DP	SH	DP	SH	DP	
Non-Scleractinian corals												
69	<i>Tubipora musica</i>											
70	<i>Millepora tenella</i>											
71	<i>Millepora exaesa</i>											
72	<i>Stylaster</i>											
73	<i>Distichopora</i>											
83	Soft corals											
Other Coelenterates												
87	Zoanthidae											
Phylum Echinodermata												
74	<i>Acanthaster planci</i>											
76	<i>Linckia</i>											
77	Other starfish											
78	<i>Diadema setosum</i>											
79	Other sea urchins											
80	Holothuroidea											
81	Synaptidae											
82	Sponges (Phylum Porifera)											
Shellfish (Phylum Mollusca)												
84	<i>Tridacna crocea</i>											
85	<i>Tridacna maxima/squamosa</i>											
86	Small bivalves											
Algae												
88	<i>Padina</i>											
89	<i>Halimeda</i>											
90	Turf algae											
91	<i>Turbinaria</i>											
92	<i>Caulerpa</i>											
Flowering plants												
93	Seagrass											
Other: Impacts												
75	<i>Acanthaster planci</i> feeding scars											

3.3.4 Kapa/Pangaimotu Shoals (Sites 1, 34) (Refer to Figure 4b and Table 2)

Overview

A relatively shallow platform extends from Pangaimotu Island along the south end of 'Utungake Island and across to Kapa Island. A number of small islands (Mala, Malafakalava) are situated in this area between 'Utungake and Kapa Islands which is primarily a sandy shoal.

Coral reefs

The narrow embayment between Pangaimotu and 'Utungake Islands (Site 34) contains a shallow reef flat dominated by sand and terrestrial sediments. Near the shore of Pangaimotu only sand and turf algae was encountered, with numerous bivalves and synaptid Holothurians. Elsewhere, a solid reef platform is found at 1 m depth, with occasional encrusting *Porites* colonies and patches of soft corals. *Diadema* urchins were abundant. The reef becomes somewhat deeper in places, with abundant *Porites rus* and *P. cylindrica* colonies. In areas where the reef platform drops off further, reef blocks and occasional *Porites* massives are interspersed with sand patches. In the centre of the small embayment, a broad sandy slope extends gradually to the southeast. Overall coral cover in this area is only 0–2%. Patches of a foliose sponge are common.

The area between the small island of Mala and the large island of Kapa is characterised by a submerged sand platform 2–3 m deep with occasional patch reefs. The reefs support 60–80% live coral cover, with moderate diversity, particularly on the upper (1 m deep) surfaces. Corymbose, plate and some branching *Acropora* dominate the shallow coral community. *Pocillopora damicornis* forms the bulk of much of these patch reefs, with 100% cover along the flanks of the reefs in many places. Coral cover was somewhat reduced and rubble more common on the patch reefs closer to Kapa Island. The 2–3 m deep sand flat surrounding the patch reefs was punctuated with occasional large *Porites* heads and scattered small massive corals and small plate and branching *Acropora* colonies.

3.3.5 Southwest Pangaimotu Reef (Site 2) (Refer to Figure 4b and Table 2)

Overview

The Maungatu Peninsula of southwest Pangaimotu has a fringing reef extending out to the north and south from the steep shoreline, which has a low cliff and notch at sea level.

Coral reefs

On the north side of the peninsula the reef flat is 1 m deep with 0–5% coral cover, and is mainly composed of scattered *Pocillopora damicornis* clumps and *Millepora tenella* bushes. Sea cucumbers and *Diadema* urchins were very common on

the shallow reef. One *Acanthaster* was encountered and about a dozen feeding scars were seen. The reef slopes gradually northward with a sand veneer over the reef limestone substrate. Occasional zones of 20–30% *P. damicornis* cover occur on this broad slope and continue to depths of 10 m and beyond. A reef ridge extends northward at 6–8 m depth and supports moderate live coral cover, primarily *Millepora* and massive *Porites* colonies.

The east-facing portion of the fringing reef, near the peninsula's headland, has a narrow, shallow fringing reef flat with patches of reef rock higher than the ambient reef flat level. The reef flat is composed of hard substrate, sand and rubble, with only 0–5% coral cover. Soft corals, filamentous algae and turf algae are common and *Diadema* urchins are abundant. The reef flat drops off as a cliff face with low coral cover. Below 8–10 m a rubble and sand slope continues down gradually.

3.3.6 Sheltered Eastern Fringing Reefs (Sites 18, 20, 21) (Refer to Figure 4b and Table 2)

Overview

The steep, east-facing shore of Kapa Island, the cliffed coast of outer old Neiafu Harbour and the steep western side of Ofu Island all have narrow fringing reefs (Figures 3, 4b). The reefs drop off into moderately deep basins in the sheltered eastern portion of the reef and island complex.

Coral reefs

The narrow reef flat in these areas is generally a solid platform with a veneer of reef rubble in places and usually only 0–5% coral cover. Small massive *Porites* colonies, *P. cylindrica* and small corymbose *Acropora* make up most of the limited coral cover. Filamentous algae, calcareous algae or *Turbinaria* algae are common or occasional on the shallow reef at these sites. *Diadema*, *Echinometra* and *Triptoneustes* urchins, sea cucumbers and various starfish are all occasional to abundant. *Acanthaster planci* were encountered with ten, one and eleven of the starfish seen at Sites 21, 18 and 20, respectively. Only a few feeding scars were observed.

The upper reef in these areas generally drops off steeply from the solid platform, with a 2–5 m scarp of dead reef framework. In some locations (e.g. Site 18) the scarp bottom exhibits a distinct undercut notch, perhaps a remnant of former sea level. Although live coral cover on the cliff-like upper reef slope is only 0–15%, some areas have moderate species diversity. Most of the corals occur only occasionally or rarely (Table 6), but a few, such as *Porites rus*, *Millepora tenella*, corymbose and plate *Acropora*, encrusting *Montipora* and *Pavona varians* are common. Soft corals are abundant in places, especially along the upper reef scarp. Sponges, bivalves and other filter feeders are also

sometimes common. Their occurrence is probably related to the low visibility and high degree of suspended particulate matter occurring at these sites.

The steep reef rock face terminates in a broad sand and rubble slope which continues down into the adjacent basin. This sediment-dominated lower slope has very low live coral cover, except where punctuated by large *Porites* massives and reef blocks supporting coral colonies.

Table 2 Species List for Sites 2, 1, 34, 18, 20 and 21

		SW Pangal		Kp. Pangal		Sheltered Eastern Reefs					
(Note: Kp. Pangai=Kapa/Pangaimotu)		2	1	34	18		20		21		
		SH	SH	SH	SH	DP	SH	DP	SH	DP	
Scleractinian corals											
Family Pocilloporidae											
1	<i>Pocillopora damicornis</i>	5	5		1	2	1	2	2	1	
2	<i>Pocillopora verrucosa</i>										
3	<i>Pocillopora meandrina</i>		1		1			2			
4	<i>Pocillopora eydouxi</i>		1								
5	<i>Seriatopora hystrix</i>					2		2			
6	<i>Seriatopora caliendrum</i>					1					
7	<i>Stylophora pistillata</i>				1			1	2		
Family Acroporidae											
8	<i>Montipora</i> (encrusting)	1	1		1	1	3		3	2	
9	<i>Montipora</i> (submassive)										
10	<i>Montipora</i> (plate/foliaceous)				3	1					
11	<i>Montipora verrucosa</i>						1			1	
12	<i>Montipora hispida</i>			2							
13	<i>Montipora digitata</i>		1	2			1				
14	<i>Acropora</i> (plate)		4		2	3	2	2		2	
15	<i>Acropora</i> (corymbose)	2	5	1	1	3	3	2	3	2	
16	<i>Acropora</i> (digitate)		3	1			2		2		
17	<i>Acropora</i> (branching)	1	3				3			1	
18	<i>Acropora</i> (bottlebrush)					1/2				1	
19	<i>Acropora palifera</i>										
19a	<i>Acropora aspera</i>						2				
20	<i>Astreopora</i>						1	1		1	
Family Poritidae											
21	<i>Porites (synarea) rus</i>		2	4	1	4/5	1	1	1		
22	<i>Porites</i> (massive)	2		5	2	5	4	2	3	4/5	
23	<i>Porites cylindrica</i>	2		3		2	2		3	2	
24	<i>Goniopora</i>			2				2	3	1	
25	<i>Alveopora</i>									1	
Family Siderastreidae											
26	<i>Psammocora contigua</i>			1	1		3			1	
27	<i>Psammocora</i> (submassive)									2	
28	<i>Psammocora</i> (encrusting)			1							
29	<i>Coscinarea</i> (submassive)					2	1				
Family Agaricidae											
30	<i>Pavona cactus</i>										
31	<i>Pavona decussata</i>						1	1			
32	<i>Pavona clavus</i>					1					
33	<i>Pavona minuta</i>										
34	<i>Pavona varians</i>							4	2		
35	<i>Leptoseris</i> (plates/encrusting)		1								
36	<i>Gardineroseris</i> (submassive)										
37	<i>Pachyseris rugosa</i>	1				1	1	1			
38	<i>Pachyseris speciosa</i>			1				1		1	

Table 2 (Cont.)

		SW Pangai		Kp. Pangai		Sheltered Eastern Reefs					
(Note: Kp. Pangai=Kapa/Pangaimotu)		2	1	34	18		20		21		
		SH	SH	SH	SH	DP	SH	DP	SH	DP	
Family Fungiidae											
39	Fungiidae		2			1		1	2	1	
41	<i>Herpolitha limax</i>										
42	<i>Halomitra pileus / Sandolitha robusta</i>										
40	Non-Fungiidae (free living)										
Family Oculinidae											
43	<i>Galaxea astreata</i>										
44	<i>Galaxea fascicularis</i>					1	1			1	
45	<i>Archelia horrescens</i>										
Family Pectiniidae											
46	<i>Echinophyllia</i> (plate/encr./fol.)							1			
47	<i>Mycedium elephantotus</i>			1							
48	<i>Pectinia paeonia</i>										
Family Mussidae											
49	<i>Acanthastrea</i>										
50	<i>Lobophyllia</i> (massive)			1/2		1	2	1	2	1	
51	<i>Symphyllia</i> (massive)	1		1/2		2	2	2		1	
Family Merulinidae											
52	<i>Hydnophora rigida</i>										
53	<i>Hydnophora</i> (massive/submassive)										
54	<i>Merulina ampliata</i>										
Family Faviidae											
53a	<i>Caulastrea</i>										
55	<i>Favia</i> (submassive)	3		1		2	2	2/3		2/3	
55a	<i>Favia stelligera</i>										
56	<i>Goniastrea</i> (submassive/encr.)									2	
57	<i>Platygyra / Leptoria</i>	1	1	1			2	2	1	1	
58	<i>Oulophyllia</i>										
59	<i>Diploastrea heliopora</i>					1	2		1		
60	<i>Leptastrea</i> (submassive/encr.)										
61	<i>Cyphastrea</i>									1	
62	<i>Echinopora</i>					1					
Family Caryophyllidae											
63	<i>Euphyllia</i> (massive)										
64	<i>Euphyllia ancora</i>										
65	<i>Plerogyra sinuosa</i>					1			1	1	
66	<i>Physogyra lichtensteini</i>										
Family Dendrophylliidae											
67	<i>Turbinaria</i> (plate/foliaceous)			2			1				
68	<i>Turbinaria</i> (encr./submassive)										

Table 2 (Cont.)

