South Pacific Regional Environment Programme

SPREP Reports and Studies Series no. 84

Palolo Deep National Marine Reserve:

A Survey, Inventory and Information Report

by

Edward R. Lovell

and

Foua Toloa

Original Text: English

Published in November 1994 by:

South Pacific Regional Environment Programme
P.O. Box 240
Apia, Western Samoa

Printed by:
Commercial Printers
Apia, Western Samoa

P 38 / 94 - 2C

Printed with financial assistance from the **Government of Australia**

Layout by **Wesley Ward**, SPREP.

Edited by **Joy Heenan**.

Front cover photograph: aerial photo of Palolo Deep.
Western Samoa Department of Environment and Conservation.

SPREP Cataloguing-in-Publication Data

Lovell, Edward R.
Palolo Deep National Marine Reserve: a survey, inventory and information report / by Edward R. Lovell and Foua Toloa. - Apia, Western Samoa : SPREP, 1994.

iv, 88 p. ; 29 cm. (SPREP report and study ; no. 84)

Includes references.
ISBN: 982-04-0111-9

1. Marine reserves - Western Samoa 2. Environmental Policy - Western Samoa 3. Conservation of natural resources. I. Title

363.70723

South Pacific Regional Environment Programme

SPREP Report and Study Series no. 84

Palolo Deep
National Marine Reserve:

A Survey, Inventory and Information Report

by

Edward R. Lovell
Biological Consultants, Fiji
Lami, Fiji.

and

Foua Toloa
Field Consultant
Apia, Western Samoa

Published in September 1994
in Apia, Western Samoa

Foreword

The Palolo Deep National Marine Reserve was one of the first Marine Reserves to be established in the South Pacific. Its location adjacent to Apia Harbour, with easy access for Apia residents and tourists staying at the main hotels, makes it a valuable resource for Western Samoa.

This document provides the results of the first detailed survey and inventory of the Palolo Deep. In the process of collecting the information, staff members of the Western Samoa Division of Environment and Conservation (DEC) were trained in basic marine survey, data collection and analysis techniques. Long term monitoring sites were established during the project to enable the DEC staff to record changes in the Palolo Deep Marine Reserve area over time. With the expected increased use of the Reserve by Apia residents and tourists alike, it is essential that this monitoring programme is in place. The information contained in this report was used by the DEC staff to prepare a detailed management plan for the Palolo Deep Marine Reserve.

I would like to acknowledge the financial support provided by the Australian International Development Assistance Bureau through SPREP's Coastal Management and Planning Programme. In addition, I would like to thank the many people who have contributed to this project. SPREP encourages the Western Samoa Government to continue the process of developing and implementing a management plan for the Palolo Deep Marine Reserve.

Vili A. Fuavao

Director

Contents

1. Summary

1.1 Introduction

The Palolo Deep Marine Reserve is a fringing reef encompassing a lagoon comprising a total area of 137.5 hectares. The area was initially formalised as a Marine Reserve in 1974 under the National Parks and Reserves Act though no management plan had been prepared. This report is to provide a greater understanding of the marine environment within the Reserve. A basic inventory and classification of the marine environment was undertaken together with provision for continued monitoring.

The project was principally one of coral reef description and secondarily a training programme in the techniques of biological survey. Transects were used to detail the occurrence of coral, algae, fish, sea urchins and substrate. Species inventories were developed for hard coral, fish, molluscs and algae. General features of the habitat such as current, depth, profile, community type and dynamics were described. Monitoring sites were established as a means of assessing change in the reserve. Interpretive material, through specimen collection and photography, was compiled. The bathymetry was detailed.

Aerial reconnaissance was employed to assist in the development of the present survey and to complement the historical aerial photographic record. Impacts of cyclones, sedimentation and the proposed Apia sewage outfall are discussed and management recommendations made. Video footage, for archival and interpretive purposes, provided a habitat record of the Palolo Deep with particular reference to the monitoring sites.

The Palolo Deep Marine Reserve Project will also take part, through the collection and dispatch of reference material, in the revision of the genus *Acropora* through the *Biogeography of the Coral Genus Acropora Worldwide* being conducted by Dr. Carden Wallace of the Museum of Tropical Queensland, Townsville, Australia. Additionally, samples of the crown-of-thorns starfish, *Acanthaster planci*, were sent to Dr. Leon Zann of the Great Barrier Reef Marine Park Authority to assist the continuation of work conducted in Western Samoa.

1.2 General Assessment

Palolo Deep is a thriving and diverse coral reef. As a Marine Reserve it is a good example of a variety of habitats. Its public appeal lies in its access and as an example of a protected coral reef area where marine life exists in natural abundance. It serves the surrounding reefs as an important source of recruitment for fish stocks and in the re-establishment of marine life after cyclones. Despite the lack of public funding, the proprietors of the Reserve are responsible for developing facilities for the public and providing protection for the Reserve.

1.3 Environmental Impacts

1.3.1 Cyclones

Cyclones are part of the climatic environment within which the Reserve develops. All habitats are conditioned by their occurrence. The major cyclone Ofa has had a pronounced effect on the reef with the total removal of coral fauna from the seaward reef slope. Tons of rubble were deposited on the reef and the fauna elsewhere on the reef flat was severely affected. Good recruitment is occurring on the seaward reef slope. The eastern reef flat has developed good luxuriance as the result of recolonisation by fragmentation and new settlement.

The Deep has proved to be a haven during this period with little damage sustained during this severe storm. Coral spawning the following year, as indicated by prolific recruitment on the seaward slope, was most probably due to such protected areas.

1.3.2 Sedimentation

Chronic sedimentation represents the most serious threat to the nature of the Palolo Deep. A reduction in the depth at which coral can survive is evident from many large dead coral heads that occur deeper than coral presently grows. The water clarity is chronically affected by suspended silt.

The fine bottom sediments are evidence of the process of silt capture as the result of terrestrial run off. A plume of silt from the Vaisigano river was observed along the western reef. Unless this situation stabilises, the composition of the fauna and flora of the Reserve will change. A community dominated by algae with a reduction in general diversity would be likely.

1.3.3 Sewage

Of considerable concern is the proposed sewage outfall. As with the capture of silt, effluent entrapment is likely to occur. This effluent may affect the Reserve in terms of elevated nutrient levels which both retard the growth of coral and promote the proliferation of algae. This results in a change in the biota where the algae overgrow and/or displace the coral. There is a consequent change in the fish fauna with larger numbers of herbivorous fishes. The environment is aesthetically degraded.

Of potentially greater concern is the possibility of health threatening organisms polluting the Reserve making it unsafe for swimming. Toxic elements may concentrate in the Deep. The main problem with the proposed outfall is its proximity to the Deep. This is of particular concern as during the summer season the wind blows directly from the outfall toward the Reserve. Further investigation is required as the value of this important natural resource and recreational site may be greatly diminished.

1.3.4 Crown-of-thorns Starfish or alamea (*Acanthaster planci*)

Though several episodes of *Acanthaster* infestation and consequent coral reef destruction have occurred in Western and American Samoa, there is no threat at present in the Palolo Deep. Though higher than normal numbers do exist, they are not adversely affecting the reef. As a tourist interest, they should be considered an asset. There are few coral reef animals as impressive as these starfish with their large spines and size, and bright colouration.

1.4 Recommendations

- ⇨ *Visitor information about the Palolo Deep should be provided on entry (coral reef ecosystem description, map, regulations, hazards).*
- ⇨ *Develop a commercial shop to better cater for the visitor and to generate revenue.*
- ⇨ *Promote the Deep as an ecotourism venue through promotion by the Visitors' Bureau and tourist interests. Develop a formal ecotourism programme with interpretive display material.*
- ⇨ *Develop an educational programme involving excursions by local schools to the Reserve to foster a better understanding of coral reefs and their importance.*
- ⇨ *Provide access to the Deep for the convenience of visitors.*
- ⇨ *Provide an inshore attraction for those unable or not inclined to visit the Deep by developing an inshore pool, complete with coral and a variety of biota from other parts of the Reserve.*
- ⇨ *Regulate usage to protect the more fragile areas of the Reserve.*
- ⇨ *Upgrade conveniences and the reef platform.*
- ⇨ *Provide assistance to the management in their task of policing the Reserve.*
- ⇨ *Continue an on-going monitoring programme to assess changes in the Deep and to provide a greater understanding of the dynamics of the Reserve.*

2. Methods

2.1 Field Methods

Initial reconnaissance of the Palolo Deep Marine Reserve allowed intuitive decisions to be made as to the definitions of the general habitats and areas of interest. A survey strategy was then developed to best describe these environments.

Surveying was by means of manta tow observation (Done et al. 1981; Done 1989), and line and belt transect methods (Marsh, Bradbury and Reichelt 1984; De Vantier et al. 1985). The methods were adapted to the survey of marine benthos following Done (1989, 1991). Qualitative information was gathered by swimming and walking.

2.1.1 Line Transects

The 20 metre transect lengths were linked, as required, to provide a reasonable sample for the description of the habitat. The transect line was laid with regard to habitat features to be described. Before the line transects could be run, familiarisation of the benthic elements was required. This was accomplished by compiling a reference collection and by constant verification in the field concerning identifications. Abbreviations of the names of benthic items or attributes were used to provide consistency and facilitate data entry.

Survey was by SCUBA and snorkel. Data was recorded on plastic sheets or underwater paper. Where possible, the origin or end of the measuring tape was placed at a point relative to a buoy base or monitoring transect stake. This would allow a more exact repositioning in replicating the transect. Readings were taken along the tape where there was a change in the underlying benthic attribute. Attributes comprised species or generic presence, dead coral and uncolonised substrate. These were measured to the nearest centimetre. The categories generally considered were *coral*, *algae* and *substrate*.

2.1.2 Belt transects

Due to the aggregated distribution of sea urchins, the small but numerous newly settled coral colonies, and the transient nature of fish, belt transects were used to assess their abundances. As with the line transect, a tape was laid over the substrate. This was usually 20 metres in length though the abundance of coral settlement in some areas limited the survey to a much shorter length due to the difficult conditions of survey. A width was decided upon to best provide a meaningful measure of the organisms to be assessed. In the case of coral settlement and sea urchins a one metre width was used. In the case of fish it was two metres.

2.1.3 Specimen collection and identification

Coral was collected both for reference and display. Specimens were collected and tagged with information describing their locality, depth, date of collection and other relevant details. They were bleached until clean in a 5% solution of household bleach (swimming pool chlorine: sodium hypochloride), washed, dried and catalogued.

Coral specimens to be used in the Reserve for educational display were photographed *in situ* so that comparisons could be made between the living organism and its display skeleton. Reference specimens to be identified by the Museum of Tropical Queensland were collected in duplicate, allowing identification of the Reserve material to be made retrospectively.

Temporary collection or field descriptions were made for other taxa to provide consistency in identification during the transect survey and general inventory. Reference books (see 10.2) provided identification. Photographs were taken for interpretive display and subsequent reference.

Specimen information and arm samples were taken from the *Acanthaster* population. The samples were preserved in alcohol and sent to Townsville, Australia for assessment.

2.1.4 Monitoring programme

Monitoring sites, designated as *Sites 1-4,* were established to provide a detailed description of small reef areas. They consisted of one metre square quadrats

which were placed at 10m intervals along the line or belt transects. At sites 1-3, the quadrat detail was described in the field. The sites were photographed using a Nikonos 15mm lens and a square metre framer to allow subsequent monitoring replication. A set of the photographs was laminated for use as a visual framing reference allowing accurate re-photography of the monitoring sites. This is essential for a useful comparison.

2.1.5 Bathymetry and currents

The bathymetry was detailed from transect records, soundings, and comparison of aerial photographic features with known depths. The bathymetry of the seaward slope was treated in a general manner as time did not allow description of the channelled relief.

The profiles have been constructed to provide a semi-quantitative appreciation of the bathymetry of the reef zone. They represent a summary of information derived from the transects which are numerically listed after the habitat headings in Section 3. The habitat zones are defined in Figure 3. The position of the profile, within a particular reef zone, is designated as a broken line in Figure 5. Its orientation is further explained by the locational information below the x-axis. The profile section is an adaption of the information contained in Figures 4 and 5. It reflects the bathymetry described in Figure 4 and requires an understanding of the zones in Figure 3.

The assessment of the current structure in the Marine Reserve is of a qualitative nature. Information was derived, generally, from field inspection as part of the transect information. Reference to seasonality was derived from anecdotal information.

A helicopter from a local operator was used for aerial photography, to provide a more complete understanding of biological and geographical features.

2.1.6 Underwater photography

Habitat and specimen shots were taken with Nikonos underwater cameras. This involved the use of extension tubes and close-up lenses for the macro photography, a 15mm lens for habitat and assemblage shots, and an SB 102 flash.

A video record of the Palolo Deep environment was made using a Sony Hi-8 Camcorder and underwater housing. The unit had autofocus and exposure, as well as wide angle and macro lenses. The raw tape was kept for archival purposes. An edited version was developed for a more manageable and informed description.

2.2 Data Analysis

Information from the line and belt transects was entered into a Lotus-123 spreadsheet programme with respect to *number of records, relative coverage and composition, mean, standard deviation, maximum and minimum occurrence, percent coverage* and/or *density* for each habitat. Macros, a spreadsheet feature, were written to facilitate cursor movement and minimise keystrokes. Details of these and the general use of the programme are found in Annex 12.1.2.

The pie graph representation of the percentage composition is taken from the table summaries. These can be enhanced either through the WYSIWYG add-in programme or ported through the programme *Slide* (see Annex 12.1). The algal categories have been clumped into red, green and brown. The coral names have been arranged by genus. The substrate is clumped to reflect the range of types without confusing definition.

Consistency in recording can be difficult in a survey conducted by several individuals. This problem was minimised by instruction, verification of the attributes, and comparison of results. As data entry requires an ordered format, the transect data was checked for consistency on entry and at the first data-sort.

3. The Composition of Palolo Deep: Habitat description

The nature of the reef system is consistent with current reef formation theory, involving the balance of present physical and biological processes together with changes in sea level. Its zonation conforms to general reef development within the context of environmental change. This includes such short term considerations as cyclones, mid-term changes such as sedimentation, and the longer term processes such as eustasy and tectonism (Connell 1973; Chappell 1980, 1981; Purdy 1974).

This area is unique in that it is subject to tectonism with substantial land movements; its volcanic history involves lava overlaying reefs. In addition, the occurrence of the largest cyclone in a hundred and fifty years (Ofa, Feb. 1990), followed by a major one (Val) the following year, have had a pronounced effect on the present condition of the reef.

Fig. 1 shows the location of the Palolo Deep Marine Reserve. An aerial photograph shows the Palolo Deep Marine Reserve (Fig. 2). The location and extent of the general zonation is shown in Fig. 3. The bathymetry is shown in Fig. 4. The position of line and qualitative transects is shown in Fig. 5. The habitat photos show representative views of the area in Fig. 6a-p.

The following sections describe the seven major habitat zones: Inshore Reef Flat; Eastern Reef Flat; Western Reef Flat; Southern Palolo Deep; Transverse Ridge and the Main Palolo Deep; the Seaward Reef Flat; and the Seaward Reef Slope. The descriptions comprise details of location, exposure, depth, profile, substrate, algae, coral, community type, and biological and physical dynamics. Line and qualitative transect information is incorporated in the text as well as in a summary table. A pie chart diagram details the percentage composition.

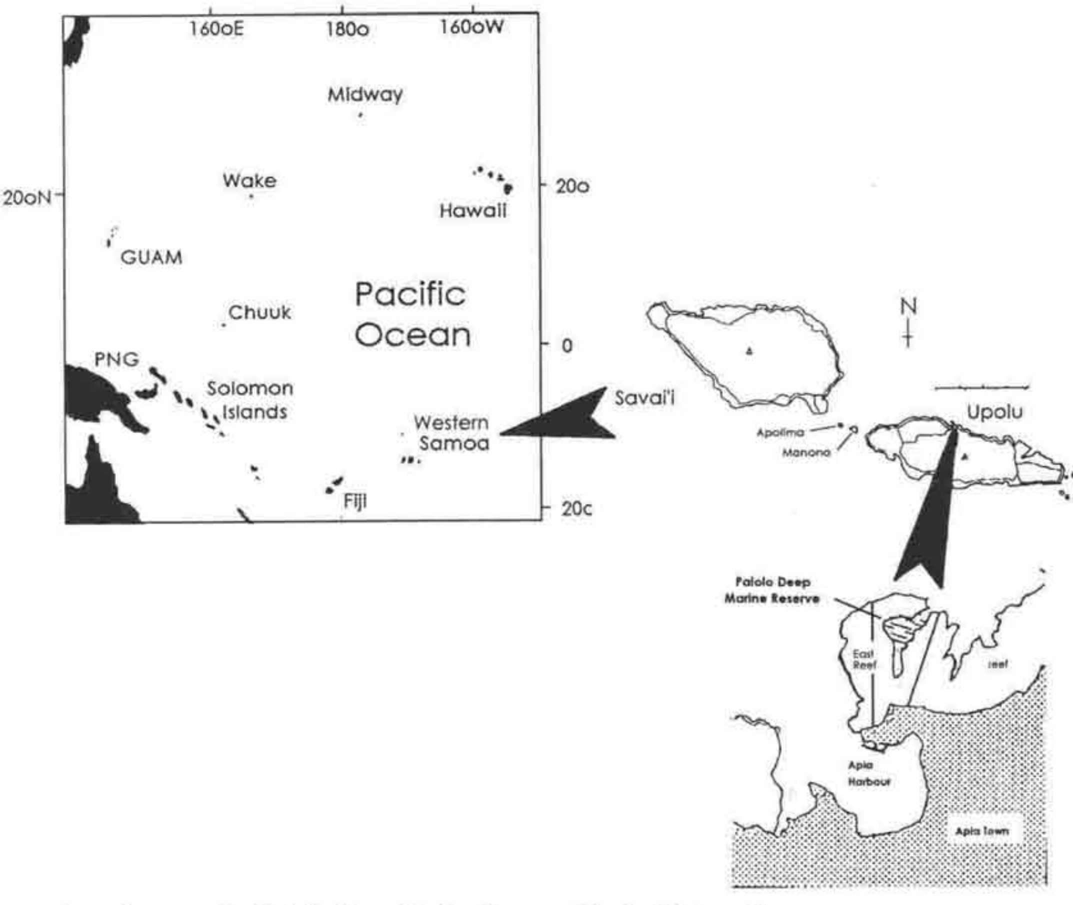


Fig. 1: Location map for Palolo Deep Marine Reserve, Upolu, Western Samoa.