		SW Pangai		Kp. Pangai		Sheltered Eastern Reefs					
(Note: Kp. Pangai=Kapa/Pangaimotu)		2	1	1	18	20	21				
		SH	SH	SH	SH	DP	SH	DP	SH	DP	
Non-Scleractinian corals											
69	<i>Tubipora musica</i>			1							
70	<i>Millepora tenella</i>	3		1		1/3	2	1	2	2	
71	<i>Millepora exaesa</i>						2		1		
72	<i>Stylaster</i>										
73	<i>Distichopora</i>										
83	Soft corals			5	2	3	3	4/5	4	2	
Other Coelenterates											
87	Zoanthidae										
Phylum Echinodermata											
74	<i>Acanthaster planci</i>	1			1	1	2	1	3		
76	<i>Linckia</i>			2	1		2		3	1	
77	Other starfish							1			
78	<i>Diadema setosum</i>	4			4	2	3/4	3		5	
79	Other sea urchins								3		
80	Holothuroidea	3			2			2		3	
81	Synaptidae			5							
82	Sponges (Phylum Porifera)			3						3	
Shellfish (Phylum Mollusca)											
84	<i>Tridacna crocea</i>										
85	<i>Tridacna maxima/squamosa</i>		1							1	
86	Small bivalves			3							
Algae											
88	<i>Padina</i>										
89	<i>Halimeda</i>		1	2		2					
90	Turf algae	3		4					3		
91	<i>Turbinaria</i>		1	1			2				
92	<i>Caulerpa</i>										
Flowering plants											
93	Seagrass										
Other: impacts											
75	<i>Acanthaster planci</i> feeding scars	2/3						2	2		

3.3.7 Northeastern Fringing Reefs (Sites 17, 19) (Refer to Figure 4b and Table 3)

Overview

In the northeast sector of the reef and island complex, there are fringing reefs along Vava'u Island and the associated islands of Okoa, Olo'ua, Mafana and Ofu which extend to the south. Although these reefs face into the prevailing wind and wave direction, they are sheltered by a chain of islands and reefs further east. The area is characterised by sediment accumulation, both from terrigenous sediments delivered from the relatively large watersheds of northeast Vava'u and from coralline sediments generated on the exposed reefs further east and transported by wind, wave and current action to the more sheltered basins in this area.

Coral reefs

The reef flats in this area are generally depauperate, with only 0–5% coral cover and a substrate dominated by coral rubble and turf algae. The little coral present is usually small massive *Porites*, *Porites* micro-atolls or clumps of branching *Montipora*. A number of other corals were occasionally encountered during the survey. *Diadema setosum* sea urchins were very abundant in places, as was soft coral, particularly at Site 17. Other urchins, such as *Echinometra*, various starfish (*Culcita*, *Linckia*) and small bivalves were also commonly encountered. Synaptid sea cucumbers were common on the inner reef flat.

The upper portion of the reef slope consists of an irregular reef framework composed primarily of dead reef rock with low levels of live coral cover. Sand patches adjacent to the reef flat often contain clumps or thickets of branching *Acropora aspera*. The solid reef framework extends only 2–3 m down from the reef platform. Beyond this a sediment-dominated slope stretches into the adjacent basins with occasional 0.5–1.5 m high outcrops of massive *Porites* colonies or dead reef rock. In addition, *Porites rus*, *Lobophyllia* and encrusting *Montipora* are abundant or common and a few other corals were encountered. The lower slope is composed completely of sediment, and terrigenous sediments are a major component of the substrate at Site 19.

3.3.8 Sheltered Cliffed Shorelines (Sites 6, 8, 14, 27, 28) (Refer to Figures 4a, 4b, 4c and Table 3)

Overview

Much of the shoreline along the relatively sheltered waters of the Vava'u reef and island complex consists of cliffs which plunge directly into the adjacent waters (Figure 3). The northwest shores of Nuapapu and Kapa Islands are characterised by these cliffed shorelines, and their coral com-

munities were investigated (Sites 8, 28). The islands of A'a and Luamoko and the north-facing shore of Ovaka Island are also generally composed of cliffs, but have small areas of reef development as well, which were included in the survey (Sites 6, 27, 14). The east shore of Hunga Island, the nearby south-facing coast of Vava'u Island, 'Oto Island and the south and east coast of Vaka'eitu Island are also primarily cliff shores with coral communities presumably similar to those described below, but these areas were not surveyed.

Coral reefs

Reef structures are generally not well developed on the steep underwater slope at Sites 8 and 28, but there are nonetheless flourishing coral communities. Coral cover is generally 30–60% and somewhat variable, consisting mainly of plate, small massive and encrusting growth forms. Diversity is moderate to high on the steep, vertical, and sometimes overhanging wall.

The most abundant and common corals are *Pocillopora meandrina*, *Goniastrea*, *Stylophora pistillata*, plate and branching *Acropora*, *Millepora tenella*, *M. exaesa*, *Pachyseris rugosa*, *P. speciosa* and *Favites*. Many other corals occur only occasionally or rarely. Soft corals and algal 'paint' are very abundant on portions of submerged cliffs, especially at Site 8. The steep slope is dissected in places by large gullies, often running down the length of the slope to the rubble debris at the cliff base.

The limited reef development at Luamoko and A'a Islands and the north shore of Ovaka Island support diverse coral communities with high levels of live coral cover. The shallow reef in these areas is not a solid, consolidated reef flat; it has considerable topographic diversity. Towards the rear of the narrow platform, particularly at Sites 6 and 27, reef rock and coral mounds 1–1.5 m high alternate with sand and rubble patches or channels. The submerged reef edge at these sites supports high coral cover, up to 100% in places. This is mainly composed of corymbose, plate and branching *Acropora*; faviids; *Porites rus* and encrusting *Montipora*. Soft coral is abundant in places on the shallow reef platform, especially at Site 6.

The reef slope at the three island locations is steep to vertical, with overhangs in places at Site 27, and is broken by occasional sand and rubble gutters. Reef topography is especially diverse at Site 14, with canyons, overhangs, cliffs and pinnacles. Coral cover at these sites is high, although somewhat variable, ranging from 40 to 80%. In addition to those species abundant or common on the reef platform, common corals on the reef slope include *Goniastrea*, *Gardineroseris*, *Stylophora pistillata* and *Millepora exaesa*. Many other corals are less common. Coral species composition and growth form are particularly diverse at Site 14. Other

corals abundant or common at this site include *Pocillopora verrucosa*, *Mycedium elephantotus*, *Oxypora* and *Pachyseris rugosa*. Accumulated rubble with coral cover of 30–60% is common on the lower slopes, notably at Sites 6 and 27. Coral cover decreases towards the bottom of the slope where loose rubble and sand dominate.

Table 3 Species List for Sites 17, 19 6, 8, 14, 27 and 28

	Northeastern Reefs				Sheltered Cliffs						
	17		19		6		8	14	27		28
	SH	DP	SH	DP	SH	DP	DP	DP	SH	DP	SH
Scleractinian corals											
Family Pocilloporidae											
1		1		1	2	2			1		
2						2			3		2
3					2	2	3	2	3		1
4						1	2		2	1	1
5	1		2	1		1	1	3		2	
6	1							2	1	2	
7	1				1	3	3	1			
Family Acroporidae											
8				2/3		3	2	2	2/3	4	1
9									1	1	1
10											
11		1				1					
12	1		4/5								
13	1		4/5								
14	2				4	5	5	2	2/3	2	2/3
15	2			2	5	5			5		2/3
16						3	4/5	2			1
17			1		5	3	3	2/4		5	
18	2					1				2	
19						2	1	2	1/2	1/2	1
19a	2		2								
20	1		1	1	1	2		1	2		1/2
Family Poritidae											
21		2	2/3	5			1	2	3		
22	3	3	5	5	2	2				2	1
23	2		1	2							
24	1							1			
25				1							1
Family Siderastreidae											
26	1			1							
27										2	
28		2		2							
29						1	1	1		1	
Family Agariciidae											
30											
31	1										1
32				1						2	
33				1				2		2	1
34			1			1			2	2	2
35							1				1
36										3	
37								3	2/3	1	2
38				1				3	2		2

Table 3 (Cont.)

	Northeastern Reefs				Sheltered Cliffs								
	17		19		6		8	14	27		28		
	SH	DP	SH	DP	SH	DP	DP	DP	SH	DP	SH		
Family Fungliidae													
39	Fungiidae			1			2		2	2			
41	<i>Herpolitha limax</i>												
42	<i>Halomitra pileus / Sandolitha robusta</i>									1			
40	Non-Fungliidae (free living)												
Family Oculinidae													
43	<i>Galaxea astreata</i>												
44	<i>Galaxea fascicularis</i>			1			2	1	1/2		1		
45	<i>Achelia horrescens</i>			1					1	1			
Family Pectiniidae													
46	<i>Echinophyllia</i> (plate/encr./fol.)			1			1	2/4		2	1		
47	<i>Mycedium elephantotus</i>						2	3/4		2	1		
48	<i>Pectinia paeonia</i>			1									
Family Mussidae													
49	<i>Acanthastrea</i>												
50	<i>Lobophyllia</i> (massive)		1	3	2	4	1		1		1		
51	<i>Symphyllia</i> (massive)		1	3	1	2	1	1	1		1		
Family Merulinidae													
52	<i>Hydnophora rigida</i>							1	1/2				
53	<i>Hydnophora</i> (massive/submassive)							1	1		1		
54	<i>Merulina ampliata</i>			1				2	1		2		
Family Favliidae													
53a	<i>Caulastrea</i>								1				
55	<i>Favia</i> (submassive)		1/2	2	1	3	2	3	3	2/3	4	2	1
55a	<i>Favia stelligera</i>							2	2				
56	<i>Goniastrea</i> (submassive/encr.)			1			2	3	3		4	1	
57	<i>Platygyra / Leptoria</i>			1			1	3		2	2	1/2	
58	<i>Oulophyllia</i>												
59	<i>Diploastrea heliopora</i>						1				1		
60	<i>Leptastrea</i> (submassive/encr.)		1		2		1						
61	<i>Cyphastrea</i>						1						
62	<i>Echinopora</i>						2			1	1		
Family Caryophyllidae													
63	<i>Euphyllia</i> (massive)						1						
64	<i>Euphyllia ancora</i>												
65	<i>Plerogyra sinuosa</i>		1		1								
66	<i>Physogyra lichtensteini</i>												
Family Dendrophyllidae													
67	<i>Turbinaria</i> (plate/foliaceous)			1		1		1	2	1	2		
68	<i>Turbinaria</i> (encr./submassive)								1				

Table 3 (Cont.)

	Northeastern Reefs				Sheltered Cliffs						
	17		19		6		8	14	27		28
	SH	DP	SH	DP	SH	DP	DP	DP	SH	DP	SH
Non-Scleractinian corals											
69	<i>Tubipora musica</i>										
70	<i>Millepora tenella</i>										
71	<i>Millepora exaesa</i>										
72	<i>Stylaster</i>										
73	<i>Distichopora</i>										
83	Soft corals										
Other Coelenterates											
87	Zoanthidae										
Phylum Echinodermata											
74	<i>Acanthaster planci</i>										
76	<i>Linckia</i>										
77	Other starfish										
78	<i>Diadema setosum</i>										
79	Other sea urchins										
80	Holothuroidea										
81	Synaptidae										
82	Sponges (Phylum Porifera)										
Shellfish (Phylum Mollusca)											
84	<i>Tridacna crocea</i>										
85	<i>Tridacna maxima/squamosa</i>										
86	Small bivalves										
Algae											
88	<i>Padina</i>										
89	<i>Halimeda</i>										
90	Turf algae										
91	<i>Turbinaria</i>										
92	<i>Caulerpa</i>										
Flowering plants											
93	Seagrass										
Other: Impacts											
75	<i>Acanthaster planci</i> feeding scars										

3.3.9 Tu'ungasika Island
(Site 22)
(Refer to Figure 4a and Table 4)

Overview

Located between the southwest corner of Vava'u Island and Hunga Island, Tu'ungasika Island was the only site investigated on the open western side of the Vava'u Group. Diving is usually very difficult if not dangerous in this area because surrounding waters are subject to considerable current action. Cliffs drop steeply into the surrounding waters around much of the island.

Coral reefs

A nascent reef platform is found in the southeast corner of the island. There is limited live coral cover on the inshore reef flat, with 20–40% cover towards the edge and upper front of the narrow platform. Soft corals are abundant, and become dominant in places on the upper reef front. There is considerable topographic diversity at this site. A steep reef front drops to 6–8 m depths. Further around the island pinnacles, small canyon-like areas, a fairly large cave and a broad reef slope were encountered.

The reef slope, pinnacles and canyons support live coral cover of 60–100%, and diversity of species and growth forms—especially foliose, coral plates, encrusting corals and small massives—are high. *Acropora palifera* and *Porites rus* are dominant in certain sections. A number of corals are abundant or common, including *Turbinaria*, encrusting and foliose *Montipora* and large plates of *Mycodium*. Many other corals occurred less frequently. Large yellow gorgonian sea fans are common around the entrance to the underwater cave. The sea fans have apparently been harvested from time to time, although the amounts harvested or their uses are not known.

Further around the west side of the island, the reef drops off gradually in a broad slope with low relief beginning at about 10 m deep. This area contains 30–50% live coral cover, consisting mainly of encrusting and small massive colonies and patches of soft coral cover.

3.3.10 West Kapa Island Fringing Reef
(Site 23)
(Refer to Figure 4b and Table 4)

Overview

The northwest extension of Kapa Island, Otea Peninsula, has a low cliffed shoreline on the side facing A'a and 'Oto Islands. A narrow, intermittent fringing reef occurs along most of this area.

Coral reefs

With only 0–5% live coral cover, the fringing reef flat can be considered depauperate. It is made up mainly of corymbose, bushy and branching

Acropora. Soft corals, turf algae, filamentous algae and algal 'paint' are common on the reef rock substrate of the reef flat. The reef platform dropped off with a 1–2 m steep slope. The scarp generally has very low coral cover, but in many places bushes and thickets of *Millepora tenella* dominate.

Below the steep, short reef drop-off, a sand and rubble slope extends into the lagoon. In shallower areas the sand sometimes supports algal growth. The middle slope supports 10% or less coral cover on isolated patches of hard substrate or on reef rock outcrops. Coral cover is irregular, increasing somewhat to depths of about 12 m in some areas and then decreasing, or exhibiting the opposite tendency elsewhere on the slope. Overall, coral cover is 40–60% in the areas of coral occurrence. Common corals include encrusting *Montipora*, corymbose and branching *Acropora*, *Seriatopora*, *Astreopora*, faviids and *Millepora exaesa*.

3.3.11 South Hunga/Fofoa Islands Reef
(Site 7)
(Refer to Figure 4a and Table 4)

Overview

A reef complex extends from the southern end of Hunga Island and Fofoa Island, connecting the two islands. A barrier reef connects Fofoa Island to the two islands further south, Foelifuka and Foata, forming a semi-enclosed lagoon.

Coral reefs

A fairly wide reef platform stretches between Hunga and Fofoa Islands. The inner reef flat is a solid platform of reef rock with very little live coral cover. The outer edge of the platform supports moderate coral coverage, mainly of corymbose *Acropora*. The edge of the platform is a short steep scarp.

A series of ridges extends out from the reef platform. The ridge slopes support high levels of live coral cover. Plate and branching *Acropora* are the dominant corals, with some very large (1–2 m diameter) plates. At the time of the survey many of the plate *Acropora*, or portions of the large plates, were dead and overgrown with algae. Other abundant and common corals include corymbose and bushy *Acropora* and faviids. The coral ridges often drop steeply into 3–5 m deep sand channels which dissected the reef complex. With increasing distance and depth from the shallow reef, the sand channels open into larger patches and the coral ridges become wider. These deeper ridges have variable 20–50% live coral cover and a fairly diverse topography. Other common corals besides *Acropora* include *Galaxea*, *Montipora* and small *Porites* massives. Many of the small colonies are dead and encrusted with algae.

3.3.12 Southwest Nuapapu Island
(Site 0, 13)
(Refer to Figures 4a, 4c and Table 4)

Overview

The southwest end of the island of Nuapapu is connected to Vaka'eitu Island by an extension of reef popularly known as the 'Coral Gardens' (Site 0). The adjacent west-facing sides of both of the islands are quite steep and do not support much reef development. The east end of Vaka'eitu Island is similarly connected to Langito'o Island by reef development (Site 13).

Coral reefs

At Coral Gardens (Site 0), the lagoon (eastern) side of the reef is a broad sandy slope with 0–5% live coral cover. The shallower portion of the slope has occasional small massive corals and a zone with thickets of short branching *Acropora aspera*. The shallow reef flat is composed of bare reef rock, sand or rubble substrate, with large plate rubble predominant towards the reef crest on the more exposed western side.

The outer reef slope at Coral Gardens commences in a gradual drop. Robust corymbose *Acropora* colonies growing on the solid reef framework are common here. Below this the reef continues its gradual slope, but topographical variation is greater because of the presence of grooves in its face. Live coral cover is high, ranging from 60 to 100%, with fairly high diversity. In addition to corymbose *Acropora*, the following corals are abundant or common: branching, bushy and plate *Acropora*, *A. palifera*, *Echinopora* and *Astreopora*. Many other corals were encountered less often. The high coral cover continues to at least 15 m depth, where coral rubble becomes more common.

The reef area between Vaka'eitu and Langito'o Islands (Site 13) also supports high diversity and coverage of corals. This area is also topographically very diverse in places, with shallow reef sections dropping steeply to sand channels 2–4 m deep. Corymbose *Acropora* is abundant and massive *Porites* colonies and soft corals are common on the shallow reef and upper reef wall. Otherwise, coral cover is a variable 30–70% and consists of corymbose and branching *Acropora*, *Turbinaria*, encrusting *Montipora* and a variety of less common corals.

Towards the west the reef becomes a broader slope with moderate live coral cover and an increase in the amount of soft corals and dead standing coral. The deeper portions of the reef at this site also support abundant soft coral cover and some corals which are not common on the shallower reef, such as *Acrhelia horrescens*, *Platygyra*, *Millepora tenella*

and *Hydnophora rigida*. Three *Acanthaster planci* starfish were seen at the site and occasional feeding scars were observed.

3.3.13 Southeast Nuapapu Island
(Sites 3, 26)
(Refer to Figure 4a and Table 4)

Overview

The narrow southeast extension of Nuapapu Island supports limited fringing reef development towards Luaofa Island. Inside the sheltered embayment of Nuapapu, a series of patch reefs extend southward towards Lape Island.

Coral reefs

The patch reefs between Nuapapu and Lape Islands do not have much live coral cover. The shallow reef flat is composed of coral rubble, often cemented together, or solid reef substrate, with filamentous algae in places. Live coral cover, mainly consisting of corymbose *Acropora* on the reef crest, is only 0–2%. The patch reef slopes are characterised on one side by a sand and rubble slope. In this section of the reef the flat occasionally dropped off with a 1 m wall. The slope on the other side often had more outcrops of reef rock with some coral colonies, usually *Acropora* thickets, *Porites* mounds or *P. rus*. *Diadema* urchins were common and occasional *Acanthaster planci* feeding scars were seen. The area between the patch reefs is characterised by sand and rubble, with occasional coral mounds or outcrops of reef rock. The deeper slope of the patch reef area has somewhat increased coral diversity with depth, although live coral cover remains moderate. The lower slope supports scattered large mounds of *Porites cylindrica*, *Pocillopora damicornis* and *Millepora tenella*, along with a variety of other corals.

The small islands at the extreme southeast end of Nuapapu have fringing reefs surrounding and connecting them. The shallow reef flat is characterised by 40–60% cover of small corymbose *Acropora* colonies, with some encrusting *Montipora*. The platform becomes a series of jagged reef rock ridges that run down-slope, interspersed with broad channels scoured into the limestone substrate and covered with a veneer of sand. Coral cover is low, with occasional patches of soft coral. The ridges and channels merge into a broad slope which extends from about 2 to 10 m in depth. The primarily sand slope is punctuated by occasional *Porites* mounds and scattered corals and reef blocks, with overall coral cover very low. The reef on the south side of Luaofa Island also has generally bare substrate with 0–2% coral cover and a zone with high cover by filamentous algae. One *Acanthaster planci* was seen.