Fig. 2: Aerial photograph of the Palolo Deep Marine Reserve.

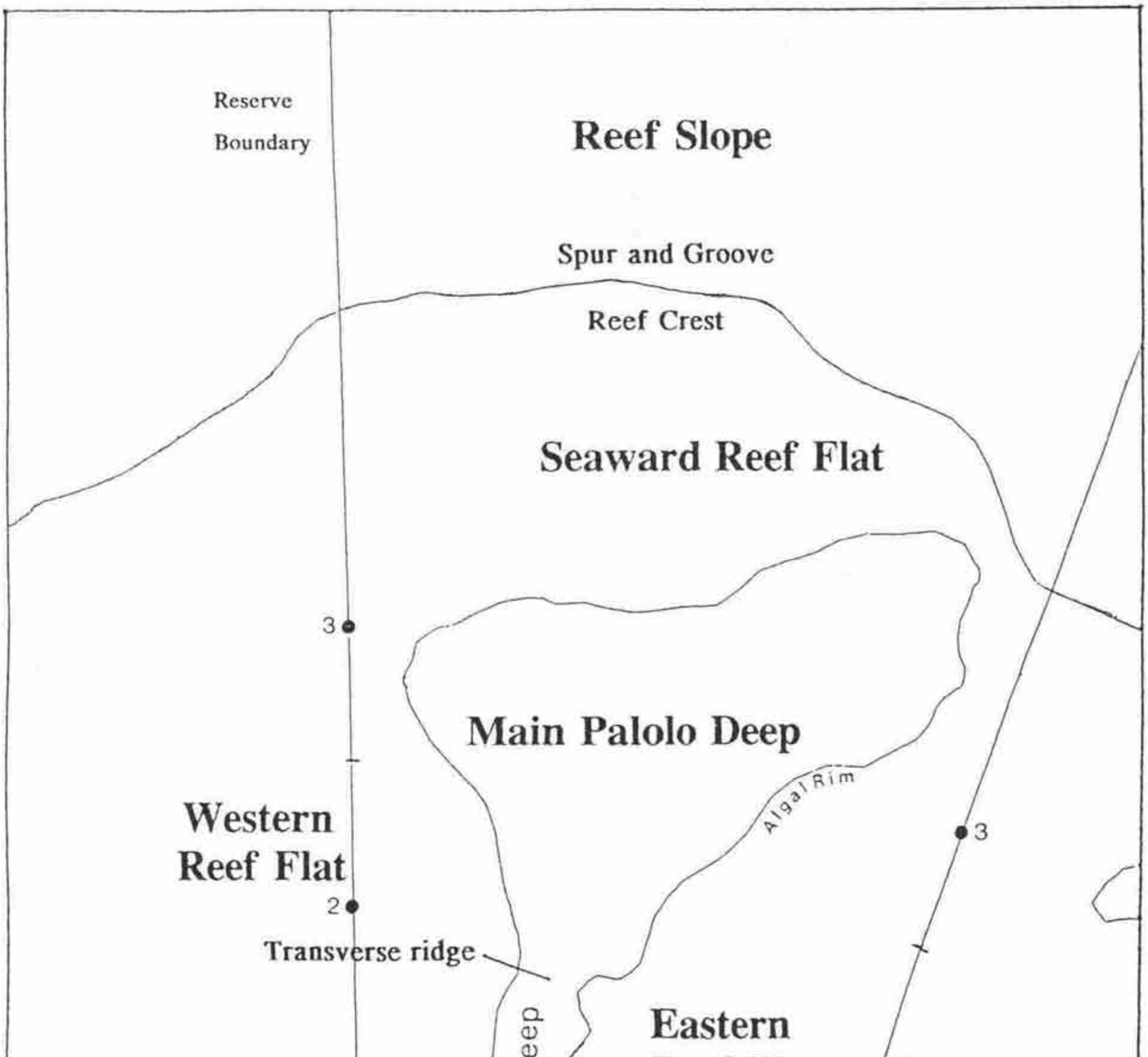


Fig. 3: General habitat zonation in the Palolo Deep Marine Reserve.

Boundary marker buoys are numbered.

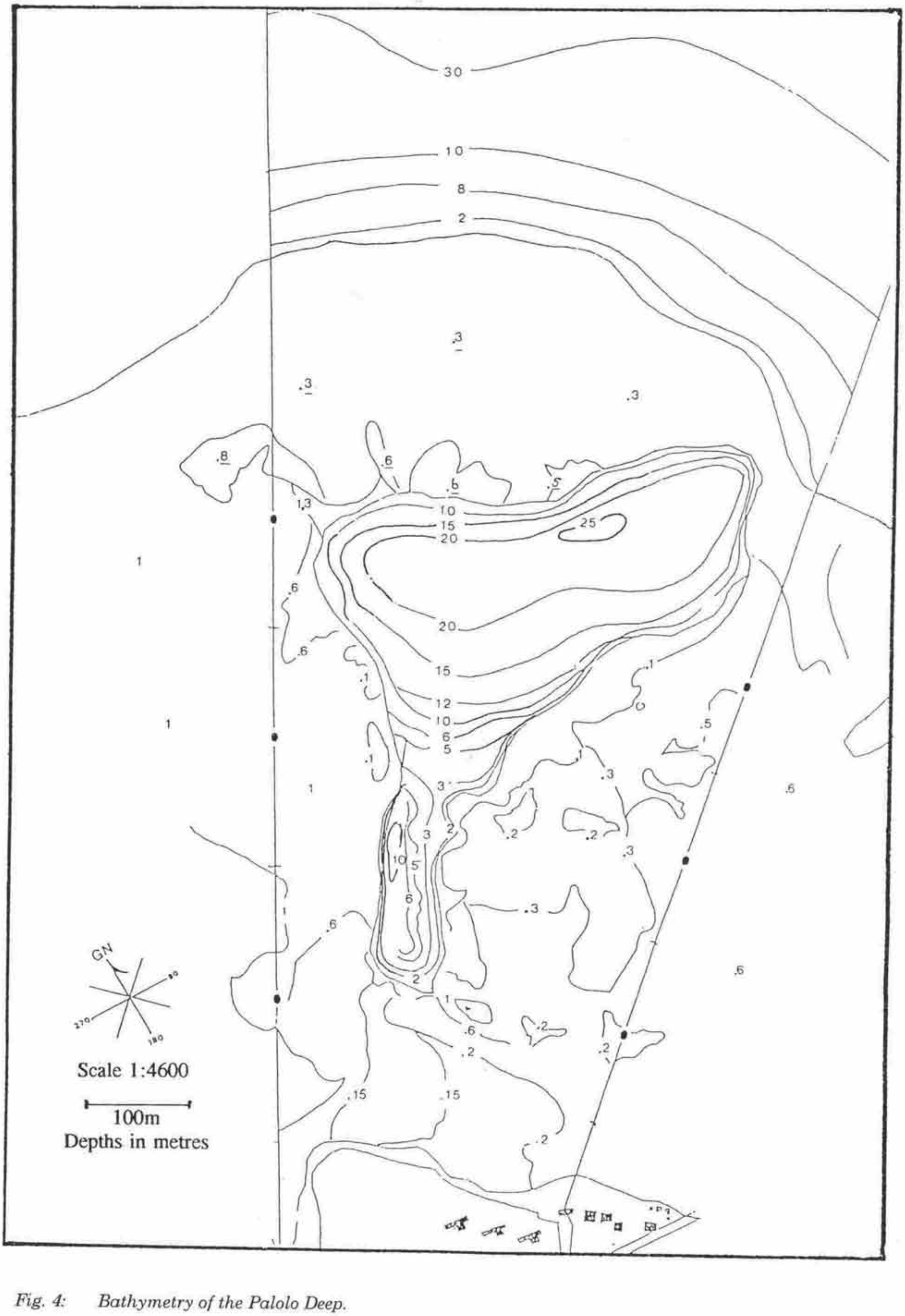


Fig. 4: Bathymetry of the Palolo Deep.

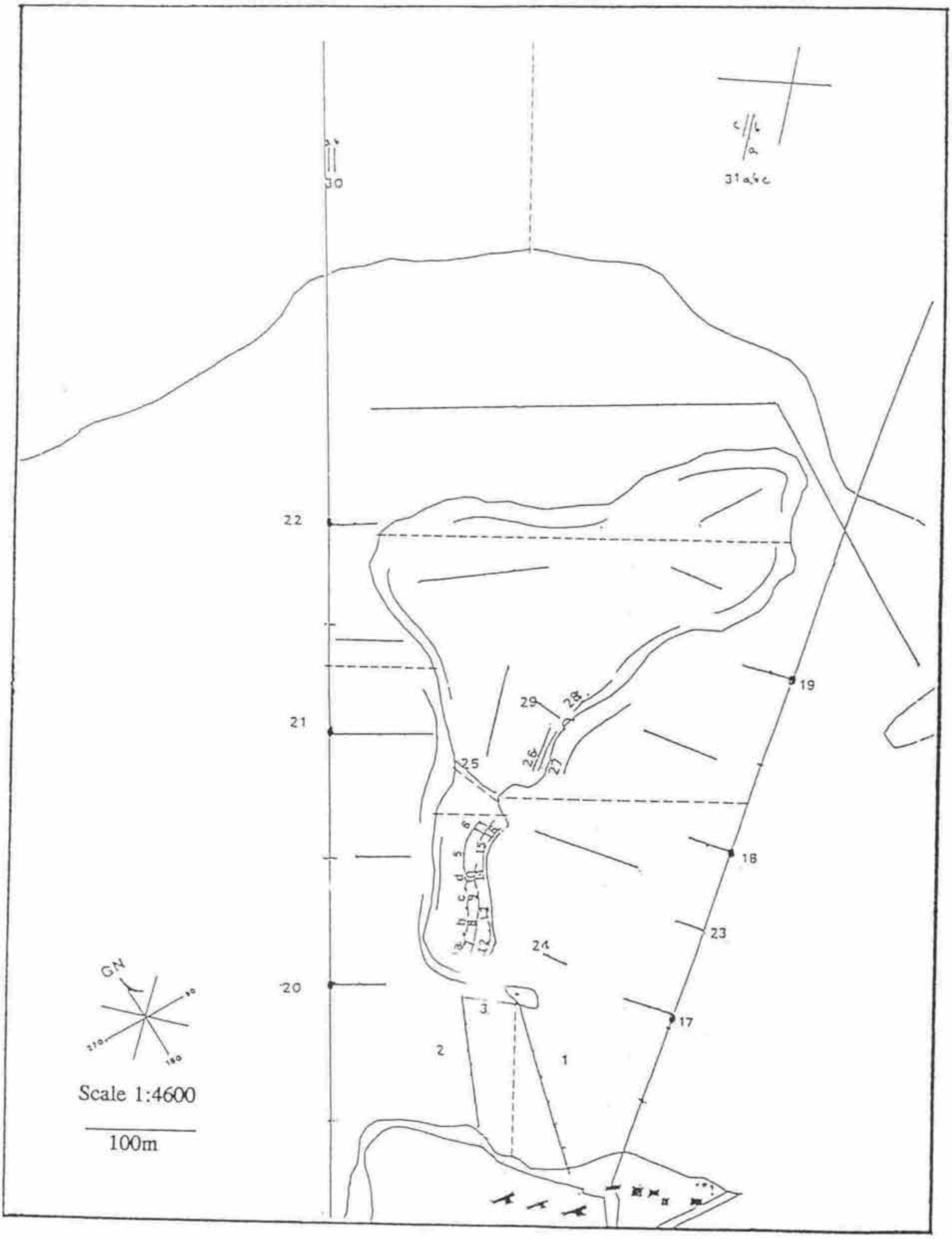


Fig. 5: Position of the line transects (numbered), qualitative transects, and bathymetry profiles (designated by broken lines).

Fig. 6: *Habitats of the Palolo Deep:*

Index:

a) An overturned Porites lutea *bommie on the Western Reef Flat.*

b) A luxuriance of coral growth on the Eastern Reef Flat north of the platform.

c) An impoverished North-eastern Reef Flat, with less coral cover and more Dictyota sp.

d) Clumps of Dictyota sp. *growing on the Southern Deep margin extending from the shallow algal/coral crest.*

e) The brown algaes Turbinaria ornatus *and* Dictyota sp. *with the coral* Porites sp. *comprise portions of the perimeter of the Southern Deep, bordering the Eastern Reef Flat.*

f) The coralline algal rim/reef flat of the seaward portion of the main Deep.

g) With their origins on the outer reef slope, the rubble crest is littered with the remnants of coral colonies. These are victims of extreme wave action. Existing as prominent banks after cyclone Ofa (Feb. 1990), their relief is now reduced. At present, they are represented as rubble covering the seaward reef flat.

h) The outer reef slope is devoid of the normal extensive coral cover. Closer inspection reveals large quantities of hard coral and algal settlement, most probably originating from places such as the Deep.

i) Porites cylindrica *on the southeastern wall of the Southern Deep.*

j) A large stand of Acropora nobilis *monopolising the Southern Deep.*

k) A colony of Pocillopora damicornis *defending its space within the sprawling expanse of* A. nobilis *colonies.*

l) A feeding scar of Acanthaster planci *within the* A. nobilis *thicket. Some* Chromis viridis *swimming above.*

m) The hard coral Plerogyra sinuosa *in the Main Deep. Relic* P. rus *colonies in the murky background.*

n) The rubble slope near the seaward entrance of the Main Deep. This talus slope is unstable with little colonisation.

o) The vertical reef wall near the seaward opening, characterising the east northeast side of the Deep.

p) Columns of largely dead P. rus *rise out of the silty bottom at 12m.*

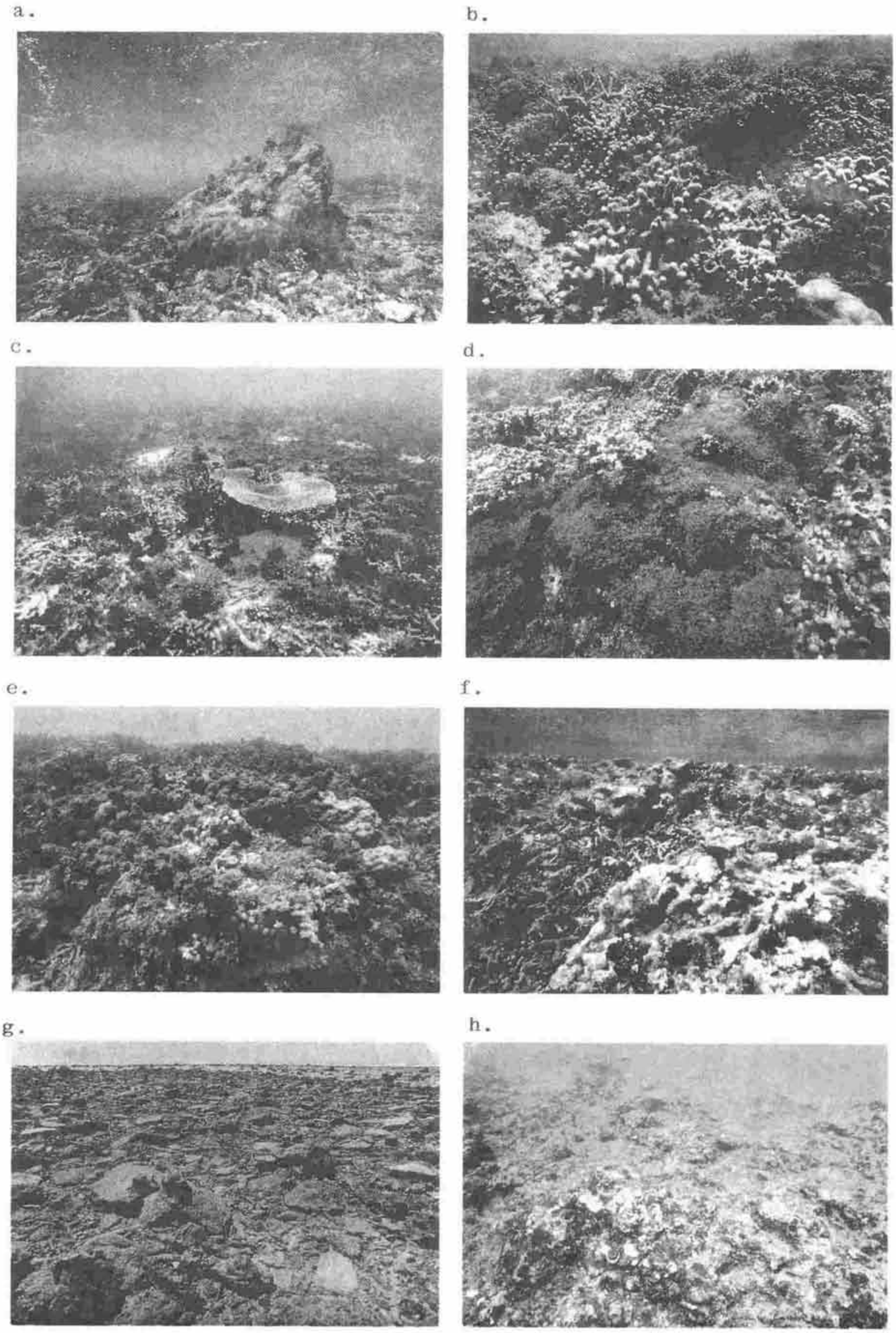


Fig. 6: *Habitats of the Palolo Deep (a-h).*

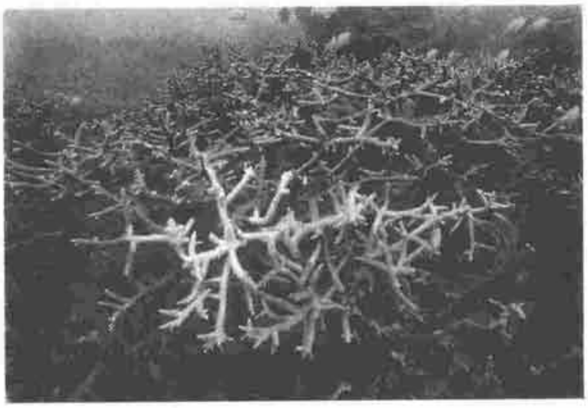
Photos: E. Lovell 1993.

i.

j.

k.

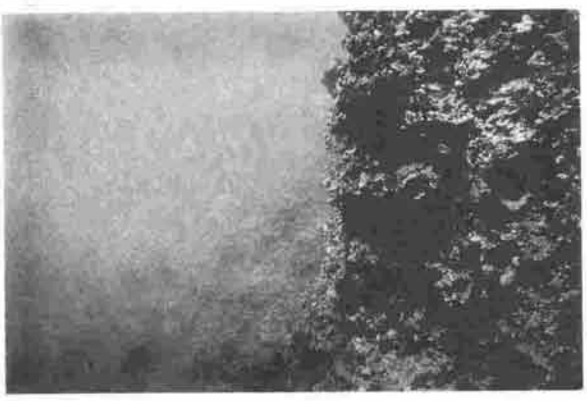
l.



m.

n.

o.



p.

Fig. 6: *Habitats of the Palolo Deep: (i-p).*

Photos: E. Lovell 1993.

3.1 Inshore Reef Flat

(Transects 1a-h; 2a-h; 3a,b)

General description

This zone is the inshore area of the Marine Reserve. It comprises two habitats: one of a largely sandy substrate with reduced biota to the southwest of the southern Deep and near shore; the other a more diverse area resulting from its proximity to the southern Deep and the presence of a more stable rubble substrate. This latter area is transitional in character, grading into the Eastern Reef Flat.

Location

The area is located inshore of a line drawn between the two inshore buoys (no. 1; east and west) marking the Reserve boundary (see Fig. 3). More generally, it is the area inshore of the southern end of Palolo Deep extending to the beach.

Exposure and Current

Wave action is confined to a wind chop or much reduced ocean swell due to the broad reef flat expanse. It is subject to the effects of tidal exposure with shallowing depths and an unstable substrate. There is a pronounced current originating from the Deep, where it wells over the southern crest, flowing to the east. Near-coastal effects occur through freshwater run off and resuspension of sediments due to wave action.

Depth

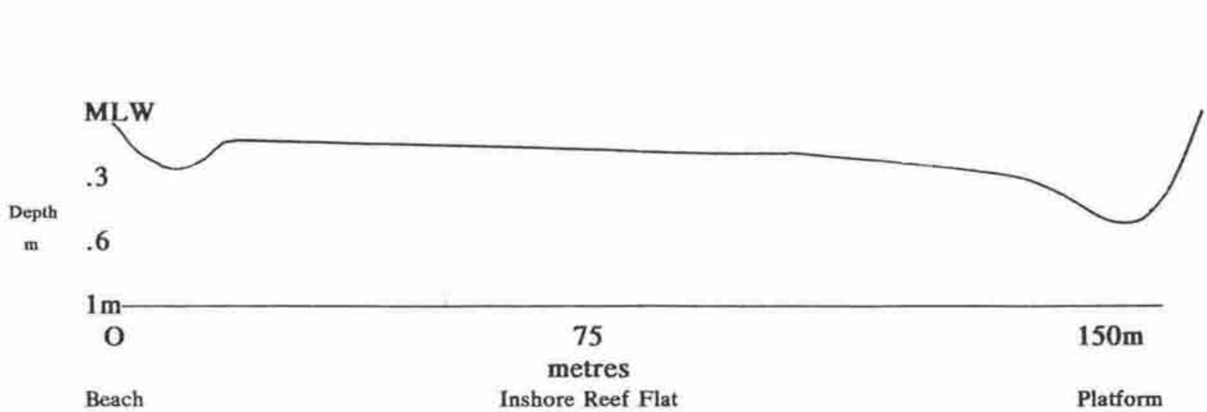
The shoreward margin of the beach slopes through the tidal range to a shallow inshore gutter which is characterised seaward by a shallow bathymetry (0.6m depth mean low water (MLW)). It deepens at the base of the platform into a channel of 1m. The zone is characterised as generally flat with coral rocks occurring sporadically. Shallowing through mounding occurs as sand and rubble aggregate around the rocks (see Fig. 4).

Substrate

The substrate comprises rubble and sand (74%). The area in proximity to the southern end of the Deep has the higher proportion of rubble (26%) and extends west. Inshore of this area is a tongue of sand which extends from the Western Reef Flat. A largely sandy substrate dominates shoreward. Coral rocks are scattered, and are prominent as sites of macroalgae and associated organisms.

Algae

Dictyota dichotoma (see Table 1) is the dominant algae with its presence mainly confined to the area peripheral to the Deep. It is associated with rubble, and its occurrence reflects this substrate element. Coverage ranged from 48% near the Deep, to a sparse 3% in the sandy areas. Its occurrence in this zone represents the inshore extent of its larger range which encompasses the Eastern Reef Flat. Elsewhere it is co-dominant with an unidentified red algae and *Sargassum sp.*.



General profile of transects in the inshore reef area (see Fig. 5).

Sargassum sp. occur as a band of foliaceous algae in raised areas of rubble in the central and western area. Other algae are *Halimeda sp.* (Fig. 34f), *Turbinaria ornata*, green filamentous and turfed algae (Table 1). The total algal cover in this area is 9%, where the sample near the Deep was entirely *Dictyota*, covering 48%.

Uncommon in the Reserve, the sea grass *Halophila ovalis* occurs in this sandy area.

Coral

Hard coral cover near the Deep is 16% with five genera represented. *Acropora nobilis* (Fig. 35c) is the most abundant (9%), although patchy. The near shore area is sparsely colonised by hard coral; the total coverage is 3%. Species occurrence is all less than one percent with *Porites cylindrica* (Fig. 35b) the most prevalent. Some medium size (60 cm) massive colonies exist, but generally the colonies are isolated. As with the algae, hard coral is more prevalent in the area near the Deep. The assemblage is a mixture of the genera *Acropora, Montipora* and *Porites*, with greater diversity closer to the Deep.

Community type

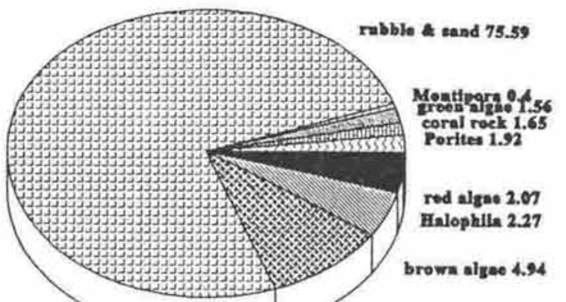
The inshore zone represents two community types grading into each other, differentiated by diversity and degree of development. The area inshore is characterised by an impoverished benthos where an unsuitable substrate and harsh conditions moderate development. Organisms are adapted to an unstable substrate or are found associated with isolated coral colonies or rock.

Near the Deep the diversity is higher with the community elements being quite different. This is the result of three factors: a more stable rubble substrate, proximity to parent stock found in abundance within the Deep, and shelter from wave action by the Deep. The current that flows from the Deep promotes the algal/coral rim to the south of the Deep and the predominance of *Dictyota sp.*. The area of *Sargassum sp.* ocurring on islands of rubble, provides good habitat and refuge for schools of juvenile fishes. These find shelter in the shallower water and among the foliaceous algae.

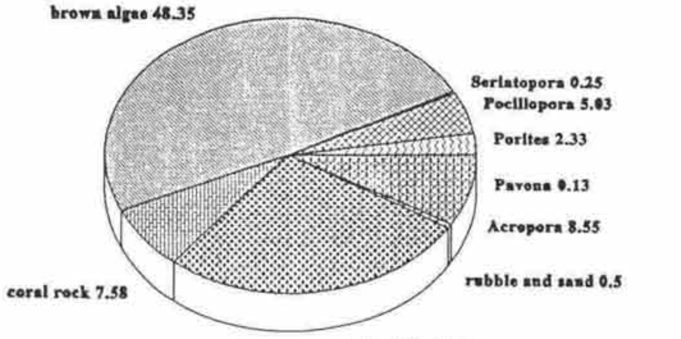
Dynamics

Tidal exposure, unstable substrate, current, wave chop and effects from the shore all play a part in making this area one of extremes. The current flowing eastward from the Deep, ameliorates the land effects. Current and wave action are responsible for the movement of the sand from the Western Reef Flat. For most of the year, the current flows into the south-east trade-wind chop which creates a more vigorous shallow water environment maintaining a cleansing mechanism for the fine sediment. This area is shallow and subject to tidal fluctuation, which gives rise to exposure and temperature extremes. These are moderated by the current and wave action. A principal limiting feature is the sandy substrate. With limited benthic attachment coupled with the vagaries of shallow water, a diverse and luxuriant inshore community is not possible.

Transect 1 a-h



Transect 3 a,b



Transect 2 a-h

Fig. 7: Graphs of the percentage composition of transects 1a-h; 2a-h; 3a,b

Table 1: Combined inshore transects in the sandy zone perpendicular to the beach (260m): Transects 1a-h; 2a-h.

	Taxa	N	Total Intercept (cm)	Mean	Std. Dev.	Max.	Min.	Percent cover
Coral	*Acropora hyacinthus*	3	57.0	32.3	7.6	30.0	10.0	0.23%
	Acropora nobilis	1	10.0	10.0	0.00	10.0	10.0	0.04%
	Montipora sp.	7	100.0	80.0	8.37	30.0	5.0	0.40%
	Porites cylindrica	3	210.0	70.0	84.85	190.0	10.0	0.84%
	Porites lutea	6	150.0	75.0	22.11	80.0	5.0	0.60%
	Porites sp.	3	70.0	43.3	15.00	50.0	10.0	0.28%
	Porites rus	7	50.0	7.2	3.94	15.0	3.0	0.20%
							Total	**2.59%**
Algae	*Algae* sp.	1	5.0	5.0	0.00	5.0	5.0	0.02%
	Coralline algae	2	34.0	17.0	7.00	24.0	10.0	0.14%
	Dictyota sp.	16	721.0	45.0	121.95	385.0	5.0	2.87%
	Green filamentous	5	25.0	5.0	2.50	5.0	5.0	0.10%
	Halimeda sp.	9	211.0	23.4	24.08	72.0	5.0	0.84%
	Red algae	11	485.0	48.0	119.02	405.0	5.0	1.93%
	Sargassum	10	370.0	37.0	62.32	205.0	5.0	1.47%
	Turbinaria ornata	20	150.0	7.5	3.28	15.0	0.0	0.60%
	Turf algae	2	155.0	77.5	17.50	95.0	60.0	0.62%
							Total	**8.59%**
Seagrass	*Halophila ovalis*	1	570.0	570.0	0.00	570.0	570.0	2.27%
Substrate	Coral rock	8	416.0	52.0	94.21	300.0	7.0	1.65%
	Dead standing coral	5	74.0	14.8	5.00	24.0	5.0	0.29%
	Rubble	27	2550.0	118.3	150.27	615.0	0.0	10.12%
	Rubble and sand	89	18560.0	208.5	230.24	1430.0	0.0	73.81%
	Sand	8	448.0	56.0	73.59	210.0	5.0	1.78%
		Total	**260m**				**Total**	**87.65%**

Table 2: Inshore reef flat parallel to shore near the southern end of the Deep (40m): Transect 3a,b

	Taxa	N	Total Intercept (cm)	Mean	Std. Dev.	Max.	Min.	Percent cover
Coral	*Acropora nobilis*	4	342.0	85.5	141.21	330.0	1.0	8.55%
	Pavona decussata	1	5.0	5.0	0.00	5.0	5.0	0.13%
	Porites cylindrica	2	12.0	6.0	4.00	10.0	2.0	0.30%
	Pocillopora eydouxi	6	201.0	33.5	28.95	80.0	5.0	5.03%
	Porites rus	7	81.0	11.6	7.78	30.0	5.0	2.03%
	Seriatopora hystrix	1	10.0	10.0	0.00	10.0	10.0	0.25%
							Total	**16.29%**
Algae	*Dictyota* sp.	5	1934.0	386.8	366.34	969.0	40.0	48.35%
Substrate	Coral rock	3	303.0	101.0	108.18	253.0	10.0	7.58%
	Rubble	15	1046.0	69.7	68.24	290.0	1.0	26.15%
	Rubble and sand	1	16.0	16.0	0.00	16.0	16.0	0.40%
	Sand	1	4.0	4.0	0.00	4.0	4.0	0.10%
		Total	**39.54m**				**Total**	**34.23%**

Table 3: Eastern reef flat extending from inshore buoy (1) westward (40m): Transect 17a,b

	Taxa	N	Total Intercept (cm)	Mean	Std. Dev.	Max.	Min.	Percent cover
Coral	*Acropora hyacinthus*	2	35.0	17.5	2.50	20.0	15.0	0.88%
	Acropora nobilis	1	2.0	2.0	0.00	2.0	2.0	0.05%
	Montipora sp.	1	15.0	15.0	0.00	15.0	15.0	0.38%
	Pocillopora damicornis	5	155.0	31.0	39.79	110.0	5.0	3.88%
	Pocillopora eydouxi	2	30.0	15.0	10.00	25.0	5.0	0.75%
	Porites cylindrica	14	216.0	15.4	9.31	38.0	5.0	5.40%
	Porites lutea	2	12.0	6.0	4.00	10.0	2.0	0.30%
	Porites rus	5	90.0	18.0	18.86	55.0	5.0	2.25%
	Porites sp.	4	35.0	8.8	4.15	15.0	5.0	0.88%
	Seriatopora hystrix	1	10.0	10.0	0.00	10.0	10.0	0.25%
							Total	**15.02%**
Algae	*Dictyota* sp.	23	2480.0	107.8	97.85	410.0	20.0	62.00%
	Halimeda sp.	4	39.0	9.8	4.54	17.0	5.0	0.98%
	Sargassum sp.	2	30.0	15.0	5.00	20.0	10.0	0.75%
	Turbinaria ornatus	1	10.0	10.0	0.00	10.0	10.0	0.25%
							Total	**63.98%**
Substrate	Coral Rock	3	85.0	28.3	22.48	60.0	10.0	2.13%
	Dead standing coral	3	230.0	76.6	71.79	177.0	13.0	5.75%
	Rubble	16	526.0	32.8	30.09	133.0	5.0	13.15%
		Total	**4000**				**Total**	**21.03%**

Table 4: Transect for eastern reef flat, extending from the Reserve boundary between buoys 1 and 2 (20m): Transect 23.

	Taxa	N	Total Intercept (cm)	Mean	Std. Dev.	Max.	Min.	Percent cover
Coral	*Acropora nobilis*	1	10.0	10.0	0.00	10.0	10.0	0.50%
	Montipora sp.	1	5.0	5.0	0.00	5.0	5.0	0.25%
	Porites cylindrica	11	128.0	11.6	3.08	20.0	10.0	6.40%\
	Psammocora contigua	2	50.0	25.0	20.00	45.0	5.0	2.50%
	Pocillopora damicornis	8	85.0	10.6	4.64	20.0	5.0	4.25%
	Porites lutea	1	5.0	5.0	0.00	5.0	5.0	0.25%
	Porites rus	1	5.0	5.0	0.00	5.0	5.0	0.25%
	Seriatopora hystrix	1	10.0	10.0	0.00	10.0	10.0	0.50%
							Total	**14.90%**
Algae	*Dictyota* sp.	4	195.0	48.8	37.14	110.0	10.0	9.75%
Substrate	Coral rock	8	445.0	55.6	62.72	190.0	5.0	22.25%
	Rubble	17	1062.0	62.5	46.44	170.0	10.0	53.10%
		Total	**20m**				**Total**	**75.35%**

Table 5: Transectsof eastern reef flat, north of the platform in an area of high coral cover (10m): Transect 24.

	Taxa	N	Total Intercept (cm)	Mean	Std. Dev.	Max.	Min.	Percent cover
Coral	*Acropora hyacinthus*	1	15.0	15.0	0.00	15.0	15.0	1.50%
	Acropora nobilis	2	20.0	10.0	5.00	15.0	5.0	2.00%
	Porites cylindrica	21	590.0	28.1	23.07	90.0	5.0	59.00%
	Pocillopora damicornis	8	110.0	13.8	4.84	25.0	10.0	11.00%
	Porites lutea	2	15.0	7.5	2.50	10.0	5.0	1.50%
	Porites rus	5	65.0	13.0	9.27	30.0	5.0	6.50%
	Zooanthids	1	15.0	15.0	0.00	15.0	15.0	1.50%
							Total	**83.00%**
Substrate	Coral rock	9	105.0	11.7	7.07	30.0	5.0	10.50%
	Rubble	3	40.0	13.3	2.36	15.0	10.0	4.00%
	Sand	2	25.0	12.5	2.50	15.0	10.0	2.50%
		Total	**10m**				**Total**	**17.00%**

Table 6: Transectsof central eastern reef flat extending from the middle buoy (40m): Transect 18a,b.

	Taxa	N	Total Intercept (cm)	Mean	Std. Dev.	Max.	Min.	Percent cover
Coral	*Acropora hyacinthus*	2	30.0	15.0	5.00	20.0	10.0	0.75%
	Acropora nobilis	7	90.0	12.9	11.29	40.0	5.0	2.25%
	Pocillopora damicornis	13	254.0	19.5	13.93	50.0	10.0	6.35%
	Porites cylindrica	8	95.0	11.9	7.04	30.0	5.0	2.35%
	Porites lutea	1	15.0	15.0	0.00	15.0	15.0	0.38%
	Porites rus	1	205.0	205.0	0.00	205.0	205.0	5.13%
	Porites sp.	5	27.0	5.4	2.58	10.0	2.0	0.68%
							Total	**17.89%**
Algae	*Dictyota* sp.	24	3089.0	128.7	104.66	370.0	18.0	77.23%
	Turbinaria ornatus	2	15.0	7.5	2.50	10.0	5.0	0.38%
							Total	**77.61%**
Substrate	Dead standing coral	1	15.0	15.0	0.00	15.0	15.0	0.38%
	Coral rock	3	50.0	16.7	9.43	30.0	10.0	1.25%
	Coral rubble	2	115.0	57.5	17.50	75.0	40.0	2.88%
		Total	**40m**				**Total**	**4.51%**

Table 7: North eastern reef flat extending from the seaward buoy (40m): Transect 19a,b.