Table 4 Species Lists for Sites 22, 23, 7, 0, 13, 3 and 26

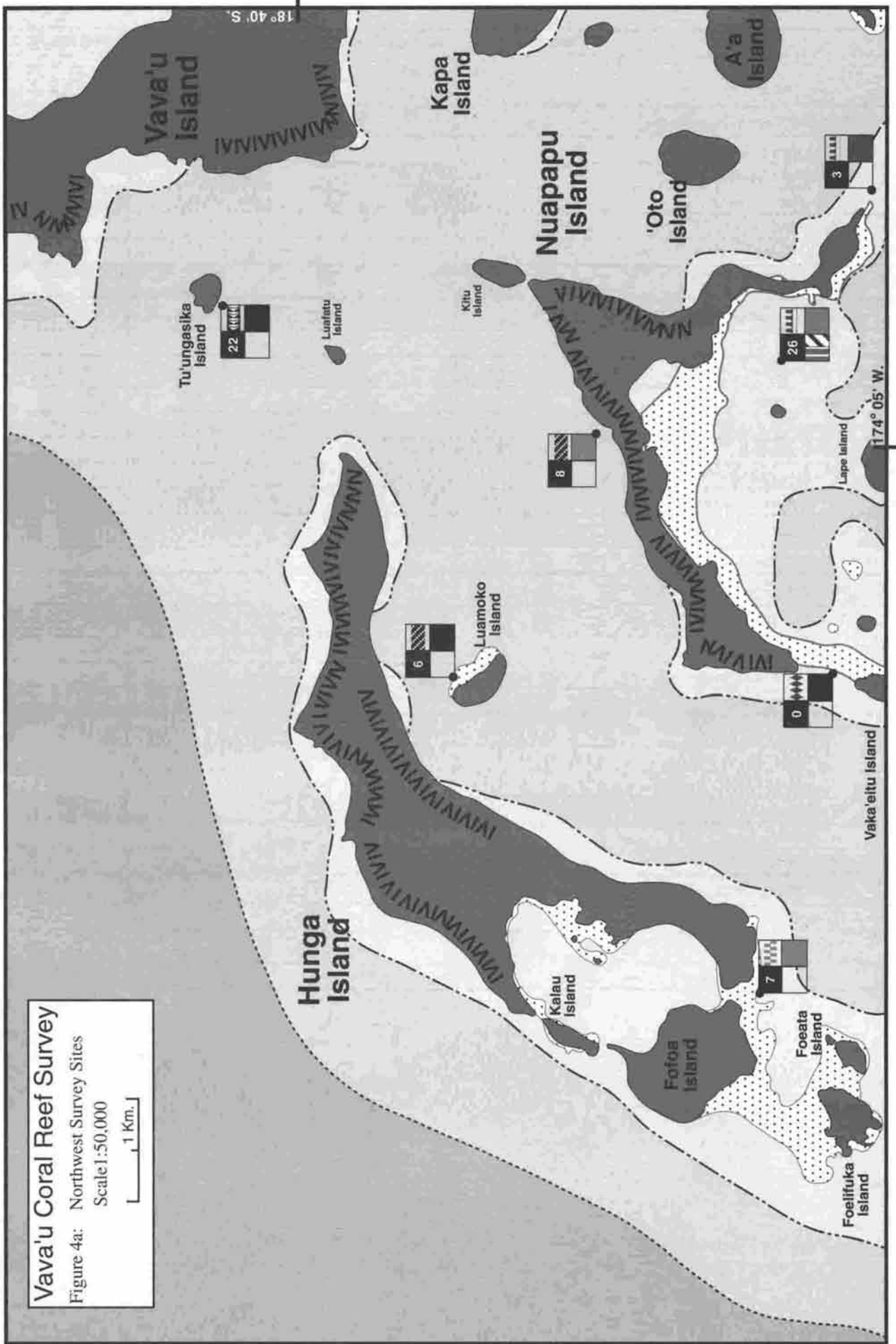
	Tu'ungasika I.			W. Kapa I.		S. Hunga		SW Nuapapu Is.			SE Nuapapu		
	22	23		7		0	13		3	26			
	DP	SH	DP	SH	DP	DP	SH	DP	SH	SH	DP		
Scleractinian corals													
Family Pocilloporidae													
1	<i>Pocillopora damicornis</i>		2		2					2	2	2/3	
2	<i>Pocillopora verrucosa</i>	2						2					
3	<i>Pocillopora meandrina</i>	2	1	2	2		2			2			
4	<i>Pocillopora eydouxi</i>	1/2			1		1	1/2		1			
5	<i>Seriatopora hystrix</i>	1	1/2	1		2		2	2				
6	<i>Seriatopora caliendrum</i>		2	4/5				2			2		
7	<i>Stylophora pistillata</i>	2		3	2		2	2	2	2		1	
Family Acroporidae													
8	<i>Montipora</i> (encrusting)	3/4	2/3	5	2	3	2	2	3	2		2	
9	<i>Montipora</i> (submassive)	1											
10	<i>Montipora</i> (plate/foliaceous)			2									
11	<i>Montipora verrucosa</i>												
12	<i>Montipora hispida</i>												
13	<i>Montipora digitata</i>												
14	<i>Acropora</i> (plate)	2		1	5		3	2			1		
15	<i>Acropora</i> (corymbose)		3				5	5		4	2/4	1	
16	<i>Acropora</i> (digitate)	2	2		4		3/4	3		4			
17	<i>Acropora</i> (branching)		3	3/4	4		3	3			3		
18	<i>Acropora</i> (bottlebrush)											1	
19	<i>Acropora palifera</i>	5		1			3	2			1		
19a	<i>Acropora aspera</i>										3		
20	<i>Astreopora</i>	2/3	1	4			3	1		1		2	
Family Poritidae													
21	<i>Porites</i> (<i>synarea</i>) <i>rus</i>	4/5	2							1	3	1/2	
22	<i>Porites</i> (massive)	5	2	1		2		4		5	2	2	
23	<i>Porites cylindrica</i>		1						1	2	3	2/3	
24	<i>Goniopora</i>			1				2	2		1/2	1	
25	<i>Alveopora</i>		1	2						1	1		
Family Siderastreidae													
26	<i>Psammocora contigua</i>										1	2	
27	<i>Psammocora</i> (submassive)												
28	<i>Psammocora</i> (encrusting)												
29	<i>Coscinarea</i> (submassive)	2					1			1			
Family Agaricllidae													
30	<i>Pavona cactus</i>												
31	<i>Pavona decussata</i>												
32	<i>Pavona clavus</i>												
33	<i>Pavona minuta</i>												
34	<i>Pavona varians</i>	1	1/2	1				2		1	2	1	
35	<i>Leptoseris</i> (plates/encrusting)						1						
36	<i>Gardineroseris</i> (submassive)												
37	<i>Pachyseris rugosa</i>			1						1	1	1	
38	<i>Pachyseris speciosa</i>	1		1							1	1	

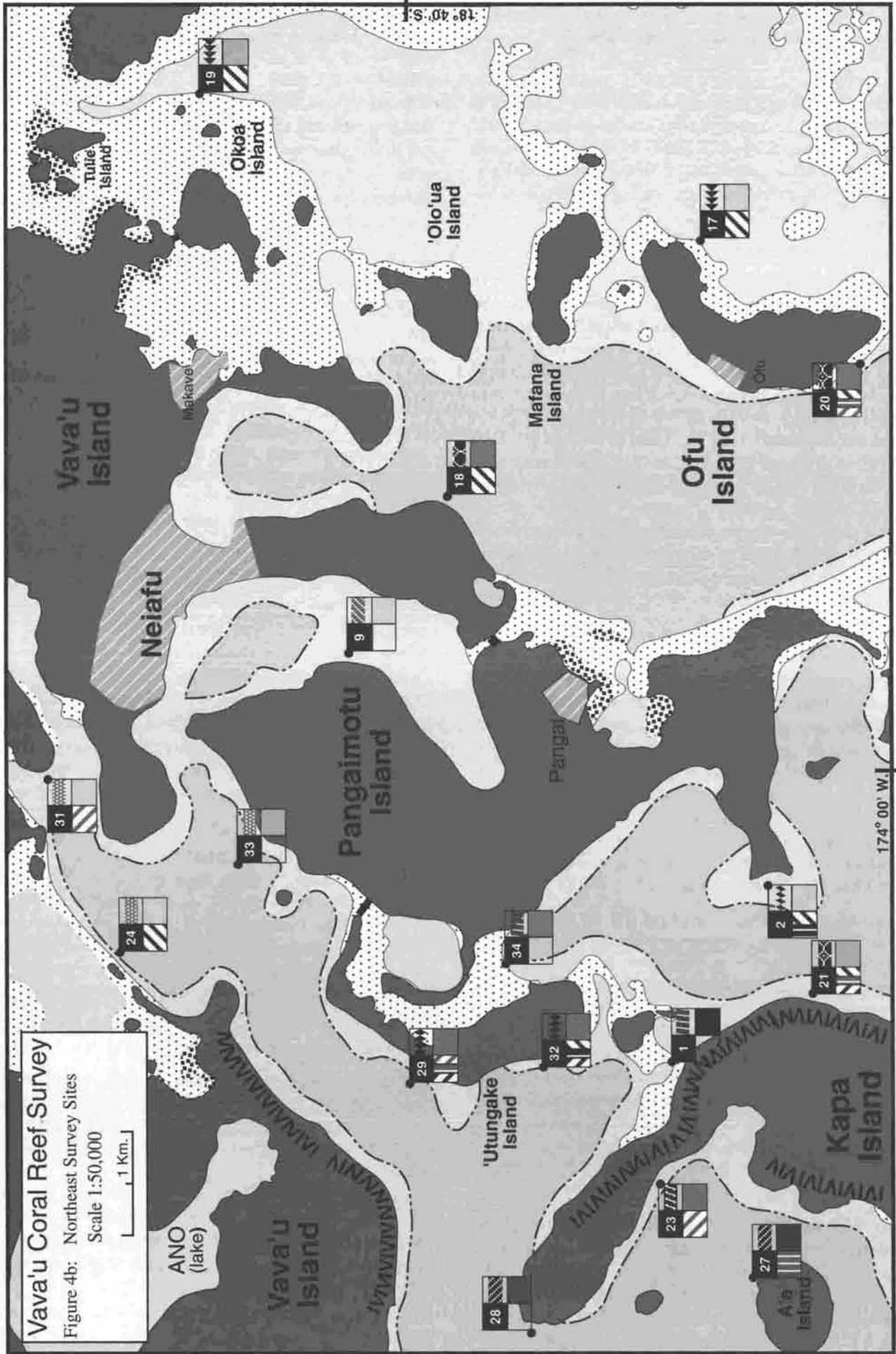
Table 4 (cont.)