	Taxa	N	Total Intercept (cm)	Mean	Std. Dev.	Max.	Min.	Percent cover
Coral	*Acropora nobilis*	5	35.0	7.0	2.45	10.0	5.0	0.88%
	Montipora sp.	4	30.0	7.5	2.50	10.0	5.0	0.75%
	Pavona decussata	4	20.0	5.0	0.00	5.0	5.0	0.50%
	Pocillopora damicornis	1	5.0	5.0	0.00	5.0	5.0	0.13%
	Porites cylindrica	14	178.0	12.7	4.32	20.0	5.0	4.45%
	Porites lutea	1	25.0	25.0	0.00	25.0	25.0	0.63%
	Porites rus	5	90.0	18.0	16.61	50.0	5.0	2.25%
	Porites sp.	1	20.0	20.0	0.00	20.0	20.0	0.50%
							Total	**10.09%**
Algae	*Dictyota* sp.	7	902.0	128.9	65.01	200.0	45.0	22.55%
	Turbinaria ornatus	3	70.0	23.3	18.86	50.0	10.0	1.75%
							Total	**24.30%**
Substrate	Coral rock	1	20.0	20.0	0.00	20.0	20.0	0.50%
	Coral rubble	24	2477.0	103.2	91.74	335.0	20.0	61.93%
	Rubble and sand	1	128.0	125.0	0.00	125.0	125.0	3.23%
		Total	**40m**				**Total**	**65.66%**

Table 8: Abundance information on Echinometra mathaei *from the eastern reef flat. Five $20m^2$ belt transects were run along the line transects as indicated.*

Belt Transects:	1	2	3	4	5
Line Transects:	inshore	(17)	(23)	(18)	(19)
Total no./$20m^2$:	70	76	200	180	100
Mean/m^2:	3.5	3.8	10	9	5
Std. deviation:	14.67	4.93	40.9	39.7	20.5
Maximum number:	13	16	21	51	15
Minimum number:	0	0	1	0	1

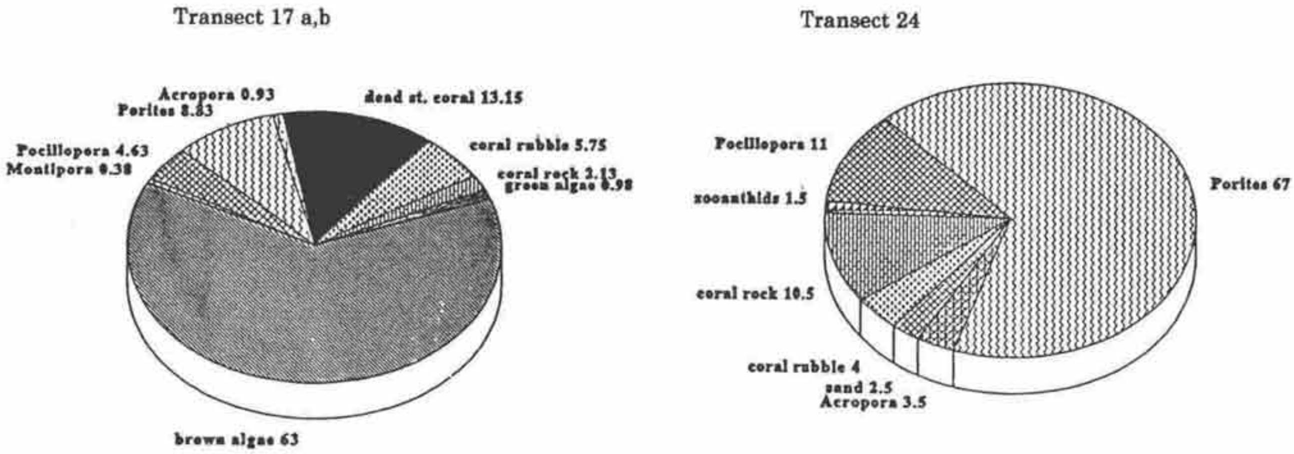


Fig. 8: Graphs of the percentage composition of transects 17a,b; and 24.

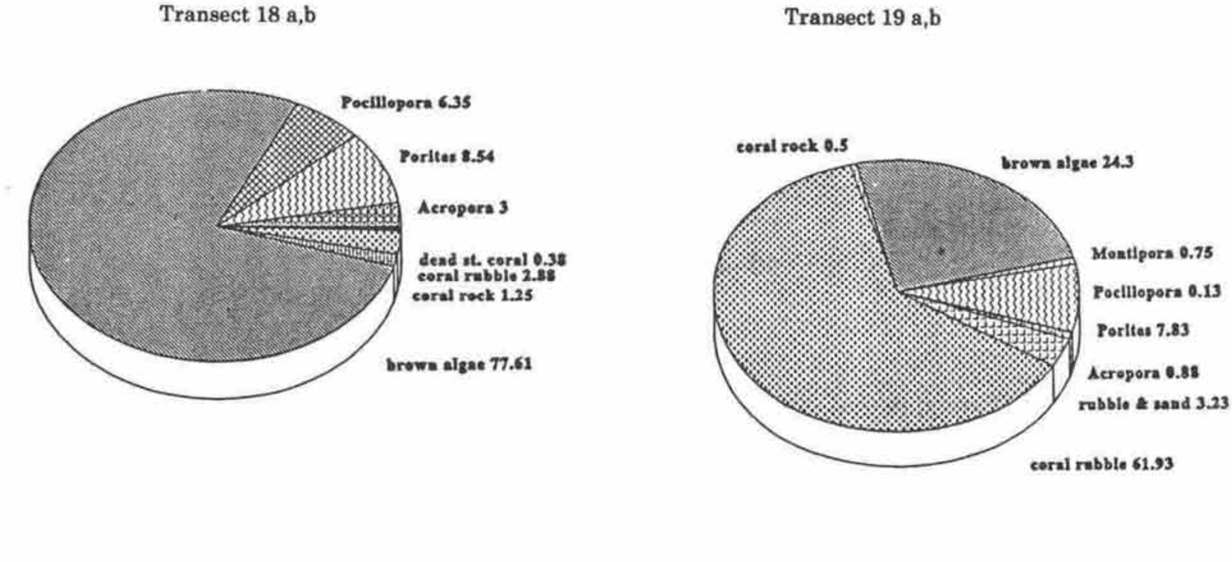


Fig. 9: Graphs of the percentage composition of transects 18a,b; and 19a,b.

3.3 Western Reef Flat (Transects 20a,b; 21a-d; 22a,b)

General description

This area is a homogeneous reef flat comprising a relatively impoverished fauna. Similar to the inshore area in nature, it appears as a disturbed unconsolidated environment, where the flat has experienced deepening through erosion. The benthic community is depauperate with sparse coral occurrence (Fig. 6a).

Location

The area is to the west of the Palolo Deep. It is bordered to seaward by the rubble banks of the outer reef flat. Its landward or southern margin grades into the inshore zone, defined generally as a line between buoy no. 1 and the southern end of the Deep (Fig. 3).

Exposure and current

Relative to the Eastern Reef Flat, this area is more exposed. Though protected by the reef crest and the rubble banks, it is subject to greater wave and current action, particularly during the summer months. This is a period characterised by the presence of strong north-west winds, creating a strong current through the Reserve.

Depth

The Western Reef Flat is generally deeper than the Eastern. The excavated nature of this area results in a depth of 1m MLW. There has been a movement of material towards and into the Deep. The bathymetry deepens gradually with its approaches to it. Exceptions to this are areas near the perimeter of the Deep where the presence of large coral colonies (*Porites sp.*) cause material to aggregate in mounds. There is also a shallow area of principally sand and rubble on the north-west margin of the Deep.

The remainder of the reef flat is shallower with the south-west margin of the Reserve characterised by a depth of 0.3m. At the margin of the southern Deep, it shallows to 0.6m, then grades into the inshore area to a depth of 0.2m, as shown below.

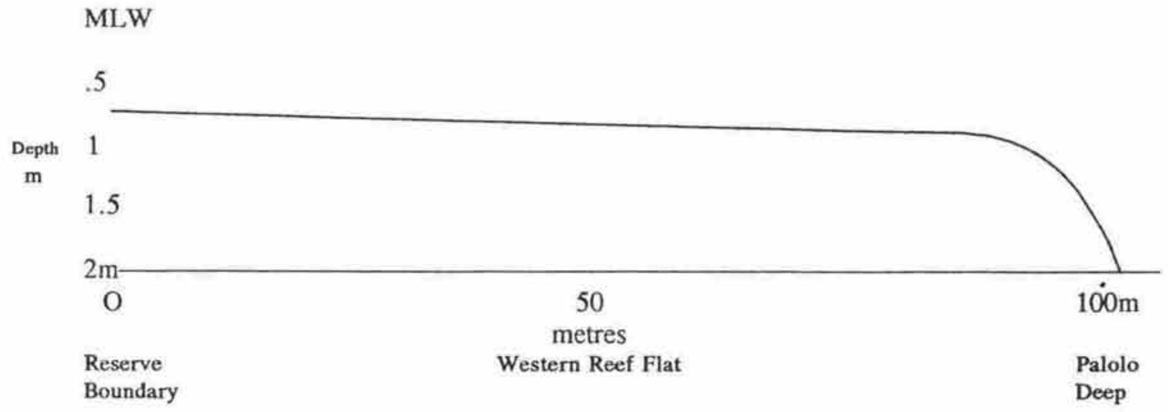
Substrate

The bare substrate percentage varies between 44% and 65%, with a greater substrate component seaward. As with the eastern flat, there is a greater percentage of rubble, varying from 27-46%. The sand component is much larger inshore and around the rim of the Deep, where it grades into the talus slope inside.

Algae

The algal percentage cover ranges between 28% and 44%. The principal algae is *Dictyota sp.*, occurring between 28% and 31%. Other algae present are *Halimeda sp.*, *Sargassum sp.*, *Turbinaria ornata,* and a green filamentous algae. In the inshore area (transect 20), *Sargassum sp.* (7%) and *Turbinaria ornata* (6%) occur.

General profile of transects in the area of the weste n reef flat (see Fig. 5)



Coral

The coral composition is impoverished with total cover ranging between 1.5% and 17%. Unlike any of the other areas, it is largely *Porites* with *Porites lutea* as the predominating species. Its occurrence ranges between 1.3% and 11%. There are large *Porites* bommies which in many cases are overturned or partially buried. These bommies, often heavily damaged, provide prominent relief from what is otherwise a flat expanse. This is a stable surface for other benthos, which form islands of diversity in what is otherwise an impoverished area.

All other species have less than 3% coverage. Other species present, in decreasing coverage, are *Acropora nobilis, A. hyacinthus, Porites rus, Montipora sp., Acropora humilis, Porites cylindrica,* and *Pocillopora damicornis.* Unlike the protected Eastern Reef Flat, this area has few small colonies. The lack of benthic development and the loose rubbly nature of the substrate give the impression that the area is periodically disturbed.

Community type

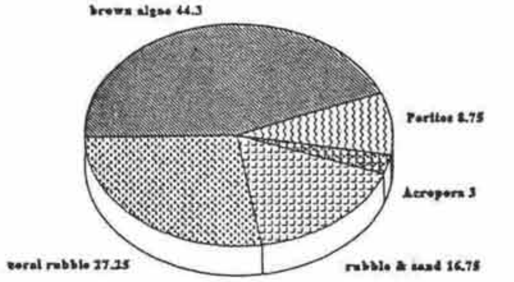
A predominance of *Dictyota sp.* covers a rubble substrate. Apart from the prevalence of *Porites* bommies, coral colonies are patchy in occurrence.

Dynamics

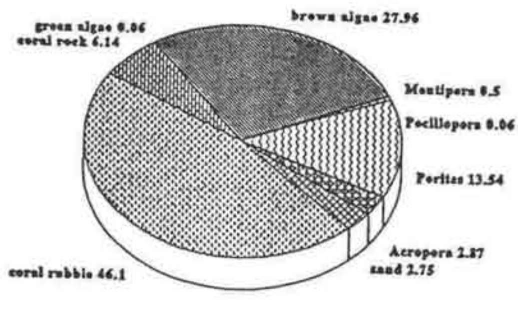
Comparison of the aerial photos (Fig. 19) shows the deepening of the Western Reef Flat to be a relatively recent event (post 1990). Being less protected than the eastern flat, the occurrence of the major cyclones may have altered the nature of this reef flat through the erosional effects of extreme wave or current action. The presence of the rubble banks may have altered the pre-cyclone Ofa influence of current and wave action. These now form a seaward barrier to the excavated area of the Western Reef Flat. The high energy season for this area is during the summer when the north-west wind and current are strong.

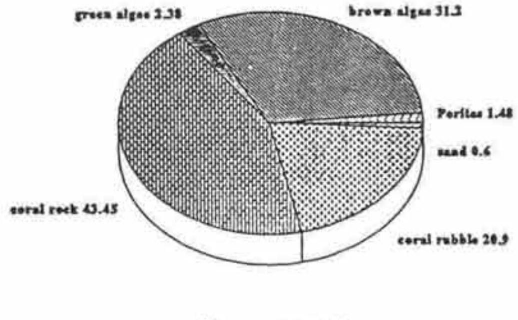
The western margin of the Deep is a talus slope of rubble which must have traversed the reef flat, grading it in the process. The rubble continues to be transported towards the Deep during periods of rough weather as the rubble banks migrate shoreward (Fig. 19: photos 1990, 1993).

Transect 20a,b



Transect 21a,b





Transect 22a,b

Fig. 10: Graphs of the percentage composition for western reef transects.

Table 9: Western reef flat, extending eastward from the inshore buoy (40m): Transect 20a,b.

	Taxa	N	Total Intercept (cm)	Mean	Std. Dev.	Max.	Min.	Percent cover
Coral	*Acropora nobilis*	1	120.0	120.0	0.00	120.0	120.0	3.00%
	Porites lutea	1	350.0	350.0	0.00	350.0	350.0	8.75%
							Total	**11.75%**
Algae	*Dictyota* sp.	6	1200.0	200.0	200.83	490.0	10.0	30.80%
	Halimeda sp.	1	1.0	1.0	0.00	0.0	0.0	0.00%
	Sargassum sp.	1	290.0	290.0	0.00	290.0	290.0	7.25%
	Turbinaria ornata	2	250.0	125.0	115.00	240.0	10.0	6.25%
							Total	**44.30%**
Substrate	Rubble	1	1090.0	1090.0	0.00	1090.0	1090.0	27.25%
	Rubble and sand	5	670.0	134.0	164.75	430.0	10.0	16.75%
		Total	**40m**				**Total**	**44%**

Table 10: Central western reef flat, extending eastward from the middle buoy (78m): Transect 21a..

	Taxa	N	Total Intercept (cm)	Mean	Std. Dev.	Max.	Min.	Percent cover
Coral	*Acropora hyacinthus*	1	205.0	205.0	0.00	205.0	205.0	2.56%
	Acropora humilis	2	25.0	12.5	7.50	20.0	5.0	0.31%
	Montipora sp.	1	40.0	40.0	0.00	40.0	40.0	0.50%
	Porites cylindrica	3	20.0	6.7	2.36	10.0	5.0	0.25%
	Pocillopora damicornis	1	5.0	5.0	0.00	5.0	5.0	0.06%
	Porites lutea	4	893.0	223.3	321.48	775.0	3.0	11.16%
	Porites rus	2	170.0	85.0	80.00	165.0	5.0	2.13%
							Total	**16.97%**
Algae	*Dictyota* sp.	10	2053.0	205.3	133.65	470.0	10.0	27.96%
	Green filamentous	1	5.0	5.0	0.0	5.0	5.0	0.06%
							Total	**28.02%**
Substrate	Rock	14	491.0	35.1	33.44	130.0	0.0	6.14%
	Rubble	25	3688.0	147.5	112.60	425.0	2.0	46.10%
	Sand	2	220.0	110.0	30.00	140.0	80.0	2.75%
		Total	**78m**				**Total**	**54.99%**

Table 11: North western reef flat, extending from the seaward buoy (40m): Transect 22a,b.

	Taxa	N	Total Intercept (cm)	Mean	Std. Dev.	Max.	Min.	Percent cover
Coral	*Porites lutea*	10	54.0	5.4	3.04	11.0	1.0	1.35%
	Porites rus	1	5.0	5.0	0.00	5.0	5.0	0.13%
							Total	**1.48%**
Algae	*Dictyota* sp.	10	1248.0	124.8	118.21	410.0	8.0	31.20%
	Halimeda sp.	9	95.0	10.6	7.62	30.0	3.0	2.38%
							Total	**33.58%**
Substrate	Coral rubble	12	1738.0	144.8	173.90	612.0	15.0	43.45%
	Rubble and sand	4	836.0	209.0	161.58	400.0	13.0	20.90%
	Sand	1	24.0	24.0	0.00	24.0	24.0	0.60%
		Total	**40m**				**Total**	**64.95%**

3.4 Southern Palolo Deep (Transects 4-6; 7-11; 12-16)

General Description

The southern end of the Palolo Deep is relatively shallow by comparison with the main body of the Deep. This site contains the most luxuriant coral development in the Reserve. It occurs almost exclusively along the eastern side. The remainder of the area is deeper, with patchy coral cover on a sand bottom. The western slope comprises a talus slope of rubble.

Location

This area extends from the main body of the Deep shoreward of the Transverse Ridge to the seaward margin of the inshore zone (Fig. 3).

Exposure and current

This area is the most protected environment in the Reserve, being surrounded by reef flats and the main body of the Deep to seaward. Current is constant except at extreme low water. It flows along the length of the Deep, spilling laterally over the rim to the south-east. As the tide falls, the current is confined to and can be seen to flow over the southern end, rising noticeably. It then forms a strong inshore current which flows past the platform. This results in the presence along the south-east rim of a consolidated coral/algal margin with *Dictyota sp.* (Fig. 6d) and higher coral cover immediately shoreward.

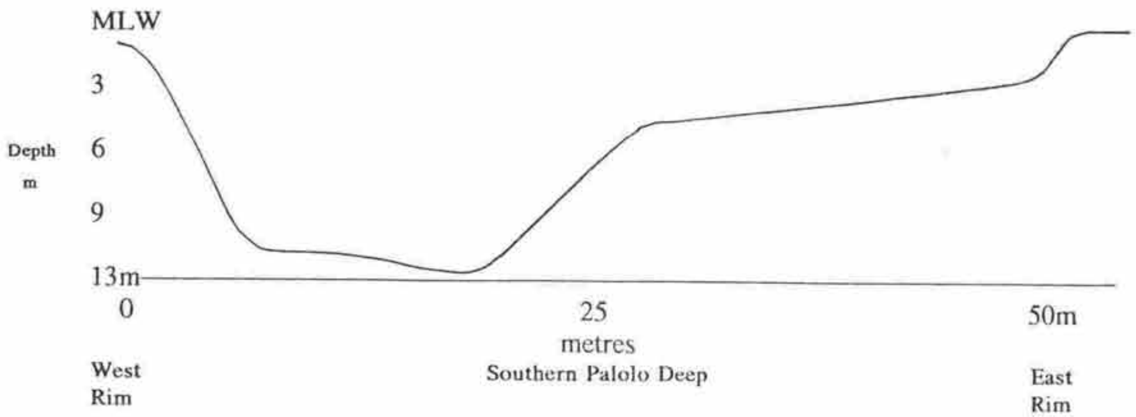
Depth

The algal margin of the Deep, to the east and south, has a depth of 0.1 metre below mean low water. The margin to the west is deeper with a depth of 0.3m. The eastern border descends to 1m to 2m where a terrace extends along the eastern side, sloping to 5m. From there it descends to a sandy bottom at 7-10m. The slope below the terrace is gradual along the length of the Deep from the southern end but is progressively more abrupt toward the seaward end. The rubble slope on the western side rises at the angle of repose from the sandy bottom (see Fig. 4).

Substrate

The uncolonised substrate component increases with depth. It varies between 29%, in the shallow area, to 46% at the terrace margin. In the upper mid-terrace zone, coral rock is the most common substrate (18%). Standing dead coral is the next most common component (6%). Other elements are rubble and sand. Mid-terrace, standing dead coral forms the largest component (17%). Rubble and sand are the next most common at 7% and 8% respectively. Rubble is the most common substrate at the terrace margin (21%). Coral rock, standing dead coral and silt and sand are the next most common components (6%, 5% and 6.5% respectively).

At depth, the substrate is characterised by silty sand with the presence of large coral boulders and varying degrees of rubble. The substrate component is high here (>80%).



General profile of transects in the area of Southern Palolo Deep (see Fig. 5)

The western margin is a rubble/boulder slope comprising coral fragments similar to those found on the seaward reef flat, grading to sand and rubble at the upper margin. Some live coral exists at its base but it is generally uncolonised.

Algae

The percent of algal cover varies from less than 1% to 24%, depending on depth. The area of least algal presence is in the mid-terrace region where the coral cover is highest and the algal presence (*Cladophoropsis*?) is confined to the base of the *Acropora nobilis* beds (Fig. 34d). This was not measured in the survey (Figs. 6k and 6l). It is always present at the base of the coral so that a measurement of *A. nobilis* is a measurement of the algae.

The proliferation of the algae is the result of the protection afforded by the pugnacious and territorial damselfish, *Stegastes lividus* (see section 6; Fig. 34c, 34d). The algae also occurs on standing dead coral but is generally grazed by herbivorous fishes. As the area is largely monopolised by this coral, there is little area for other algae to develop. By contrast, the areas peripheral to this area are less monopolised and algal diversity is greater.

In the shallow area, there is 13% algal presence (Fig. 6e). This figure would be higher if the slope below the algal ridge or the ridge itself were assessed. The greatest percentage is unidentified (8%). *Halimeda opuntia* and coralline algae were the next most prevalent. By contrast with the reef flat, *Dictyota sp.* was poorly represented (0.15%).

The deeper area was represented by algal species. *Jania sp.* were the next most common component, characteristic of this deeper area and occurring extensively. *Halimeda opuntia* was present as a minor component.

Coral

Here the hard coral is the most luxuriant in the Reserve. The shallow and mid-terraces have a living cover of 61% and 64% respectively. The deeper margin of the assemblage has a 30% coverage. The hard coral assemblage is co-dominated by three species: *Acropora nobilis*, *Porites rus*, and *Porites cylindrica* (Figs. 6i, 6j). Their relative cover in the 2-3m depth is 20%, 20% and 12% respectively. In the mid-terrace depth of 3m, their relative cover is 31%, 15% and 17% respectively. At the 4-5m depth, percentage cover is 6%, 8%, and 11% respectively.

Comparing the mid and shallow terrace transects 7-11 and 12-16 respectively, it can be seen that the *Acropora nobilis* and *Porites rus* are relatively equal in occurrence in the shallow area with *Porites cylindrica* half as common. Within the mid-terrace, *Acropora nobilis* becomes twice as common (31%) as the two *Porites* species which are of equal incidence (15% and 17%). With depth (transects 4a-d; 5; 6), *Porites cylindrica* becomes dominant (11%) with *Acropora nobilis* and *Porites rus* more equal (6% and 8% respectively).

The other corals in the assemblage occur individually at less than 2%, with the exception of *Seriatopora hystrix* with a 3%-4% coverage.

Community type

Four distinct habitats exist, two of which are co-dominated by three species, the other two having very little living cover. The first habitat is the vertical south-east margin comprising an algal/coral ridge at the crest or margin of the Deep. This grades down the slope becoming a relatively diverse assemblage (10 spp. coral :5 spp. algae) not subject to the monopolisation as seen on the terrace.

The more vertical portion of the slope has less coral cover and is characterised by smaller colonies, generally dominated by *P. rus* and *P. cylindrica* with small colonies of *Seriatopora hystrix*. *A. nobilis* is a minor component in this area. The algal component is higher than the adjacent terrace (13% vs. 1%) though this fails to take into account the filamentous green algae that exists within the *Acropora nobilis* stands.

The terraced area is characterised by a greater prevalence of *Acropora nobilis* (31%), monopolising large areas. An important component of this area is the association of the damsel *Stegastes lividus* and the filamentous green algae (Potts 1977). Though not measured in the transects, the algae co-occur with all of the *A. nobilis* and other branching coral. Its presence is at the base of the colonies and is a dominating feature of the assemblage (see Section 6: 34c, 34d).

The deeper portion of this area is characterised by a greater abundance of algae, such as *Jania sp.*. The uncolonised substrate becomes greater. The deepest portion of this area is impoverished with little living cover. It is largely a sandy substrate with scattered coral rock and rubble.

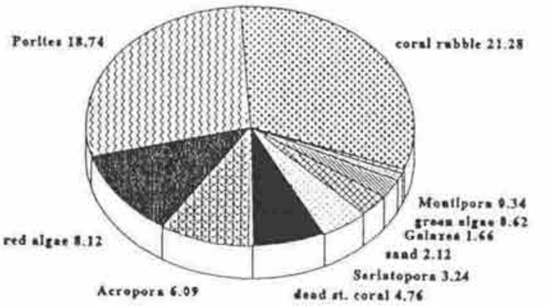
Dynamics

A process common to the Palolo Deep, this is a depositional environment characterised by its turbid water and silty depths. Chronic, current born siltation is a continuing problem for the benthos. Cleaning mechanisms require energy. Successful growth strategies such as the open branching form of *Acropora nobilis,* minimise this requirement. The colony maintains its living presence above the substrate with its ramose branches cleaned by the current action. Another factor is turbidity, limiting the penetration of light. Consequently coral occurrence is generally at less than 5m depth.

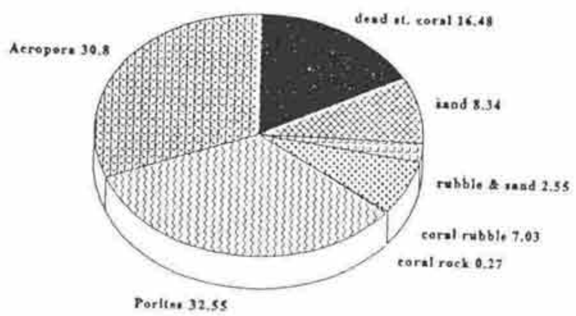
The relic existence of large *Porites rus* or *P. cylindrica* colonies in the silty, murky bottom of the Deep is evidence of a more suitable environment in former times. They presently occur only about the margin of the Deep, suggesting environmental change.

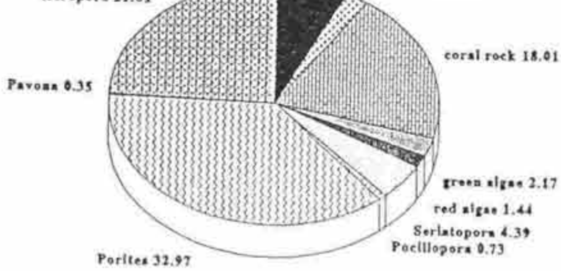
Substrate is the principal factor limiting much of the living cover. Reef development is consolidated on the eastern side but is represented by an unstable boulder and rubble substrate on the western margin. Rubble generated by successive cyclones continues to create an unstable slope. The bottom is composed of fine silt, old bommies and imported material from the shallower areas.

Transect 4-6



Transect 7-11





Transect 12-16

Fig. 11: Graphs of the percentage composition of transects .

Table 12: Southern Palolo Deep, 4-5m depth profile (118m): Transects 4-6

	Taxa	N	Total Intercept (cm)	Mean	Std. Dev.	Max.	Min.	Percent cover
Coral	*Acropora hyacinthus*	3	35.0	11.7	6.2	20.0	5.0	0.49%
	Acropora nobilis	10	648.0	64.8	53.4	150.0	10.0	5.60%
	Galaxea astreata	3	175.0	58.3	33.5	100.0	18.0	1.66%
	Montipora sp.	1	17.0	17.0	0.0	17.0	17.0	0.34%
	Porites cylindrica	8	1310.0	163.8	174.6	541.0	10.0	11.12%
	Porites rus	9	890.0	98.9	118.1	420.0	10.0	7.62%
	Seriatopora hystrix	5	365.0	73.0	90.2	250.0	10.0	3.24%
							Total	**30.07%**
Algae	?Algal spp.	12	1845.0	153.8	115.1	460.0	15.0	15.58%
	Halimeda opuntia	1	50.0	50.0	0.0	50.0	50.0	0.62%
	Jania sp.	5	950.0	190.0	171.3	435.0	35.0	8.12%
							Total	**24.32%**
Substrate	Coral rock	6	650	108.3	143.1	410	10	5.62%
	Rubble	12	2530	210.8	317.0	1190	20	21.28%
	Dead standing coral	11	548	49.8	44.6	170.0	4.0	4.76%
	Rubble and silt	5	670.0	134.0	63.1	230.0	40.0	3.87%
	Sand	2	230.0	115.0	35.0	150.0	80.0	2.12%
	Silt	2	150.0	75.0	25.0	100.0	50.0	1.45%
	Silt and sand	4	755.0	188.8	52.5	265.0	140.0	6.49%
		Total	**118m**				**Total**	**45.59%**

Table 13: Southern Palolo Deep, mid-terrace, 3m depth profile (109m): Transects 7-11.

	Taxa	N	Total Intercept (cm)	Mean	Std. Dev.	Max.	Min.	Percent cover
Coral	*Acropora nobilis*	17	3254.0	191.4	199.18	776.0	40.0	30.80%
	Pocillopora damicornis	2	32.0	16.0	8.00	24.0	8.0	0.29%
	Porites cylindrica	11	1920.0	174.5	208.57	640.0	30.0	17.48%
	Porites rus	13	1656.0	127.4	172.86	440.0	2.0	15.07%
	Seriatopora hystrix	5	110.0	22.0	12.08	45.0	10.0	1.00%
							Total	**64.64%**
Algae	?Algal species	1	70.0	70.0	0.00	70.0	70.0	0.64%
	Halimeda sp.	1	5.0	5.0	0.00	5.0	5.0	0.05%
							Total	**0.69%**
Substrate	Coral rock	1	30.0	30.0	0.00	30.0	30.0	0.27%
	Dead standing coral	19	1940.0	102.1	92.07	320.0	5.0	16.48%
	Rubble	12	772.0	64.3	54.47	202.0	5.0	7.03%
	Rubble and sand	4	280.0	70.0	32.60	115.0	25.0	2.55%
	sand	11	917.0	83.4	118.58	450.0	10.0	8.34%
		Total	**10.9m**				**Total**	**34.67%**

Table 14: Southern Palolo Deep, upper mid-terrace, 2-3m depth profile (98m): Transects 12-16.

	Taxa	N	Total Intercept (cm)	Mean	Std. Dev.	Max.	Min.	Percent cover
Coral	*Acropora aspera*	3	190.0	63.3	40.28	120.0	30.0	1.90%
	Acropora nobilis	20	1891.0	94.6	114.75	490.0	6.0	19.91%
	Galaxea astreata	1	38.0	38.0	0.00	38.0	38.0	0.38%
	Montipora sp.	1	60.0	60.0	0.00	60.0	60.0	0.60%
	Pavona varians	1	35.0	35.0	0.00	35.0	35.0	0.35%
	Porites cylindrica	33	1171.0	35.5	29.21	125.0	2.0	11.71%
	Pocillopora damicornis	1	73.0	73.0	0.00	73.0	73.0	0.73%
	Porites lutea	1	100.0	100.0	0.00	100.0	100.0	1.00%
	Porites rus	52	2074.0	39.9	53.99	310.0	2.0	20.26%
	Seriatopora hystrix	11	439.0	39.9	18.36	65.0	12.0	4.39%
							Total	**61.23%**
Algae	?Algal species	10	625.0	62.5	45.89	180.0	10.0	8.25%
	Coralline algae	4	144.0	36.0	24.60	75.0	13.0	1.44%
	Dictyota sp.	1	15.0	15.0	0.00	15.0	15.0	0.15%
	Halimeda opuntia	7	217.0	31.0	20.08	60.0	7.0	2.17%
	Turbinaria ornata	2	65.0	32.5	17.50	50.0	15.0	0.65%
							Total	**12.66%**
Substrate	Coral rock	29	1611.0	55.6	60.23	280.0	3.0	18.01%
	Dead standing coral	22	618.0	28.1	31.10	110.0	2.0	6.18%
	Rubble	8	206.0	25.8	19.95	60.0	4.0	2.06%
	Rubble and sand	5	216.0	43.2	18.30	65.0	10.0	2.16%
	Sand	1	50.0	50.0	0.00	50.0	50.0	0.50%
		Total	**98.3m**				**Total**	**28.91%**

3.5 Transverse Ridge and the Southeast Margin of the Main Palolo Deep

(Transects 25; 26a,b; 27a,b; 28a,b)

General Description

The ridge is a natural boundary between the Main Deep and the Southern Palolo Deep. This area is similar to, and extends from, the coral zones of the Southern Deep. The bathymetry of the area is different, sloping to a greater depth. Laterally, the Transverse Ridge mounds from 10m on the southern side with a gentle slope into the Main Deep (Figs. 6m, 6p). The area extending along the perimeter of the Main Deep progressively steepens to a vertical relief (Fig. 6o). The coral cover is high and principally comprises *Acropora spp.*

Location

The area is midway along the north-south axis of the Palolo Deep. It begins from the southern side as an extension of the terraced area of the Southern Deep, extending to the western perimeter (Fig. 3). It also comprises an area extending to the north-east, along the south-east margin of the Main Deep for a distance of 120m.

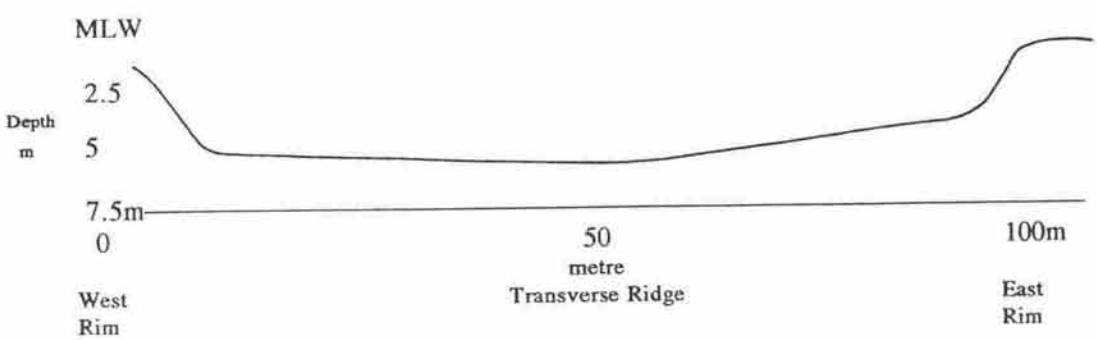
Exposure and Current

The area is very protected by its depth and being bound on both sides by the margins of the Deep. The current is a pronounced feature of this area. The boundary affects the current structure by creating a constriction which causes the current to accelerate with velocity second only to the Deep margin near the platform. This flow provides improved conditions for the coral development which flourishes on the ridge.

Depth

The depth in this area varies, being generally defined by the 6m depth contour on either side of the ridge. From here it rises to 3-4m at mid-ridge, shallowing to 2m at the base of the eastern rim. The profile across the ridge is gentle with the steeper slope on the southern side. The slope becomes more abrupt along the south-east side of the Main Deep. Here it descends to depth with a 45% slope. The profile consists of a 2m level at the base of the rim with the coral cover being limited to 5m. The base of the slope is at 10-12m where the sandy bottom grades slowly to >20m (Fig. 4).

Dead standing coral and the combined substrate of rubble and sand occur in equal quantities on the transverse ridge (11% and 12% respectively). In the coral covered area along the south-east rim, the dead standing coral component becomes dominant with 29% coverage. Rubble extends to depth from 5m. Lateral to the ridge to the north and at a depth greater than 12m, fine sand predominates.



General profile of transects in the area of Transverse Ridge (see Fig. 5).

Algae

In all areas where there are branching *Acropora spp.* is also the filamentous algae (*Cladophoropsis sp.?*) growing from the base of the coral thickets (Fig. 6l). As with the rest of the southern margin, the rim is predominantly coralline algae, and other genera such as *Turbinaria* and *Halimeda* present (Fig. 6e). Its seaward development becomes pavement-like , capping the area of vertical relief (Fig. 6f).