		Tu'ungasika I.		W. Kapa I.		S. Hunga		SW Nuapapu Is.			SE Nuapapu		
		22	23		7		0	13		3	26		
		DP	SH	DP	SH	DP	DP	SH	DP	SH	SH	DP	
Family Fungiidae													
39	Fungiidae	1	1/2	1/2			0			2	2	1	
41	<i>Herpolitha limax</i>		1										
42	<i>Halomitra pileus / Sandolitha robusta</i>												
40	Non-Fungiidae (free living)												
Family Oculinidae													
43	<i>Galaxea astreata</i>												
44	<i>Galaxea fascicularis</i>	1/2	1	1		3	1	2	1		2	1/2	
45	<i>Achelia horrescens</i>		1	2					0			1	
Family Pectinidae													
46	<i>Echinophyllia</i> (plate/encr./fol.)	3					2	1	1				
47	<i>Mycedium elephantotus</i>	3					1		1				
48	<i>Pectinia paeonia</i>											1	
Family Mussidae													
49	<i>Acanthastrea</i>	1					1						
50	<i>Lobophyllia</i> (massive)	1		1/2		1	2	1	1		1	2	
51	<i>Symphyllia</i> (massive)	1	1/2	1/2			2	1	1				
Family Merulinidae													
52	<i>Hydnophora rigida</i>			1				2	2/3				
53	<i>Hydnophora</i> (massive/submassive)				1		1	1					
54	<i>Merulina ampliata</i>		1										
Family Faviidae													
53a	<i>Caulastrea</i>	1										1	
55	<i>Favia</i> (submassive)		1	2/3	3		2	2		4	1/2	2	
55a	<i>Favia stelligera</i>	1					1	1		1			
56	<i>Goniastrea</i> (submassive/encr.)	2					2	2		3			
57	<i>Platygyra / Leptoria</i>		1		1		2	2	3	2	2		
58	<i>Oulophyllia</i>												
59	<i>Diploastrea heliopora</i>					1							
60	<i>Leptastrea</i> (submassive/encr.)						1						
61	<i>Cyphastrea</i>												
62	<i>Echinopora</i>			2		1	4	1					
Family Caryophyllidae													
63	<i>Euphyllia</i> (massive)					1							
64	<i>Euphyllia ancora</i>												
65	<i>Plerogyra sinuosa</i>										2	2	
66	<i>Physogyra lichtensteini</i>												
Family Dendrophylliidae													
67	<i>Turbinaria</i> (plate/foliaceous)	2/3	1			1	2	2/3	1		1	1/2	
68	<i>Turbinaria</i> (encr./submassive)												

Table 4 (cont.)

	Tu'ungasika I.	W. Kapa I.		S. Hunga		SW Nuapapu Is.			SE Nuapapu		
	22 DP	23 SH DP	7 SH DP	0 DP	SH	DP	3 SH	26 SH DP			
Non-Scleractinian corals											
69	<i>Tubipora musica</i>										
70	<i>Millepora tenella</i>	1	5 4	1		2	1 3		1/2	2	
71	<i>Millepora exaesa</i>	2	4 1	2		1	1		2	1	
72	<i>Stylaster</i>										
73	<i>Distichopora</i>										
83	Soft corals	5	3	4			3 3	3			
Other Coelenterates											
87	Zoanthidea										
Phylum Echinodermata											
74	<i>Acanthaster planci</i>						1		1		
76	<i>Linckia</i>									1	
77	Other starfish	1	1							1	
78	<i>Diadema setosum</i>		1 2						3	2	
79	Other sea urchins	1	1 1				2				
80	Holothuroidea		1 1								
81	Synaptidae										
82	Sponges (Phylum Porifera)		2								
Shellfish (Phylum Mollusca)											
84	<i>Tridacna crocea</i>	2									
85	<i>Tridacna maxima/squamosa</i>	2	2				1				
86	Small bivalves										
Algae											
88	<i>Padina</i>										
89	<i>Halimeda</i>							1			
90	Turf algae		2 2						4	2	
91	<i>Turbinaria</i>										
92	<i>Caulerpa</i>										
Flowering plants											
93	Seagrass										
Other: Impacts											
75	<i>A. planci</i> feeding scars							1		2	





3.3.14 South Kapa Island Patch Reefs (Sites 4, 25) (Refer to Figure 4d and Table 5)

Overview

Just offshore of the south end of Kapa Island, a series of patch reefs extends parallel to Kapa Island for a distance of about 3 km between Nuku Island and the southernmost tip of Kapa. At the southern end of Kapa Island they merge into the wide fringing reef which extends offshore.

Coral reefs

The shallow reef flat portion of the patch reefs is generally composed of sand, rubble and hard patches, with overall low coral cover. Towards the edge of the reef flat, the eastern (windward) side of the patch reef at Site 4 has increased live coral cover, ranging from 30 to 60%. The corals are dominated by small (20–50 cm diameter) plate and corymbose *Acropora*. The reef drops off onto a 1–2 m deep terrace with 20–50% coral cover, also dominated by plate and corymbose *Acropora* colonies up to 80 cm in diameter. Other corals were occasionally or rarely encountered. Some areas of both the reef flat and the terrace are composed of reef rock occupied by filamentous algae or soft coral (*Sarcophyton*).

On the western side of the patch reef, a shallow terrace is also evident. However, on this side the terrace and upper slope are primarily composed of scoured limestone with only 0–2% coral cover, which includes a few very large table *Acropora*. On both sides of the patch reef, the middle and lower reef slopes support limited coral cover. Sand patches become increasingly common as the slope evens out towards the sand and rubble bottom at about 10 m depth. Isolated coral colonies, mainly small massives and clumps of branching *Acropora*, are found on the sand bottom.

The extended fringing reef off the southeast point of Kapa Island has characteristics generally similar to those of the nearby patch reefs. In addition to the *Acropora* on the reef flat, *Pocillopora damicornis*, *P. meandrina* and *Seriatopora caliendrum* colonies are common in this area (Site 30). The reef slope drops off more steeply, without a well-developed terrace and with only 0–5% live coral cover. However, submerged patches of reef development somewhat detached from the main reef support high coral cover with moderate coral diversity, including large colonies of massive *Porites*, *P. rus*, columnar *Pavona* and *Pachyseris rugosa*.

Site 30 was included in the survey because it was identified as an area of *Goniopora* abundance, where the coral had been harvested. *Goniopora* and *Euphyllia* were common in some parts of the lower reef, away from the main slope. In these areas there were many damaged coral colonies and the damage appeared to be relatively recent.

3.3.15 Taunga Island Fringing Reef (Site 5) (Refer to Figure 4d and Table 5)

Overview

The north end of Taunga Island has a wide sandy beach and sand spit which extends to the north. A wide fringing reef surrounds the north and west sides of the island. A large deep opening cuts through the reef in the middle of the west side of the island.

Coral reefs

The inner reef flat is primarily composed of sand and filamentous algae. *Linckia* starfish were common, and *Porites* micro-atolls were occasionally encountered in this area. The outer portion of the reef flat supports 20–40% live coral coverage, dominated by corymbose and small plate *Acropora* 20–40 cm in diameter. Reef rock substrate with turf algae occupies much of the reef crest. Other common corals on the shallow reef include small massive *Porites*, *Pocillopora damicornis*, *Pavona varians* and occasional soft coral patches. About 10–15 *Acanthaster planci* were observed on the shallow reef and some were feeding.

In places, the reef drops off with a steep or overhanging wall and live coral cover is only 0–5%. Down to about 15 m depths the lower slope is dominated by plate and branch rubble and blocks. Occasional mounds of live coral occur on the mainly dead reef slope. These include *Pachyseris rugosa*, *Goniastrea* and a scattering of other corals. A gradual sand slope and occasional branching *Acropora* are found at greater depth.

Towards the reef point at the north, the steep reef wall which forms the upper slope is less deep, in places terminating in a sand flat at 2 m depths. Towards the embayment in the fringing reef just south of the survey site, a terrace composed of cemented branch and plate *Acropora* rubble has formed. Small plate and corymbose *Acropora* colonies (5–10 cm in diameter, some up to 50 cm) are abundant on the cemented rubble, and a number of other corals have also colonised the substrate.

3.3.16 Southern/Eastern Reef Barrier: Back Reef (Sites 12, 30) (Refer to Figures 4c, 4d and Table 5)

Overview

Extensive reef platforms form a barrier system along the south and east of the Vava'u reef and island complex. The inshore portion of these reef platforms has a fairly broad slope that gradually drops off into the more sheltered waters inshore of the reefs. In the northeast portion of the reef platform (Site 30), the back reef extends in a series of shoals towards Lautala Island.

Coral reefs

The shallow portions of the back reef are composed of reef rock, rubble and sand substrate and have scattered variable coral cover of 15–30%. Bushy, plate and corymbose *Acropora* and *Millepora tenella* are common on the reef flat, and many other corals are occasionally seen. Dead standing plate *Acropora* and large plate rubble are common at both sites. Two *Acanthaster planci* were seen at Site 30 and none at Site 12, although feeding scars were occasionally encountered at both sites.

The back reef slope along the east–west reef platform (e.g. Site 12) extends broadly to about 10 m depth. A series of reef rock ridges interspersed with sand and rubble patches occurs in this area. Coral cover is restricted to the solid substrate and is generally 0–10%. Abundant and common corals include corymbose and branching *Acropora*, *A. florida*, *Seriatopora caliendrum*, *S. hystrix* and *Goniastrea*. At about 10 m depth, a gradually sloping hard ground terrace was encountered with solid

limestone substrate and occasional mounds and outcrops of coral, much of which is dead standing *Acropora* plates and bushes. Beyond this area, at about 20 m depth, higher coral cover occurs at the edge of a more well-developed reef front which drops off more steeply. Although coral cover is low overall in this area, diversity is moderately high.

The back reef slope of the north–south reef barrier (e.g. Site 30) drops steeply down to a terrace at depths of 3–4 m. This area consists of bare limestone substrate, sand, rubble, large blocks and reef rock outcrops standing 2–3 m above the surrounding reef floor. Coral cover is very low and confined to the reef blocks and outcrops. Abundant corals include the *Acropora* species common elsewhere on the back reef and massive *Porites* colonies. The back reef in this area extends in a series of shallow patches towards Lautala Island. Part of these are made up of very large (2–3 m high and 4–8 m wide), occasionally monospecific, mounds of *Pocillopora damicornis*.