Coral

The Transverse Ridge is characterised by branching *Acropora nobilis* with clumps of *Acropora grandis*. *Porites cylindrica* is represented as a minor component (4%) becoming dominant along the steeper Deep margin (29%). *Porites rus* is the next most dominate with 10% coverage. The *Porites* colonies are often large along the steep rim, forming buttress or cornice-like features. In some cases these have toppled.

Community type

The community composition varies with depth and habitat. This includes the tidal and wave influenced rim, consolidated by coralline algae (Fig. 6f). At greater than 2m, the area is mainly covered by branching coral. Branching coral with the periodic occurrences of *Porites rus* and *P. cyclindrica* is present on the steeper portions and in uncolonised areas of rubble and silt. At depths greater than 5m a rubble slope occurs with little coral, colonised by expanses of *Jania sp.* and concentrations of zooanthids.

At the base of the slope is a sandy, silty substrate with large coral rock or relic bommies which have been recolonised by zooanthids and limited hard coral. Some large *Porites rus* colonies occur with substantial dead, silt covered areas. The sand is devoid of obvious benthos with the exception of several species of holothurians (*Holothuria sp., Bohadschia sp.,* and *Stichopus sp.*) (Fig. 6p).

Dynamics

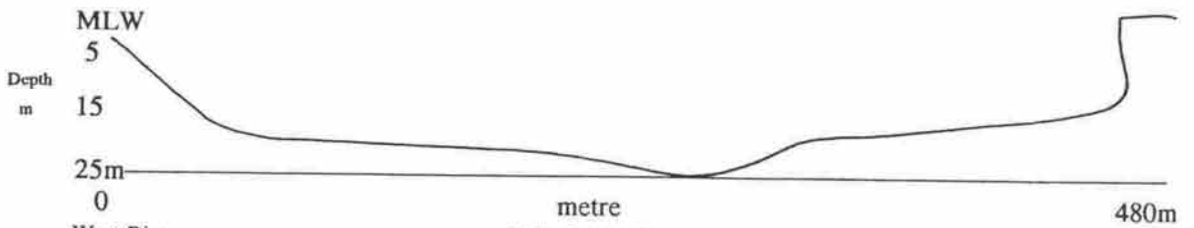
The ridge area is consolidated by sprawling branching *Acropora spp.* This consolidation extends along the Deep margin. Below this, in the steeper areas, is a talus slope. Here the source of material is from the growing rim, which is greater than 5m. The bottom of the Deep comprises the fine silt found at the bottom of this zone.

The water is generally turbid and the rock surfaces are covered with silt. The current, at depth, is minimal with the transport largely taking place in the shallower layers (< 3m). Deposition occurs throughout the Deep as material is washed in and settles as the current slows with depth. Coral growth is limited by substrate, the constant rain of silt and the availability of light in the deeper areas. Zooanthids, as principal monopolisers, flourish in the absence of other benthos such as coral or algae (Fig. 34j).

The Remainder of the Palolo Deep

The south-east margin of the main body of the Palolo Deep continues to the north-east with the relief steepening to vertical surfaces often undercut (Fig. 6o). Rubble slopes occur intermittently. The algal crest is most developed in this area with the surface of the reef flat heavily cemented (Fig. 6f). Coral growth is limited by the relief with larger colonies appearing to be nearly toppling.

The north margin comprises rubble dumped over the edge of the Deep, forming a talus slope (Fig. 6n). This area extends to and along the western margin. The profile becomes more vertical as it approaches the transverse ridge. These surfaces appear to be in a state of more rapid erosion, as there is little coral growth. The depth profile is through the section of maximum width and depth.



General profile of transects in the area of Main Palolo Deep (see Fig. 5)

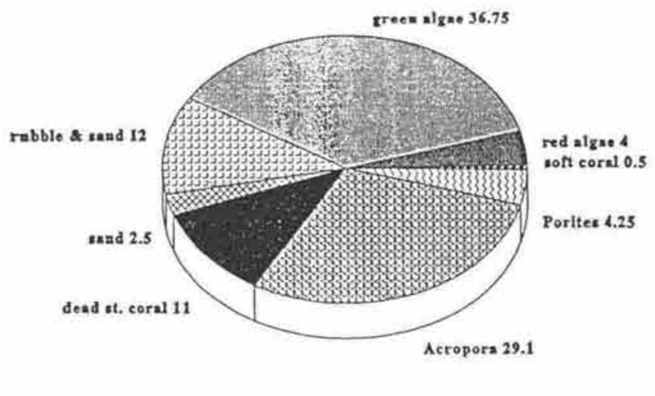
Table 15: Transverse ridge across the Palolo Deep (40m): Transect 25.

	Taxa	N	Total Intercept (cm)	Mean	Std. Dev.	Max.	Min.	Percent cover
Coral	*Acropora grandis*	4	110.0	27.5	8.29	40.0	20.0	2.75%
	Acropora nobilis	6	930.0	155.0	212.50	610.0	10.0	26.35%
	Porites cylindrica	1	170.0	170.0	0.00	170.0	170.0	4.25%
	Soft coral	1	20.0	20.0	0.00	20.0	20.0	0.50%
							Total	**33.85%**
Algae	Filamentous algae	2	1470.0	735.0	405.00	1140.0	330.0	36.75%
	Coralline algae	1	160.0	160.0	0.00	160.0	160.0	4.00%
							Total	**40.75%**
Substrate	Dead standing coral	3	440.0	146.7	157.92	370.0	35.0	11.00%
	Rubble and sand	1	480.0	480.0	0.00	480.0	480.0	12.00%
	Sand	1	100.0	100.0	0.00	100.0	100.0	2.50%
		Total	**38.8m**				**Total**	**25.50%**

Table 16: Southeast margin of the Main Palolo Deep (120m): Transects 26a,b; 27a,b; 28a,b.

	Taxa	N	Total Intercept (cm)	Mean	Std. Dev.	Max.	Min.	Percent cover
Coral	*Acropora grandis*	4	260.0	65.0	11.18	80.0	50.0	2.17%
	Acropora nobilis	8	2020.0	252.5	164.45	530.0	40.0	16.83%
	Pocillopora damicornis	1	10.0	10.0	0.00	10.0	10.0	0.08%
	Montipora sp.	1	15.0	15.0	0.00	15.0	15.0	0.13%
	Porites cylindrica	14	3465.0	247.5	216.80	760.0	25.0	28.88%
	Porites rus	14	1205.0	86.1	45.83	160.0	30.0	10.04%
	Seriatopora hystrix	2	100.0	50.0	40.00	90.0	10.0	0.83%
							Total	**58.96%**
Algae/ zooanthids	Filamentous algae	1	100.0	100.0	0.00	100.0	100.0	0.83%
	Zooanthids	1	430.0	430.0	0.00	430.0	430.0	3.58%
							Total	**4.41%**
Substrate	Coral rock	3	380.0	126.7	124.99	300.0	10.0	3.17%
	Dead standing coral	14	3420.0	244.3	165.99	580.0	50.0	28.50%
	Rubble	2	65.0	32.5	7.50	40.0	25.0	0.54%
	Sand	4	530.0	132.5	65.34	240.0	80.0	4.42%
		Total	**120m**				**Total**	**36.63%**

Transect 25



Transect 26 a,b; 27 a,b; 28 a,b

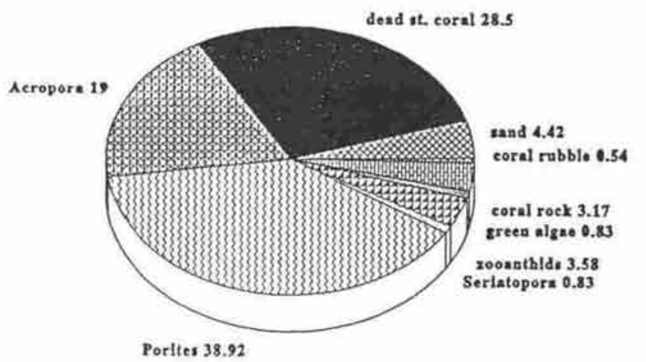


Fig. 12: Graphs of the percentage composition of transects 25; 26a,b; 27a,b; 28a,b.

3.6 Seaward Reef Flat

This area, represented by a rubble strewn reef flat with rubble banks (Fig. 6g), is exposed at low tide and wave-swept at high. The substrate is unstable and characterised as a boulder zone with the material being continually transported shoreward by wave action.

Despite its superficial rubble nature, the underlying reef structure is perhaps the most consolidated of all the reef zones with its dense, pavement-like nature resulting from growth in a high energy environment. The reef crest, from which the spur and groove system originates, forms a buttress against wave action. Rubble is constantly being generated by this action. Cyclone Ofa gave rise to prominent banks by the removal and transport of fore-reef material to this area (Zann and Sua 1991).

The zone is impoverished by the effects of exposure (dehydration, temperature extremes and wave action) limiting the biota. This is largely colonised by coralline algae, which has cementing powers to bind the rubble and create a wave resistant structure. The rubble exists in varying sizes and, as a result, has a variety of habitats. The larger, more stable pieces, reflect a rocky shoreline habitat whereby exposure mediates faunal occurrence. Most of the fauna is cryptic, particularly at low water, or nocturnal.

Occurring in this zone are two interesting structures, the seaward entrance to the Deep, and a small Deep outside the Reserve (Fig. 13a). The entrance comprises shallow channels resulting from a reef structure similar to the spur and groove system. Oceanic water constantly enters the lagoon through this feature, being driven by wave action. Augmenting this flow is the shape of the reef crest whereby waves are refracted into this opening.

Fig. 13: a) Photograph showing the spur and groove system, the seaward entrance to the Palolo Deep and the adjacent smaller Deep.

The small Deep is located at the edge of the reef crest 100m to the east of the Main Deep. Its nature is similar to the seaward portion of the larger Deep. It is mantled by coralline algae and has rubble slopes that have been cascaded into it from the seaward side forming a talus slope. At depth the reef face is steep and often undercut on the eastern and southern margins. Significant coral development occurs in areas of stable substrate. Distinct from the Palolo Deep, this area is more conducive to coral growth, as it has no suspended silt problem and possesses an environment where wave action aerates and continually changes the water.

3.6.1 The Spur and Groove System

This area forms the buttress structure which buffers the force of the oceanic swells (Fig. 13a,b). Reef development here is the most consolidated of all the reef structures. The bathymetric relief is irregular. The channels and extensions from the reef flat form the spur and groove system. These extend as ridges on the reef slope with depth, and consequently form channels often scarping to 2m and descending in a branching pattern. Sand and rubble exist in the bottom of the scoured channels.

Functionally, the spur and groove system breaks the wave force, moderating the effects of this high energy zone. The grooves or channels allow the transport of reef material down the front of the reef. The surging action of the swells scour the channels with this rubble and sand. This zone is universal to exposed areas and is also described at Aleipata (Andrews and Holthus 1989).

b) Photograph showing the branching channels of the spur and groove system extending down the reef slope.

3.7 Seaward Reef Slope

General description

The seaward reef slope is an area characterised by exposure to oceanic waves, rugged relief and a bathymetry ranging from 0-30m. It is unique in that it has been totally denuded by cyclone Ofa and is now regenerating. It is covered by patches of encrusting algae and small coral colonies (Figs. 6h, 30-32). It is the zone which extends from the exposed spur and groove system at low water, to the sandy margin offshore.

Location

This area is the northern most seaward margin of the Palolo Deep Marine Reserve. It is the central part of the reef front of East Reef (Figs. 1,3), which extends from the eastern margin of the Apia harbour entrance to the west, to the Viala river reef pass to the east.

Exposure and current

This habitat is the most exposed in the Reserve. It forms a buttress against oceanic swells with the dense reef structure and benthos conforming to a high energy system. Depth is a substantial buffer, with breaking wave action confined to the upper margin. Strong surge occurs at depth. The current is longshore and seasonally variable.

Depth

From the intertidal spur and groove system inshore, the reef slope descends to a depth of 30m. Its initial descent from the spur and groove system is 2m, followed by a 15^{o}-30^{o} slope. At its most seaward extent, it descends 8-10m vertically, to a coarse sandy bottom. The reef slope relief is characterised by a series of branching channels similar in configuration to the spur and groove system. Though the slope profile is gradual with respect to the bathymetry at the level of the ridges, the general profile is one of undulating relief with channels of varying depth (2-7m). The channel sides are steep with a sandy floor.

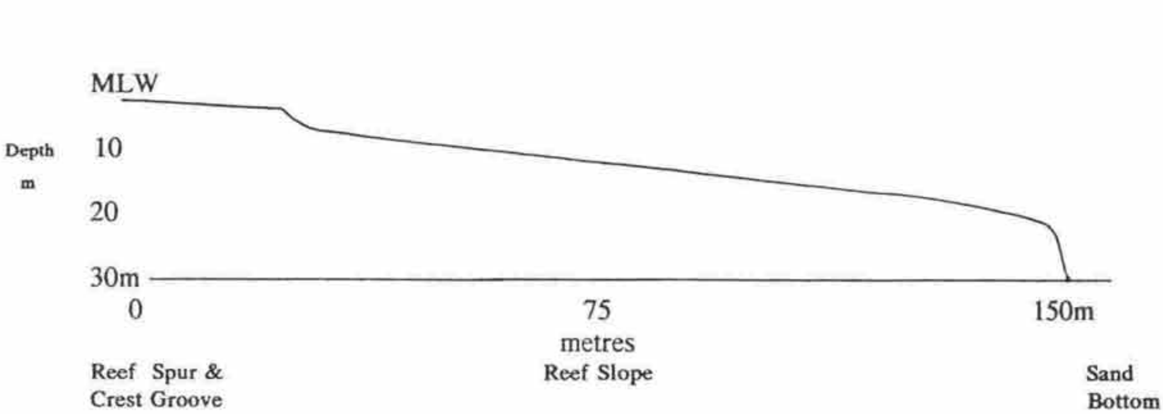
The reef substrate is largely consolidated coral rubble and rock with loose rubble and sand in the channels. Unlike the fine silt of the Palolo Deep, the margin of reef base is coarse, white carbonate sand. Loose sand and rubble are found in the channels and are subject to constant movement by wave action.

Algae

The most prolific benthos at site 3 are patches of an unidentified brown algae that encrust the reef surfaces at >3m. *Halimeda sp.* is common among the rubble hollows. Coralline algae occurs in light coloured patches, bordering each other as they grow together on the reef surface. They are the principal colonisers, collectively making up most of the living cover.

Coral

The occurrence of coral is represented solely by recolonisation after cyclone Ofa. All previous coral was removed by the cyclone. At present, numerous small coral colonies are evident on the reef slope. These comprise five genera. The only recruit identifiable to species level is *Pocillopora eydouxi*. *Acropora spp.* form the overwhelming majority of coral settlement, comprising 64% at site 3 and 87% at site 4 (Tables 17, 18). By assessing the modes of the colony diameters, age classes may be inferred. Densities of 7.8 colonies /m^2 were recorded at site 3 and 33 colonies/m^2 at site 4.



General profile of transects in the area of the seaward reef slope (see Fig. 5).

At site 3, 171 colonies were measured, representing four genera (Table 17). They had a mean density of 7.7 colonies/m^2. The *Acropora spp.* were the most numerous with 5 colonies/m^2. The relative numbers illustrate the preponderance of recruitment from the Acroporidae: *Acropora* and *Montipora spp.* (Fig.15). Recruitment by a six month (4cm diameter), eighteen month (6.5cm) and two and a half year (8.5cm) old colony was discernible in the *Acropora* (Fig. 14). The colony size range was 1-12cm. For the *Montipora*, three age classes were discernible for similar time periods with 2cm, 5cm, and 7cm.

At site 4, five genera are represented with a sample size of 598 (Table 18). The composition of the sample is overwhelmingly *Acropora* (Fig. 17). There are two size classes discernible at 3cm and a 6.5cm size class. This presumably represents recruitment at six months and eighteen months old (Fig. 16). The lack of a third size class indicates no recruitment the first year after cyclone Ofa, which may relate to the occurrence of cyclone Val. The minimum and maximum colony size was 1cm to 13cm.

Fish

Large numbers of herbivorous fish frequent the reef front. The fish are principally scarids, labrids and acanthurids grazing on the encrusting fleshy and coralline algae. Habitat dependent species like the damsel fishes were seen colonising the many spaces amongst the rubble. Top level consumers were rare although a coral trout and grouper were sighted. Pelagics were represented by a small school of unidentified scombrids. Schools of antherinids and caesios were seen about the reef surface.

Community type

This area is characterised by the recolonisation of the fore-reef, after the total removal of coral fauna two years previously by cyclone Ofa. Small colonies which had settled after cyclone Ofa were widespread and appeared unaffected by cyclone Val. Both coral and algal size categories indicate that the small colonies are the result of mass spawning (Wallace and Bull 1981; Wallace 1985 a,b; Babcock et al. 1986). This would have occurred in the months of October and November, for the two or three seasons after cyclones. Coral growth appears good, discernible at generic level.

The lack of living habitat has simplified the reef community with the absence of commensal fauna. Soft corals were established, and with their relatively faster growth, colonies were observed up to 30 cm diameter. Large encrusting colonies of *Diploastrea heliopora* and *Porites sp.* have survived the cyclones, though dead patches indicate some damage.

Dynamics

The reef slope, typically the most luxuriant of all the reef environments, has suffered the removal of virtually all of its living material. That, together with other reef debris, has cascaded on to the reef flat, or been left to be consolidated on the slope. This shows a process of reef development where the reworking of the substrate yields a new surface of varied relief. Recolonisation has been underway for at least two years, with good settlement.

The reef structure has developed in response to a high energy environment with respect to its topography and consolidation. Through the presence of channels and buttresses, the spur and groove system breaks the force of the wave action. This also conveys sand from the reef crest or flat system to fore-reef areas. This sand and rubble transport is vital to the formation of the system. The depth of the channels is the result of sand-abrading wave action.

The understanding of eustasy is important to the explanation of reef morphology. The general reef topography was formed as the result of aerial erosion during the interglacial periods of the Pleistocene (Fig. 18). This process is discussed in the geomorphology section (see Section 4).

Table 17: Combined reef slope belt transects at site 3.

Taxa	N	Total Intercept (cm)	Mean	Std. Dev.	Max.	Min.	Density nos./m^2
Acropora sp.	110	621.5	5.65	2.40	11	1	5
Montipora sp.	48	239	4.98	2.02	12	2	2.18
Porites sp.	4	13	3.25	1.30	5	2	0.18
Pocillopora eydouxi	9	54.5	6.06	3.42	12	2	0.41
Group statistics:	**Total no.**	**sum**	**Mean**	**Std.**	**Max.**	**Min.**	**Density**
	171	928	4.98	0.76	3.4	1	7.77

Table 18: Combined reef slope belt transects at site 4.

Taxa	N	Total Intercept (cm)	Mean	Std. Dev.	Max.	Min.	Density nos./m^2
Acropora sp.	521	2630.1	5.0	3.05	55.0	1.0	15.88
Goniastrea sp.	2	9.0	4.5	1.50	6.0	3.0	0.16
Montipora sp.	21	107.0	5.1	1.62	8.0	2.5	1.87
Pocillopora eydouxi	15	79.5	5.3	2.11	8.0	2.0	1.03
Porites sp.	39	188.4	4.8	2.07	12.0	2.0	0.41
Group statistic:	**Total no.**	**Sum**	**Mean**	**Std. dev.**	**Max.**	**Min.**	**Density**
	598	3014	4.95	0.07	55.00	1.00	19.35

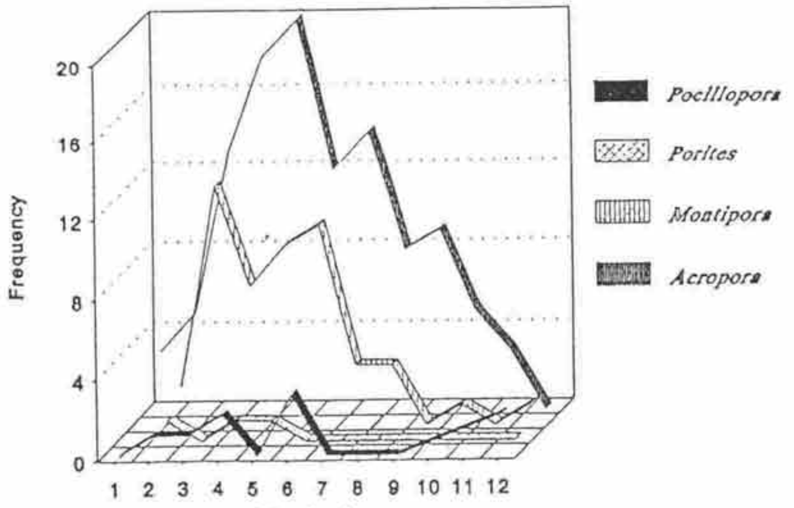


Fig. 14: Frequency/size of coral colony diameters of four genera at site 3.

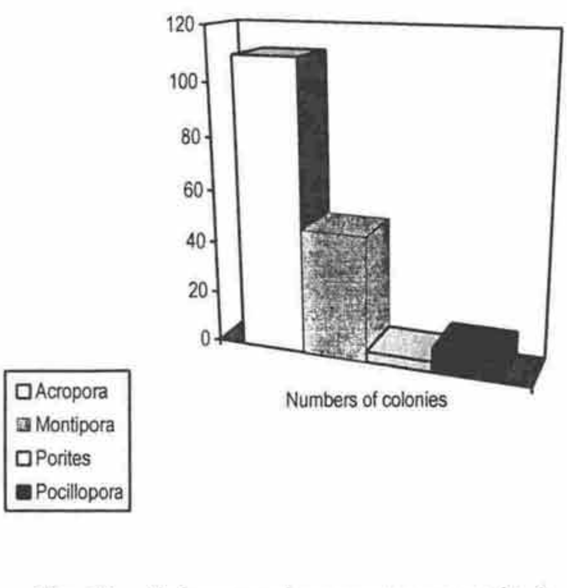


Fig. 15: Colony numbers per genera at site 3.

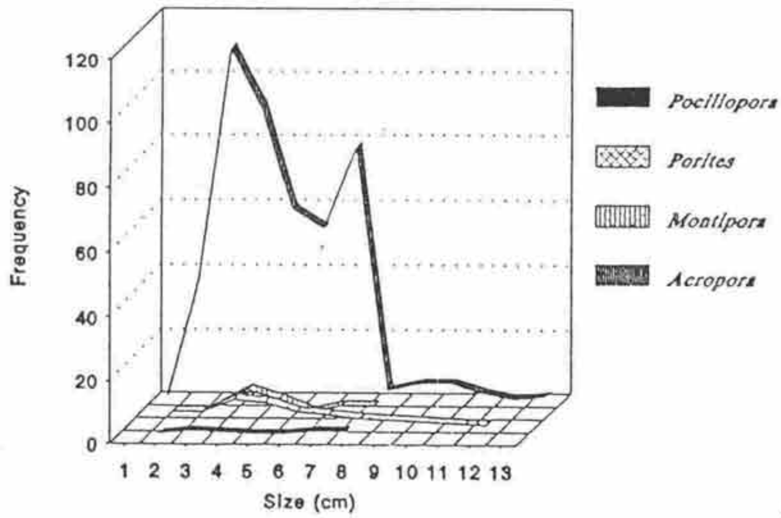


Fig. 16: *Frequency and size of coral colony diameters of four genera at site 4.*

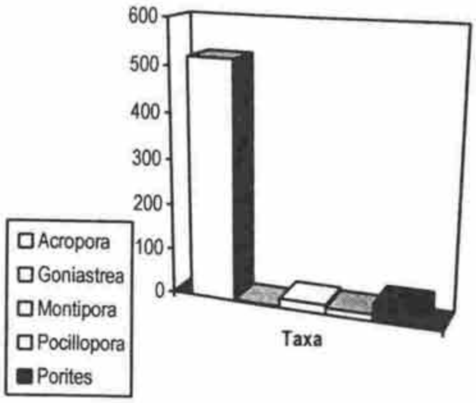


Fig. 17: *Colony numbers per genera at site 4.*

3.8 Fish Survey

The survey of fish at the Palolo Deep involved compiling a species list (Sec. 7.3) and an initial description of differences between habitats. One hundred and eight species in 32 families were identified within the Palolo Deep Marine Reserve. The swimming transects detail the presence of families and relative numbers (Table 21) at monitoring site 2. Though lacking replication, it does provide a general description. Presence/absence information and relative abundances describe the differences between the habitats (Table 19).

The most impoverished area was the Western Reef Flat (transect 21) with a low complement of family presence and abundance. By contrast, the two transects (I, II) run in the southern Palolo Deep had a relatively high abundance of 62 and 101 individuals respectively, in nine families. The Transverse Ridge had 213 individuals, largely due to a school of acanthurids that entered the survey area. The Eastern Reef Flat had intermediate numbers, with a decrease seaward.

The degree of coral cover in the habitat appeared to be controlling abundance. Habitat preference is shown by the presence of larger numbers of pomacentrids and chaetodons, with balistids, serranids and holocentrids found only in the Deep. The Seaward Reef Slope (transect 31) is characterised by an abundance of fish. Eighty-eight individuals in 5 families were recorded. Occurrence here did not correlate with living coral cover but rather with rubble relief and an abundance of algae.

The Palolo Deep offers protection to the fish fauna in a variety of ways. Fishing is prohibited, allowing a reproductive population for recruitment. It would have been particularly important as a refuge during cyclone Ofa when other areas were inundated by the storm. During the diurnal tidal rhythm, fish retreat to the Deep at low tide, returning to the reef flat to graze only at higher water.

Species associations, exclusive to habitat, are evident with the high abundance of coral eating chaetodons among the *Acropora nobilis* thickets. The territorial Bluntsnout Gregory, *Stegastes lividus*, is also associated here in large numbers (4 individuals/m^2).

At monitoring site 2, fish transects (I, II) were conducted for comparison with other habitats and to provide some basis for resurvey as part of the monitoring programme. Table 19 provides a record of this information.

Table 19: Comparative fish abundance at monitoring site 2, the eastern reef flat, the transverse ridge and the seaward reef slope. (The sample transect area is 40m X 2m.)

Transect no.	I	II	17	18	19	21	25	31
Family:								
Holocentridae	4	3	0	0	0	0	0	0
Serranidae	1	3	0	0	0	0	0	5
Mullidae	4	1	3	6	5	6	6	0
Chaetodontidae	14	17		0	4	0	8	0
Pomacentridae	32	49	[illegible]	1	6	12	33	20
Labridae	3	5	9	14	3	6	10	18
Scaridae	0	0	0	12	6	0	0	15
Acanthuridae	4	6	1	0	0	0	130	30
Siganidae	1	16	8	3	3	0	30	0
Monacanthidae	0	0	3	0	0	0	0	0
Balistidae	3	1	0	0	0	0	0	0
Others	0	0	8	4	0	0	3	0
Total:	**62**	**101**	**40**	**34**	**22**	**18**	**213**	**88**

Transect locations:

I, II : Monitoring site 2 transects
17-19 : Eastern Reef Flat
21 : Western Reef Flat
25 : Transverse Ridge
31 : Seaward Reef Slope

4. Geomorphology

4.1 Reef Origin

The living reef types found in Western Samoa are wholly fringing reefs, although Moreton et al. (1989, MS) in following the terminology of Stearns (1944), classifies the seaward crests of some of these as barrier reefs.

The formative elements of accretion and erosion combine with the processes of conditioning by sea level fluctuation and periodic aerial erosion, vertical movement through tectonic activity, and the overlaying and establishment of new surfaces by lava flows, to create the present reefs.

Assessment of coral reef history is complicated. Early development was in the post-Pliocene, where it grew on an erosion built platform resulting from the degradation by Pliocene volcanic activity. On Upolu, the situation was unique as many of the old reefs were buried by volcanic activity (Kear and Wood 1959), providing new surfaces for development when the sea level rose.

The Palolo Deep reef developed on the eastern end of a gentle sloping shelf, was created during the mid to late Pleistocene by the Mulifanua volcanics. The most extensive Western Samoan reefs also occur on this substrate extending along the north coast. They are much more expansive to the west with their seaward margins two miles off the coast. It is here that the decreased bathymetry has allowed the formation of barrier-like reefs. Reef development to the east is much reduced where the oldest volcanics (Fagaloa) of much older Pliocene age have lost their barrier reefs during the Pleistocene submergence or sea level rise. The bathymetry here is much steeper inhibiting reef development as it was unable to keep pace with the submergence.

Relic or drowned barrier reefs (at 50-80m near shore and 80-100m depth, occurring 1-1.5 km offshore) have been speculated (Moreton et al. 1989 MS.). These would be much older than the present reefs and would have been exposed to aerial erosion several times during the Pleistocene when sea levels were at their lowest. Rather than their demise due to rapid submergence, it is likely that volcanic activity was responsible.

The area overlaid by Pleistocene lava flows was extensive and those areas peripheral to them must have been affected and probably extinguished.

The Pleistocene is the epoch of the Ice Age. It was characterised by several major periods of glaciation separated by warm intervals. During each glaciation the polar icecaps increase their volume, which consequently causes a drop in sea level. Eustatic fluctuation during the Pleistocene (see Fig. 18 below) alternatively caused these reefs to emerge and drown. Sea level fluctuated between present mean sea level and minus 150m (Chappell 1981).

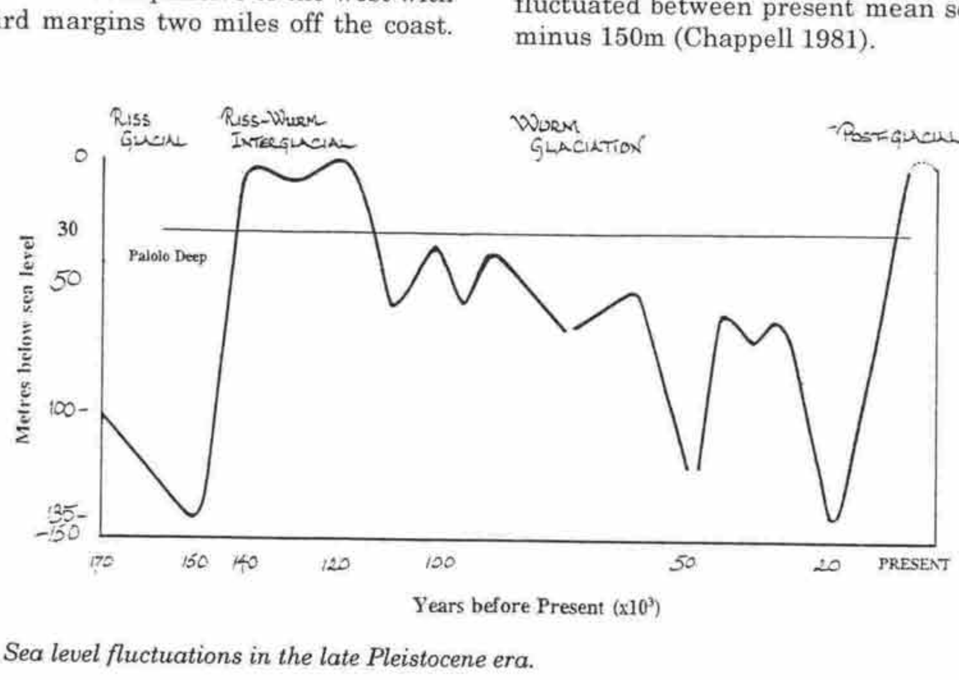


Fig. 18: Sea level fluctuations in the late Pleistocene era.

During the last glaciation (20,000 years ago), the sea dropped to over 100 metres below its present level. Worldwide, coral reefs were exposed, often left high above sea level. This period was so dominated by sea level changes that for about three-quarters of its history, most of the reef areas that we see today have been out of the water. Acid rain can etch through limestone with comparative ease, so that during the centuries when rain fell on the carbonate rock it was dissolved. At those times the reefs would have been eroded, producing caves, gutters and valleys in the limestone matrix. After they were flooded by the sea, marine life would gradually re-establish and corals would start to grow (Veron 1986).

The reef is built by layers of coral and coralline algae, growing upon the eroded gutters and valleys. To a large extent, these eroded substrata govern the shapes of modern reefs. The caves formed through this dissolving process subsequently collapsed, forming Deeps or Blue holes.

During the period of submergence from the late Pleistocene to a Recent or Holocene high sea level, drowning of reefs occurred on the steeper coasts. As well as submergence, emphasis must be given to the erosional aspect of the steep reef slope, where early coral colonisation and consolidation is prevented through lack of protection in a high energy environment. The present reefs owe their occurrence to the reduced slope of the lava flows, which permit successful settlement and development (Moreton et al. 1989 MS).

Due to volcanism, development of most of Upolu's reefs is very recent. It occurred on a surface that was laid down in the late Pleistocene when the sea level was lower than the base of the existing reefs. This provides us with a minimum reef age of about 8000 years. B.P. for the Palolo Deep. This presumption is based on known sea level fluctuation without the complication of tectonic activity. The seaward reef base is 30m deep and would not have been subject to colonisation until that time (Fig. 18).

Though tectonics and the likelihood of the reef structure being greater in extent than is evident may modify this presumption, it is unlikely that it is older than the Holocene (< 20,000 years B.P.). This means that unlike most of the coral reef systems of the world, the present reef relief is not the result of a living veneer, overlaying the karst or weathered topography of the pre-Pleistocene reefs.

4.2 Blue Hole or Embayment?

The most interesting feature of the Palolo Deep Marine Reserve is the Deep itself, a steep sided lagoon embedded into the reef flat. Moreton et al. (1989) attributes this feature to the progressive closure of one of the convolutions or embayments "by which the barrier reefs outer margin is inturned into a grotto, or closely sheltered 'deep hole'".

Two physical features support this theory. Firstly, the maximum depth in the Deep is equivalent to that at the base of the seaward reef slope. Also communication between the Deep and the ocean still exists through a shallow channel in which the spur and groove system is shared. The embayment prior to closure may have been the old river course of the Vaiala River, now responsible for the adjacent embayment.

Alternative hypotheses concern freshwater upwelling via volcanic tunnels or pipes which concentrate the emerging groundwater into wells (Kear and Wood 1959) inhibiting coral growth. Solution is a likely mechanism for the formation of the Deep, whereby a cavern has been created by freshwater dissolving the carbonate, leading to a cave which has subsequently collapsed (Palmer 1984).

This hypothesis mitigates against the recent age of the reefs. This is because the process occurs during subaerial periods, when the reefs have been exposed by a lowering of sea level. The recent formation of the reefs (< 10,000 years ago) would not have allowed this to occur as older reefs had been covered by volcanic material in the Pleistocene. If this volcanic activity occurred prior to 150,000 years ago, then the mechanism is valid. This is because sea level reached present levels twice during the Riss-Wurm interglacial before receding for 100 thousand years (Fig. 18). The development of the blue holes on the Great Barrier Reef in Australia is thought to be the result of several low sea level periods (Bachshall et al. 1979).

Variously known as 'blue holes', submerged sinkholes or drowned dolines are thought to be a karst feature developed during the Pleistocene lowering of sea level (Agassiz 1894). These occur throughout the world with most of the examples described in the Caribbean (Agassiz 1894; Jordan 1954; Dill 1977; Stoddart 1962). Blue holes exist in Australia (Bachshall et al. 1979) and at Bikini and Eniwetok atolls (Emery, Tracey and Ladd 1954).

The origin of the blue hole has been considered in the context of the antecedent karst hypothesis whereby recent reef growth is but a thin veneer over the aerially eroded Pleistocene reef growth (Purdy 1974). The term 'blue hole' comes from the colour of the deeper water of the feature in contrast to the lighter green/brown colours of the reef flat.

From the description, the *Lighthouse Reef Blue Hole* in British Honduras (Dill 1977) is a similar feature with respect to its superficial appearance from the air and with respect to its ecological zonation, debris concentrations and fine sediment bottom. Elements of profile such as the undercutting of the vertical wall areas indicate that it may indeed be a collapsed cave. Porosity in the walls, where rubble material has also been consolidated, is another similarity.

The blue holes on the Great Barrier Reef are similar to the Palolo Deep in that they have a coral rim giving way to a steep slope with a fine sandy bottom. There is high coral cover near the surface, diminishing with depth. Below the shallow area of coral development, rubble predominates, often occurring in chutes whereby it slides down depressions in the slope. The relatively flat bottom is characterised by creamy, sticky mud.