Table 5 Species Lists for Sites 4, 25, 5, 12 and 30

(Note: "T.I." - Taunga I.)		S. Kapa I.			T.I.	S/E Back Reef			
		4	25		5	12		30	
		DP	SH	DP	SH	SH	DP	SH	DP
Scleractinian corals									
Family Pocilloporidae									
1	<i>Pocillopora damicornis</i>	2	3	2	3	2		5	3
2	<i>Pocillopora verrucosa</i>			1					
3	<i>Pocillopora meandrina</i>		3	2	2	2	1		
4	<i>Pocillopora eydouxi</i>	1	2		1				
5	<i>Seriatopora hystrix</i>	1		1	2		3		
6	<i>Seriatopora caliendrum</i>		2/3	3			4/5		2
7	<i>Stylophora pistillata</i>	2		2	2	2	3		1
Family Acroporidae									
8	<i>Montipora</i> (encrusting)	3	1/2	2	1	3	2	2	
9	<i>Montipora</i> (submassive)								
10	<i>Montipora</i> (plate/foliaceous)								
11	<i>Montipora verrucosa</i>				1		1		
12	<i>Montipora hispida</i>								1
13	<i>Montipora digitata</i>								
14	<i>Acropora</i> (plate)	3			6	4/5		4	
15	<i>Acropora</i> (corymbose)	5	5		5	5	4	4	4
16	<i>Acropora</i> (digitate)	5			5	5	4		
17	<i>Acropora</i> (branching)	2	2	2			5	2	2
18	<i>Acropora</i> (bottlebrush)		2	1	1				
19	<i>Acropora palifera</i>		2				1		
19a	<i>Acropora aspera</i>								
20	<i>Astreopora</i>	1		1	1		1/2		2
Family Poritidae									
21	<i>Porites (synarea) rus</i>		3	4/5					
22	<i>Porites</i> (massive)	2	1	5	2		2	4	3/4
23	<i>Porites cylindrica</i>	2	2	2	1		2	1	
24	<i>Goniopora</i>			3		2	1		1/2
25	<i>Alveopora</i>		1	1	1	1	1		
Family Siderastreidae									
26	<i>Psammocora contigua</i>	1		1	1			1	
27	<i>Psammocora</i> (submassive)		2						
28	<i>Psammocora</i> (encrusting)								
29	<i>Coscinarea</i> (submassive)				1			2	
Family Agariciidae									
30	<i>Pavona cactus</i>								
31	<i>Pavona decussata</i>								
32	<i>Pavona clavus</i>			1					
33	<i>Pavona minuta</i>								
34	<i>Pavona varians</i>	2			2		1		1
35	<i>Leptoseris</i> (plates/encrusting)				1				
36	<i>Gardineroseris</i> (submassive)								
37	<i>Pachyseris rugosa</i>		2	5	3		1		
38	<i>Pachyseris speciosa</i>	1	2	2	1				

Table 5 (Cont.)

(Note: "T.I." - Taunga I.)		S. Kapa I.			T.I.	S/E Back Reef			
		4 DP	25 SH DP		5 SH	12 DP DP		30 SH DP	
Family Fungiidae									
39	Fungiidae		2	1	2	2	1		
41	<i>Herpolitha limax</i>	1		1			1		
42	<i>Halomitra pileus</i> / <i>Sandolitha robusta</i>								
40	Non-Fungiidae (free living)		2						
Family Oculinidae									
43	<i>Galaxea astreata</i>								
44	<i>Galaxea fascicularis</i>	1	2/3	1/2		2		2	
45	<i>Achelia horrescens</i>		1				1		
Family Pectinidae									
46	<i>Echinophyllia</i> (plate/encr./fol.)				1/2				
47	<i>Mycedium elephantotus</i>				1	1	1		
48	<i>Pectinia paeonia</i>	1							
Family Mussidae									
49	<i>Acanthastrea</i>								
50	<i>Lobophyllia</i> (massive)	2	1	1	1	1	2		1
51	<i>Symphyllia</i> (massive)			1	1		1		2
Family Merulinidae									
52	<i>Hydnophora rigida</i>	1		1		1	1		
53	<i>Hydnophora</i> (massive/submassive)	1	1						
54	<i>Merulina ampliata</i>		2	3					
Family Favitidae									
53a	<i>Caulastrea</i>						1		
55	<i>Favia</i> (submassive)	2	1/2		2/3	2/3	2	2	2/3
55a	<i>Favia stelligera</i>								
56	<i>Goniastrea</i> (submassive/encr.)	2		1	3		3		
57	<i>Platygyra</i> / <i>Leptoria</i>	1	1	1	2		1/2	1	2
58	<i>Oulophyllia</i>								
59	<i>Diploastrea heliopora</i>			1			1	2	
60	<i>Leptastrea</i> (submassive/encr.)	1			1		1		
61	<i>Cyphastrea</i>	1					1		
62	<i>Echinopora</i>		1						
Family Caryophyllidae									
63	<i>Euphyllia</i> (massive)			1		1			
64	<i>Euphyllia ancora</i>								
65	<i>Plerogyra sinuosa</i>		1		1				2
66	<i>Physogyra lichtensteini</i>								
Family Dendrophylliidae									
67	<i>Turbinaria</i> (plate/foliaceous)	1	1		1	1		1	1
68	<i>Turbinaria</i> (encr./submassive)								

Table 5 (Cont.)

(Note: "T.I." - Taunga I.)	S. Kapa I.			T.I.	SE Back Reef			
	4	25		5	12		30	
	DP	SH	DP	SH	DP	DP	SH	DP
Non-Scleractinian corals								
69	<i>Tubipora musica</i>				1			
70	<i>Millepora tenella</i>			2	3			1/2
71	<i>Millepora exaesa</i>			2		1	2	2
72	<i>Stylaster</i>							
73	<i>Distichopora</i>				3			
83	Soft corals			2	2	2	2	1/2
Other Coelenterates								
87	Zoanthidae							
Phylum Echinodermata								
74	<i>Acanthaster planci</i>				3		1	1
76	<i>Linckia</i>			1		3		
77	Other starfish					1	1	
78	<i>Diadema setosum</i>				2	1	2	3
79	Other sea urchins				1	1		
80	Holothuroidea							
81	Synaptidae				1			
82	Sponges (Phylum Porifera)				3	2		
Shellfish (Phylum Mollusca)								
84	<i>Tridacna crocea</i>				1			
85	<i>Tridacna maxima/squamosa</i>			1		2	1	
86	Small bivalves							
Algae								
88	<i>Padina</i>							
89	<i>Halimeda</i>							
90	Turf algae				3		2	2
91	<i>Turbinaria</i>							
92	<i>Caulerpa</i>							
Flowering plants								
93	Seagrass							
Other: Impacts								
75	<i>Acanthaster planci</i> feeding scars				1		2	1

3.3.17 Southern/Eastern Reef Barrier : Outer Reef (Sites 16, 10, 11, 15, 35) (Refer to Figures 4c & 4d and Table 6)

Overview

An extensive reef platform that runs primarily east-west forms a discontinuous barrier south of the main complex of reefs and islands of Vava'u. The reef system extends approximately 8.5 km from Ovaka Island eastward to 'Euakafa Island and continues from 'Euaki Island a further 6 km towards the east. The reef system then extends about 7.5 km in a north-south direction, forming a barrier along the east front. Although this reef barrier is largely exposed on the east, additional reef development on the northeast provides some protection.

Coral reefs

The reef flat of the southern reef barrier is characterised by shallow reef rock substrate with patchy coral cover of 30% or less, often made up of small plate, corymbose or encrusting *Acropora* colonies, low clumps of the branching *Acropora aspera* or small massive *Porites*. Coral cover is particularly low on the reef flat on the northern end of the eastern barrier (Site 16). Away from the reef front, the reef flat becomes slightly deeper with sand and rubble patches and channels, especially on the wide fringing reef platform south of 'Euakafa Island (Site 11). These back reef zones often contain patches of branching *Acropora* and low massive *Porites* mounds. In areas where the reef front drops down to a relatively shallow (3-4m deep) terrace (e.g. Site 15), the short steep slope has 5-20% live coral cover. This is primarily composed of corymbose and branching *Acropora*, *A. humilis*, *A. formosa*, faviids and *Seriatopora caliendrum*. Dead standing *Acropora* and soft coral are common. At Site 15, the reef slope dropped down to a sand terrace at 4 m, with occasional *Porites* mounds.

On much of the southern barrier the upper reef slopes gradually down to a narrow terrace. Live coral cover on the upper slope ranges from moderate, variable cover of 20-60% to consistently high cover of 50-80%. This coral cover is mostly composed of branching, small plate, corymbose and digitate *Acropora* colonies. Other common corals include *Pocillopora verrucosa*, encrusting and foliose *Montipora*, *Stylophora pistillata*, *Seriatopora*, *Platygyra* and occasional soft corals. The upper reef slope at Site 35, in particular, has high coral coverage and a diverse coral community. In addition, the site is topographically complex because of its steep walls and intervening channels that have rubble slopes at their lower end. A disconnected patch reef of similar character occurs just off the main reef.

The reef slope of the northern end of the east-facing barrier (Site 16) is notably depauperate, with only 10% or less live coral cover primarily consisting of

Acropora and *Symphyllia*. The steep upper slope is often vertical and composed mainly of dead reef rock and large patches of soft coral (*Sarcophyton*). At 8-12 m depths, agglomerations of branching coral rubble and large block rubble dominate the lower slope. Two *Acanthaster planci* were seen in this area.

In contrast, the middle and lower slope of the southern reef barrier drops down somewhat steeply to a sand and rubble bottom at about 20 m depth. On much of the lower reef slope, especially towards the east (Sites 11,10), the coral community exhibits evidence of *Acanthaster planci* damage. These areas often have live coral cover of only 0-20%, or at most up to 40%. In contrast, this slope has large areas of dead standing coral colonies grown over with turf algae and encrusting algae. Soft corals are common. Dozens of *Acanthaster* feeding scars were noted at Site 10 and a few at Site 11. A total of 7 *Acanthaster planci* were actually seen at Site 10 and 2 were seen at Site 11.

The live coral cover of the middle and lower slope in these areas is made up of a mixed coral community, including bushy, corymbose and bottlebrush *Acropora*, *Seriatopora*; *Stylophora pistillata*; occasional large patches of *Echinopora*; fungiids; miscellaneous faviids and *Alveopora*. A large number of other corals were occasionally or rarely encountered. Sand and rubble patches are interspersed among the live and dead coral, with occasional chutes of *Halimeda* sand and coral rubble near the bottom of the slope.

The west-facing portion of the southern barrier (Site 35) did not show any evidence of *Acanthaster* damage and has high coral cover and diversity throughout the site. The reef front drops off fairly steeply, forming walls in places. These areas have primarily encrusting, foliose and plate growth forms of coral. Except for *Acropora palifera* and *Porites rus*, most of the corals are only occasional or rare. Below the steep reef front, the lower slope forms a series of hard substrate ridges separated by sand and rubble channels. Coral cover is high. *Halimeda* algae is common and *Halimeda* material forms a major component of the sand. The coral ridges extend gradually down-slope and coral cover decreases at depths below 20 m. Coral cover on the ridges is primarily open branched *Acropora*, *A. palifera*, fungiids, *Acrhelia horrescens*, *Stylophora*, *Pocillopora verrucosa*, encrusting faviids.

3.3.18 Southern Island Reefs (Site 36) (Refer to Figure 4c and Table 6)

Overview

About 15 small islands, both low islands (sand cays) and high islands, and numerous reef patches and shoals are scattered across the open southern waters of Vava'u. All of the islands are surrounded by fringing reefs, which are generally exposed to

strong wind and wave action. The leeward (west) side of one island, Fonua'one'one, was surveyed.

Coral reefs

The shallow reef flat around Fonua'one'one is a scoured platform apparently subject to considerable wave activity. The upper reef slope supports up to 50% live coral cover. This cover is in patches predominantly made up of plate and corymbose *Acropora*, and some large areas of soft coral cover.

The main reef slope drops off steeply with a series of spur and groove formations, and some grooves, with vertical walls and flat bottoms, appear canyon-like. Coral cover is high, ranging from 80 to 100% on the slope. Species diversity is also high. Abundant and common corals include corymbose, plate and bush *Acropora*; *A. palifera*; *Goniastrea*; *Oxypora*, *Fungia*; *Pocillopora verrucosa*; encrusting and plate *Montipora*; *Stylophora*; *Symphylia*; *Mycedium* and *Favites*.

Table 6 Species Lists for Sites 10, 11, 15, 16, 35 and 36

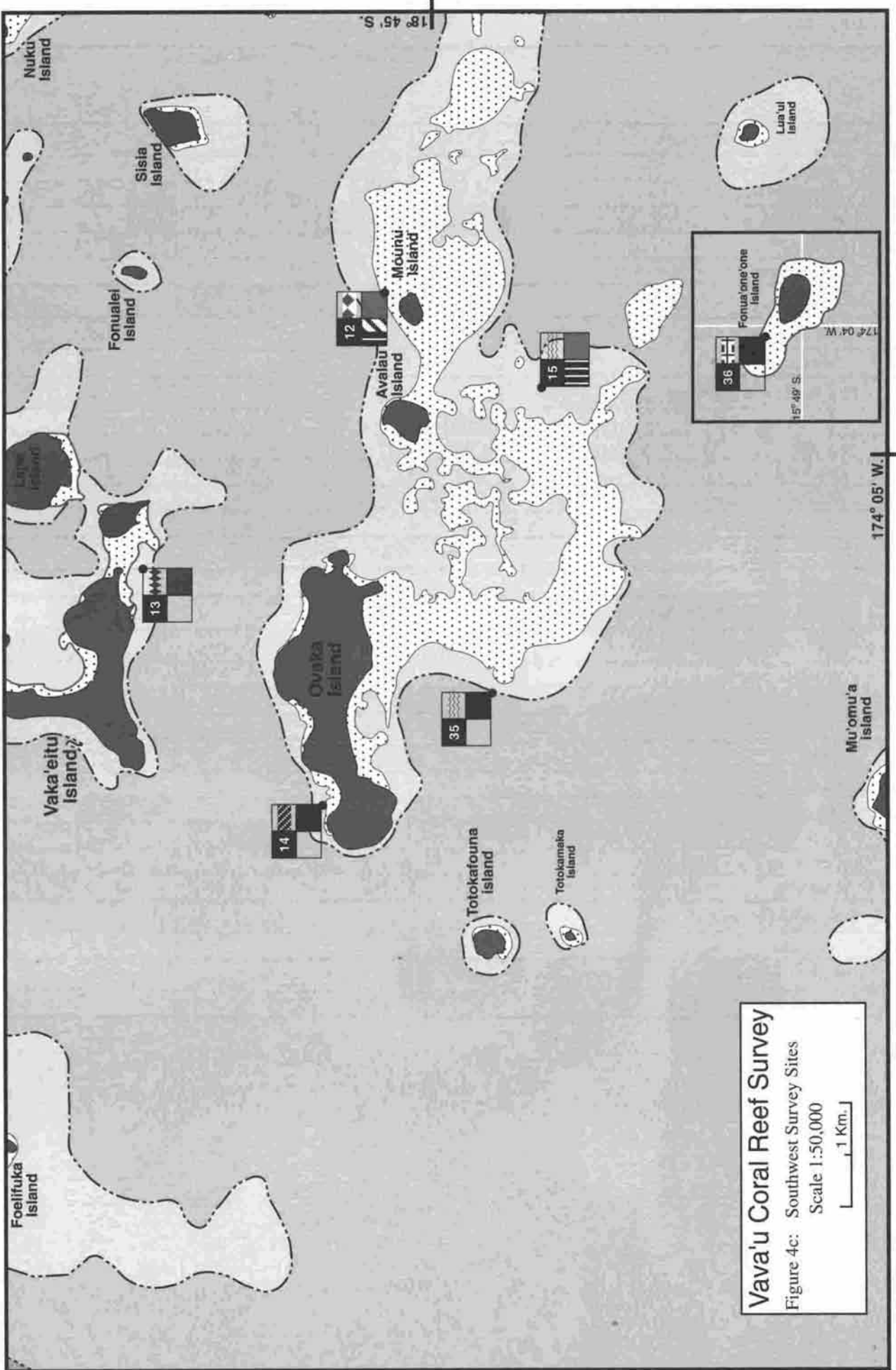
SI = Southern Island	Southern/Eastern Outer Barrier Reef										S. I. Reefs.	
	10		11		15	16		35		36		
	SH	DP	SH	DP	SH	SH	DP	SH	DP	SH	DP	
Scleractinian corals												
Family Pocilloporidae												
1	<i>Pocillopora damicornis</i>	2	1	2	1	1		1		1/2	1	2
2	<i>Pocillopora verrucosa</i>					2	1		3	3		3
3	<i>Pocillopora meandrina</i>			2	1							2
4	<i>Pocillopora eydouxi</i>					1			2	1		2
5	<i>Seriatopora hystrix</i>	3	4	2						1		1
6	<i>Seriatopora caliendrum</i>					3				1/2		1/2
7	<i>Stylophora pistillata</i>	3	4	3	3/4	2		1		2/3		3
Family Acroporidae												
8	<i>Montipora</i> (encrusting)		2	2	2	2	1	2		2	2/3	3
9	<i>Montipora</i> (submassive)											
10	<i>Montipora</i> (plate/foliaceous)		2		2				3	2		2
11	<i>Montipora verrucosa</i>											
12	<i>Montipora hispida</i>											
13	<i>Montipora digitata</i>											
14	<i>Acropora</i> (plate)		1	1			1	3	4	2	5	1
15	<i>Acropora</i> (corymbose)	5	5	5		5		5	5		5	3
16	<i>Acropora</i> (digitate)		2	4		4						3
17	<i>Acropora</i> (branching)		5	2		4			3		2	2/3
18	<i>Acropora</i> (bottlebrush)		5							5		
19	<i>Acropora palifera</i>	4	2	3				1		5		
19a	<i>Acropora aspera</i>					2						
20	<i>Astreopora</i>	1	1	1		1	1		1	2/3	2	
Family Poritidae												
21	<i>Porites</i> (<i>synarea</i>) <i>rus</i>									2		
22	<i>Porites</i> (massive)	1	2	2	4	1/2	1	2		2	2	1
23	<i>Porites cylindrica</i>											
24	<i>Goniopora</i>		1			1	1	2		1		
25	<i>Alveopora</i>	1	1		3			1		2/3	1	
Family Siderastreidae												
26	<i>Psammocora contigua</i>											
27	<i>Psammocora</i> (submassive)											1
28	<i>Psammocora</i> (encrusting)											
29	<i>Coscinarea</i> (submassive)							1				1
Family Agariciidae												
30	<i>Pavona cactus</i>											
31	<i>Pavona decussata</i>					1						
32	<i>Pavona clavus</i>											
33	<i>Pavona minuta</i>							1				
34	<i>Pavona varians</i>		1	1	1					1/2		1
35	<i>Leptoseris</i> (plates/encrusting)									1/2		
36	<i>Gardineroseris</i> (submassive)								2	1/2		2
37	<i>Pachyseris rugosa</i>		1					1		1		
38	<i>Pachyseris speciosa</i>		1									

Table 6 (Cont.)

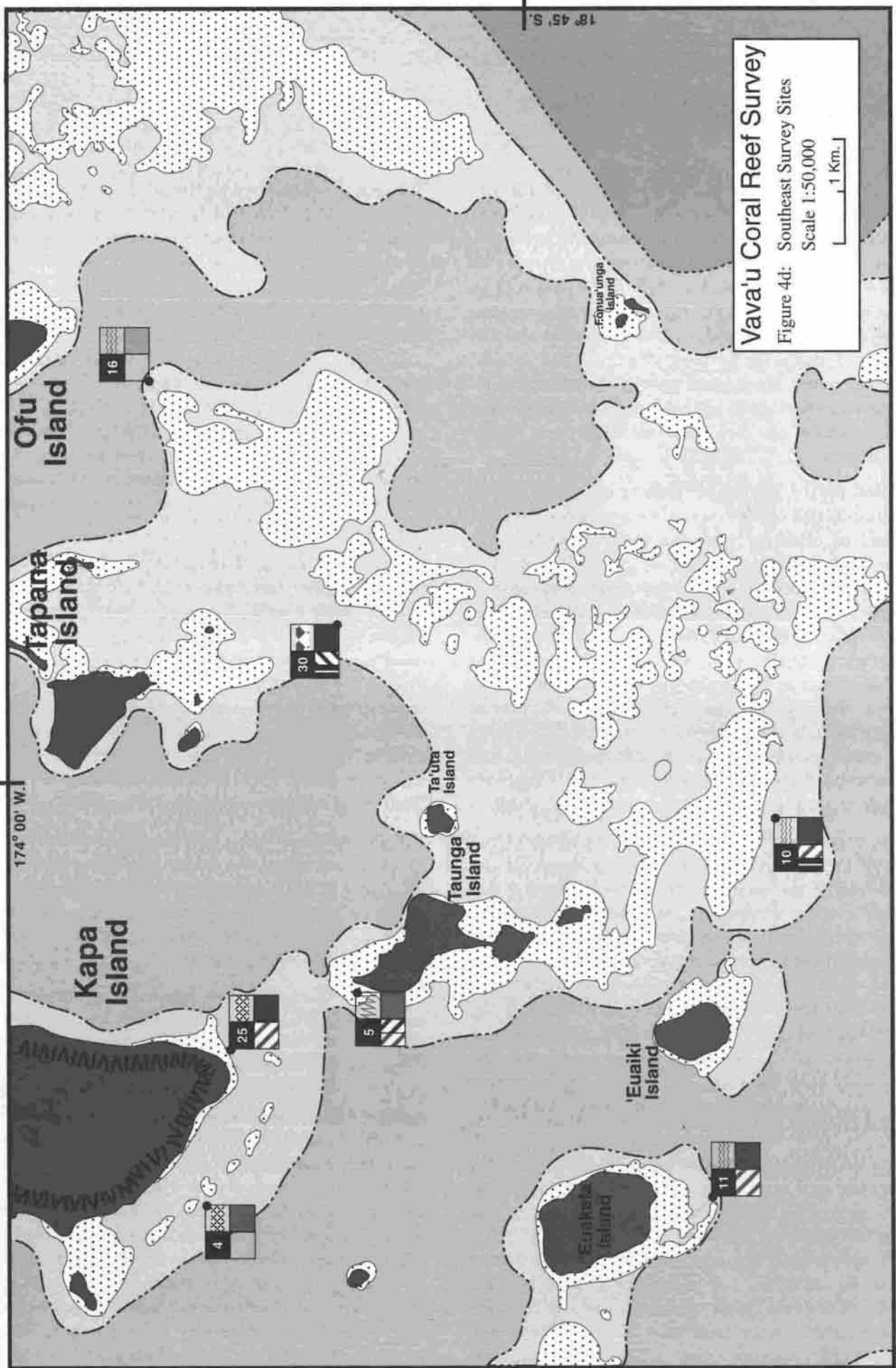
		Southern/Eastern Outer Barrier Reef										S. I. Reefs.	
		10		11		15	16		35		36		
		SH	DP	SH	DP	SH	SH	DP	SH	DP	SH	DP	
Family Fungliidae													
39	Fungiidae	2	0		2			1		3		0	
41	<i>Herpolitha limax</i>												
42	<i>Halomitra pileus / Sandolitha robusta</i>												
40	Non-Fungliidae (free living)				2							1	
Family Oculinidae													
43	<i>Galaxea astreata</i>												
44	<i>Galaxea fascicularis</i>	1	1	1					2	1/3		1/3	
45	<i>Acrhelia horrescens</i>		1					1		3			
Family Pectinidae													
46	<i>Echinophyllia</i> (plate/encr./fol.)		1						1	1/2		0	
47	<i>Mycedium elephantotus</i>		1		1					1/2		0	
48	<i>Pectinia paeonia</i>												
Family Mussidae													
49	<i>Acanthastrea</i>								1			2	
50	<i>Lobophyllia</i> (massive)	2	1		1		1			1	1	2	
51	<i>Symphyllia</i> (massive)	1	1	1	1			3	1	1	1	0	
Family Merulinidae													
52	<i>Hydnophora rigida</i>	1											
53	<i>Hydnophora</i> (massive/submassive)				1	1	1			1/2		1	
54	<i>Merulina ampliata</i>		1									1	
Family Faviidae													
53a	<i>Caulastrea</i>												
55	<i>Favia</i> (submassive)	3	2/3	2	3	2/3		2	2	2/3	2	3	
55a	<i>Favia stelligera</i>		1	1					2	1		2	
56	<i>Goniastrea</i> (submassive/encr.)	2	2	2		2		2		2		0	
57	<i>Platygyra / Leptoria</i>	2/3		2	1	1	1	1	2	1/2		2	
58	<i>Oulophyllia</i>												
59	<i>Diploastrea heliopora</i>							2					
60	<i>Leptastrea</i> (submassive/encr.)												
61	<i>Cyphastrea</i>		1									2	
62	<i>Echinopora</i>				2/3					1/2		1/2	
Family Caryophyllidae													
63	<i>Euphyllia</i> (massive)	1								1			
64	<i>Euphyllia ancora</i>												
65	<i>Plerogyra sinuosa</i>							1					
66	<i>Physogyra lichtensteini</i>												
Family Dendrophylliidae													
67	<i>Turbinaria</i> (plate/foliaceous)		1		1	1	1	1	2	2		2	
68	<i>Turbinaria</i> (encr./submassive)											2	

Table 6 (Cont.)

	Southern/Eastern Outer Barrier Reef										S. I. Reefs.	
	10		11		15	16		35		36		
	SH	DP	SH	DP	SH	SH	DP	SH	DP	SH	DP	
Non-Scleractinian corals												
69		1										
70		1	1		1	1		2	1	1	1	
71	2	2		1				2				2
72												
73												
83		3	2		3	4	4			3/4	2	
Other Coelenterates												
87												
Phylum Echinodermata												
74	2	1					1					
76					1							
77						2						
78		1	2			1						
79						1						
80		1	2		2	3						
81												
82												
Sponges (Phylum Porifera)												
Shellfish (Phylum Mollusca)												
84												
85		1	1						1			
86												
Algae												
88												
89		2						1/2	3		3	
90						3						
91												
92												
Flowering plants												
93												
Other: Impacts												
75	2	3	1		2							



Vava'u Coral Reef Survey
 Figure 4c: Southwest Survey Sites
 Scale 1:50,000
 1 Km



4. Discussion

Existing information on the coral reefs of Tonga has been summarised elsewhere (UNEP/IUCN 1988). This source notes that, although coral reefs are widespread in Tonga, reef surveys and research have been sporadic and limited. Some fieldwork on the coral reefs of Vava'u was carried out by Dawson (1971). Chesher (1984a; 1984b) investigated portions of the reefs as part of a pollution sources survey and a black coral survey. Based on the information contained in these surveys, the use and conditions of the coral reefs of Tonga were briefly summarised in a further report (Chesher 1985).

Based on the results of this survey, the coral reef communities of Vava'u can be categorised on the basis of diversity and live coral cover (Figures 4a-d). In general, sites of lower diversity and/or live coral cover occurred near the main land mass of Vava'u Island and in the eastern portion of the survey area. Sites of higher coral cover and diversity were more generally found away from the major islands and in the western portion of the survey area. However, for the most part, the complex of reefs and islands of the Vava'u area exhibited a mix of coral communities of moderate diversity and moderate live coral cover with no major patterns evident.

The current survey indicates that the coral reefs of Vava'u appear to be a mix of healthy, degraded and recovering reef communities. Degradation of the coral reefs is a result of both natural and human influences. Natural sources of degradation include the effects of wave activity resulting from cyclones and storms. Human destruction and degradation of the coral reefs of Vava'u result directly from the breakage of coral during fishing activities and indirectly from the input of increased silt and possibly chemicals (e.g. pesticides) and nutrients into the lagoon from land-based activities (Chesher 1984a; 1985).

The occurrence of *Acanthaster planci*, *Diadema* urchins and dead standing coral can be mapped based on the results of the present survey and earlier surveys (Dawson 1971; Chesher 1985) (Figures 4a-d). The presence of these indicators of reef disturbance, not surprisingly, parallels the state of the coral reefs: the disturbance factors are concentrated near land and in the eastern reef areas where coral diversity and live coral cover were found to be lower.

The lack of information on the corals and coral reefs of Tonga, and of Vava'u in particular, was highlighted by the number of coral genera or species encountered which have not been recorded for Tonga (based on distribution maps in Veron 1986). Subject to confirmation by a coral taxonomist, these records provisionally include *Seriatopora hystrix*, *S. caliendrum*, *Sandolitha robusta*, *Acrhelia horrescens*, *Pectinia paeonia*, *Merulina ampliata*, *Oulophyllia*, *Diploastrea heliopora*, *Euphyllia*, *E. ancora*, *Plerogyra sinuosa*, *Physogyra lichtensteini*, *Tubipora musica*, *Millepora tenella* and *M. exaesa*. More thorough field studies by a qualified coral taxonomist will undoubtedly lead to additional coral genera and species being recorded for Tonga.

Although the genus *Goniopora* and the closely related *Alveopora* were apparently the main target species for the coral harvest operations, the present survey revealed that both of these genera are very uncommon on the coral reefs of Vava'u (Tables 1-6). The single site at which *Goniopora* was common had extensive damage to the *Goniopora* colonies. On the other hand, massive *Porites* colonies, the other coral genus apparently being collected for export, is relatively common on the coral reefs of Vava'u and is abundant in some areas (Tables 1-6).

The 49-hectare Pangaimotu Reef Reserve is one of seven protected areas in Tonga (SPREP 1993). Three additional marine protected areas have been proposed for the Vava'u group, surrounding the islands of Tu'ungasika, Maninita and Vaka'eitu (Kelleher & Blakely 1995).

Although not a primary objective of this survey, the information gathered in this first area-wide inventory of the coral reefs of Vava'u forms part of the basis for more comprehensive coastal management planning for Vava'u, especially if resource-use information were gathered to supplement the survey. In particular, the results could be used to assess the value of the proposed protected areas and identify additional sites from among the especially diverse and healthy coral reefs of Vava'u that merit protection. Protected areas can be supplemented by other forms of marine resource and area management that help to ensure resource sustainability. Maintenance of healthy reef zones is important because they may be serving as "seed areas" that assist in the recovery of areas subject to various forms of degradation.

5. Conclusions and recommendations

The coral reefs of Vava'u support a mix of healthy, degraded and recovering coral communities. Sources of reef degradation include both human-induced and natural factors, although there may be some synergistic interaction between them. Human-induced degradation includes land-based pollutants (sediment, pesticides, other chemicals, nutrients, etc.) and resource exploitation (particularly destructive fishing practices whereby coral colonies are destroyed). Natural factors include cyclone damage, infestations of the coral-eating crown-of-thorns starfish (*Acanthaster planci*) and infestations of the *Diadema* sea urchin.

As elsewhere in the South Pacific, the coral reef habitat is the basis for inshore fisheries and provides other materials and services to the people of Vava'u. These include protection from storm and cyclone wave action, a source of sand and aggregate material and a recreational attraction for tourists and residents. The coral colonies of the reefs of Vava'u themselves form the essential building blocks of the reef, the living habitat for reef fish and invertebrates and the basis of the beauty and complexity of a reef which attracts tourists and divers. Legally, the coral reefs of Vava'u and their resources are the property of the Kingdom of Tonga and its people and are thus to be used wisely for the benefit of everyone.

In general, therefore, it is impossible to justify the removal of coral colonies for the short-term economic benefits of a commercial enterprise owned by a few individuals. However, if a strict permitting system, based on a specific inventory and management plan, and with frequent monitoring and surveillance, were imposed, the removal of limited numbers of reef corals might be allowable. Nonetheless, the results of this survey reveal that many of the coral communities of Vava'u are under stress due to a series of human-induced and natural factors.

It is therefore recommended that:

1. The harvesting of live coral not be allowed on the coral reefs of Vava'u.
2. If harvesting of live coral is proposed for any reef areas in Tonga, the proposal should be subject to an Environmental Impact Assessment and should be evaluated using the Environmental Guidelines for Coral Harvesting in preparation by SPREP.
3. The results of the survey should be used to identify potential coral reef reserves and marine park areas for Vava'u.
4. In the long term, the development of a comprehensive coastal management plan for Vava'u is required to ensure the conservation, management and sustainable use of the coral reefs and reef resources of Vava'u.

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