The description of collapsed dolines (Bachshall et al. 1979) provides a good description of a feature similar to the Palolo Deep. Futher evidence for this theory is provided by the presence of a small Deep to the east. This structure appears as a collapsed cavern. It is most improbable that this small but relatively deep structure could be created by a closing off of a convolution of the reef margin.

4.3 Enviromental Change

From the coral growth in the bottom of the Deep it appears that change has occurred. Now appearing as relic material, coral growth must have been luxuriant at greater depth in a former time.

The following processes appear to maintain the Deep. Firstly, coral growth about the edges is limited by the angle of the slope. Consolidation is confined to the rim with the area below less so and the coral colonies subject to toppling as they increase in size. Depth and turbidity limit the vertical extent amenable to growth. The east/south-east portion of the Deep is the best example of this, with its steep slope and shear faces (Fig. 6o).

The strongest cyclone in 150 years (Ofa) followed a year later by a strong cyclone (Val), altered the physical nature of the Palolo Deep and its adjacent reef area. The outer reef slope was assaulted by huge waves for a week, at which time the existing coral reef was removed. This material progressively scoured the reef front down to bare rock, with a large portion of it finding its way on to the reef crest as rubble banks. During this period and with the subsequent cyclone Val, much of this material was deposited into the Deep forming rubble slopes on the northern and western sides.

Secondly, though cyclonic activity adds material to the Deep, its turbulence may serve to remove substantial quantities of the suspendible material. Though the large quantity of rubble created by cyclone Ofa may represent a once in a hundred and fifty year event, this is but a moment in the history of the Deep where such an event must have occurred many times. The rubble slopes had been well established prior to cyclone Ofa (Zann and Sua 1991; Dahl 1978).

4.4 History of the Palolo Deep for the last 39 years

The most recent changes in the Palolo Deep concern terrestrial changes around it. Particularly over the last 20 years, urban development, including land fill reclamation, and the clearing of the watershed have increased the silt load in the rivers and streams discharging into the ocean. Currents, particularly with respect to circulation through Apia harbour, convey this silt across the East reef. Here, the Palolo Deep acts as a sink where accumulation occurs. This silt is continuously resuspended, affecting the living environment within.

Inspection of aerial photography taken periodically since 1954 provides an insight into some of the changes that have taken place on the reef flat (see Fig. 19). Though interpretation of the aerial photos can be difficult due to differences in perspective and photographically induced contrast, valuable information can be gained by a general comparison.

The presence of rubble banks is a consistent feature of outer reef flat topography. Though now more extensive after cyclone Ofa (Zann and Sua 1991), these banks are always present as the result of the constant accumulation of fore-reef material over time from varying degrees of storm and large oceanic swell conditions.

The reef flat benthos is seen to change in location and concentration. The protection of the eastern reef flat by the Deep, allowing greater benthic development, is evident in the 1954, 1970 and 1993 photos. The western reef flat shows a marked change in the 1954 and 1970 photos. This may relate to such events as the extensive landfill and coastline alteration during the harbour dredging in the 1960s and the construction of the main port in the 1970s.

The current regime was altered, changing the western reef flat environment. This change is coincidental with the rural and urban development, where river borne silt loads have progressively increased. The early 1980s saw the development of the Royal Samoan Hotel project with its xtensive landfill and dredging adding to the suspended sediments.

Growth in the south-east margin of the Palolo Deep is evident since the 1954 photo with a change in the perimeter profile. The intertidal *Porites* flat extending from the algal rim into the east reef flat shows greater development when compared with the 1954 and 1970 photos. An exception to this is the area buried by rubble at the seaward end.

At the rim is an area of surface consolidation. Underwater inspection reveals erosional features such as undercutting at the large *Porites* bommie (Fig. 35d) and in the vertical reef face near the entrance (Fig. 6o). A prominent talus slope occurs along the south-east margin of the Main Deep. It is likely that these features are a result of cyclone Ofa, as the perimeter profile indicates growth and not progressive erosion.

Other post-cyclone Ofa features, evident from the 1990 photo, are the large rubble banks with the reef flat benthos of 1970 removed. These rubble banks represent a change in the two habitats. With their origins from the reef slope, this habitat is now open to colonisation. The area of deposition is now one of constantly changing substrate, which, due to its relief, is more like a rocky shore habitat with varying degrees of intertidal exposure.

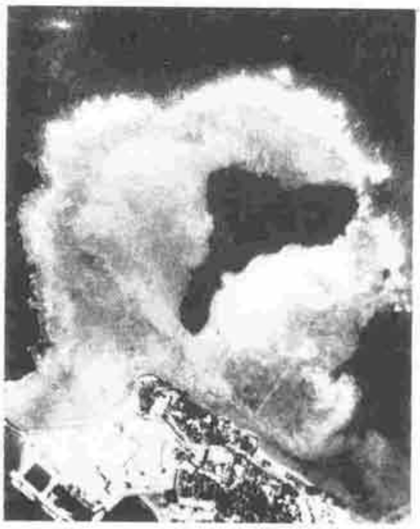
In the 1993 photo the continued excavation of the Western Reef Flat is obvious. This had its beginning as early as 1987, but became more developed in 1990 and is now a major erosional feature. This is an area of substrate instability and must contribute to the coarser component of the Deep's sediment.

Fig. 19: An aerial view of the Palolo Deep from the years 1954 to 1993.

1954

1970

1980



1987

1990

1993

5. Monitoring Programme

Four monitoring sites were set up to allow continued assessment of the condition of the benthic assemblage over time (Fig. 20). For three of the sites (1, 2 and 3), each station comprises a series of quadrats located 10 metres apart. In sites 1 and 3 there are three quadrats per station while in station 2 there are six (Figs. 21-32).

The composition of each was noted and photographed. The quadrats are one metre square and are permanently positioned by steel stakes. These quadrats are positioned along transect lines of known position. The configuration of the lines and quadrats vary with the site. The line transects were analysed as spreadsheet data and tabulated in the manner of the general survey data. Site 4 is represented by belt transects only.

5.1 Site 1

Site 1 is positioned along Transect 18a,b originating from the middle buoy (no. 2) on the eastern Reserve boundary. The first quadrat is located 10m from the base of the buoy, while the second and third are located at 10m intervals along the line at 20m and 30m respectively.

5.2 Site 2

Site 2, near the transect ridge, is located in the Southern Palolo Deep in the general area of the survey transects numbered 6, 11 and 16. This area represents the seaward end of the area surveyed in the Southern Palolo Deep near the Transverse Ridge. Six quadrats have been established with line transects connecting quadrat pairs, located on the same depth profile (i.e. quadrat nos. 1-2, 3-4, 5-6). The line transect information is compiled in Table 20.

A fish survey for the same area is summarised in Table 21. The sample is from two belt transects which run from quadrat one to five and from quadrat two to six (see Sec. 2. Methods).

5.3 Site 3

Site 3 is located on the Reef Slope. It is represented by a combination of three quadrats with two line transects extending along the edge of the quadrats and two belt transects adjacent (Fig. 20). Information from the line transects is compiled in Tables 22 and 23. The belt transect information is used in the description of the seaward reef slope (section 3.8; Table 17; Figs. 14, 15). The site location is in line with the western boundary of the Reserve. The compass bearings are: western headland 280^{o} compass (most seaward), eastern headland 99^{o} compass (most seaward), eastern end of the tiled dome on the government building 210^{o} compass, and east side of the Palolo Deep platform 193^{o} compass. The site depth is 10m.

5.4 Site 4

Site 4 comprises two belt transects. The information is compiled in Table 18 and Figures 16 and 17. The location of the site is marked on Figure 20. Its position is marked by steel stakes. The site depth is 12m.

5.5 Monitoring Fequency

The monitoring frequency should be at six monthly intervals or after an event of probable influence. At times when a particular effect or process is occurring, the frequency of monitoring should be adjusted so that it is adequate for description. The procedure should include photography of the quadrat areas and reassessment of the line transects. The monitoring effort must be commensurate with the change to be assessed. A short comparative description may suffice if little change is evident from the original photographs. Coral bleaching or death, storm damage, crown-of-thorns presence, changes in the relative composition of the substrate and biota are elements that should be recorded.

Fig. 20: Location of the monitoring sites and belt transect.

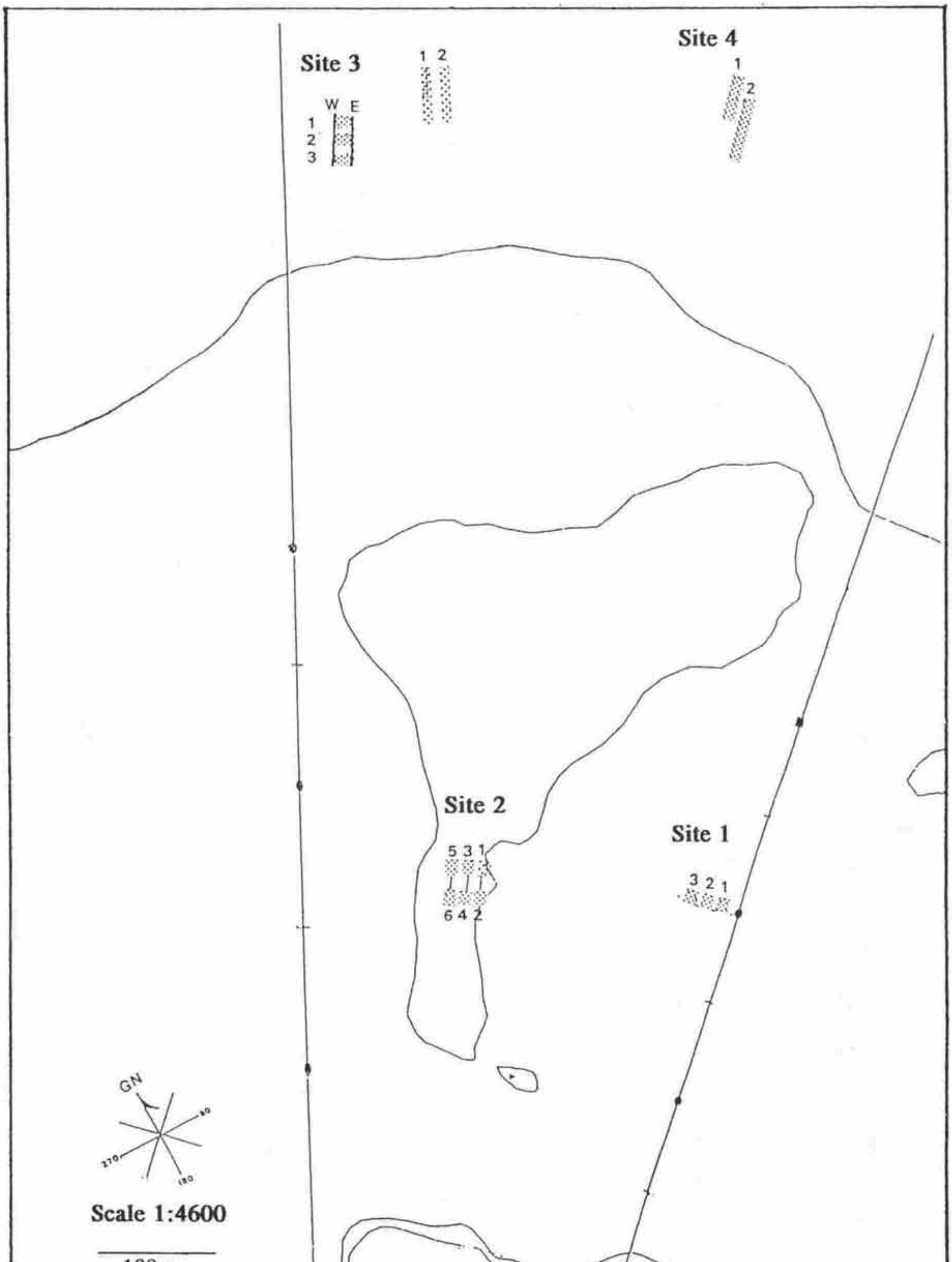


Fig. 21: Eastern Reef Flat: site 1; quadrat 1

Species identification:

1 *Dictyota sp.*
2 *Montipora sp.*
3 *Pocillopora damicornis*
4 *Porites cylindrica*
5 *Porites rus*

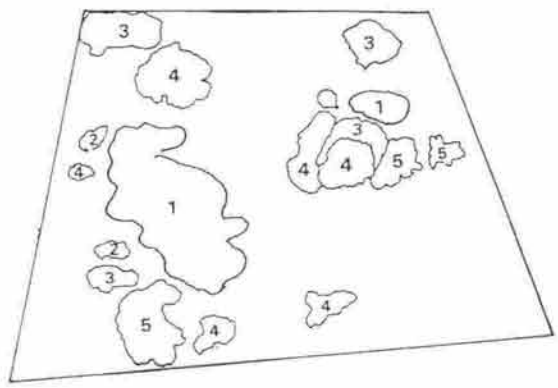
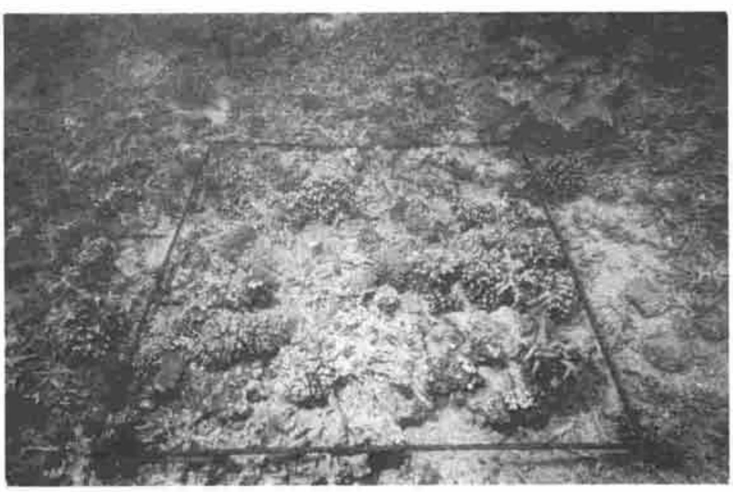


Fig. 22: Eastern Reef Flat: site 1; quadrat 2 .



Species identification:

1 *Acropora nobilis*
2 *Pocillopora damicornis*
3 *Porites cylindrica*
4 *Porites rus*
5 *Psammocora contigua*

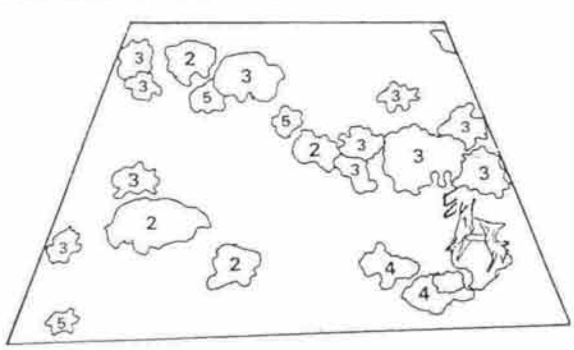
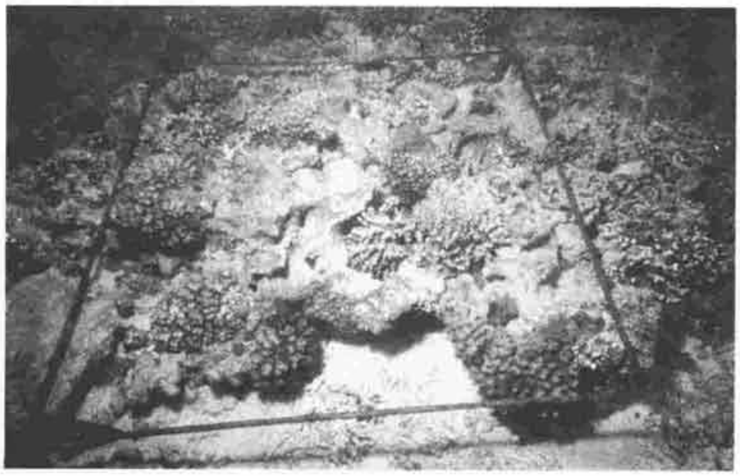
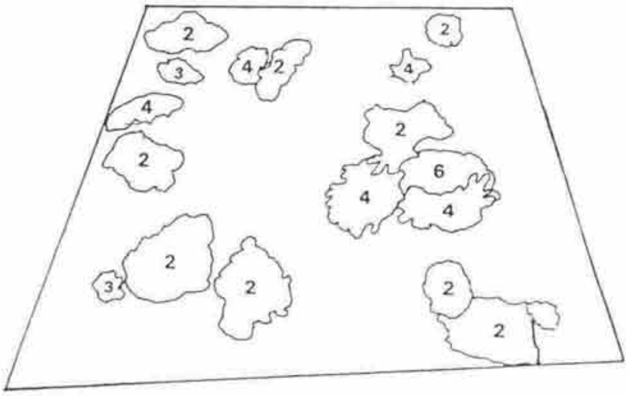


Fig. 23: Eastern Reef Flat: site 1; quadrat 3 .

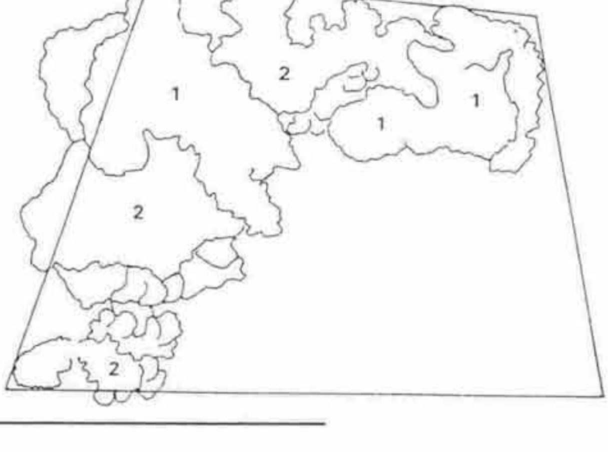




Species identifications:

1. *Montipora sp.*
2. *Pocillopora damicornis*
3. *Porites verrucosa*
3. *Porites cylindrica*
4. *Psammocora contigua*

Fig. 24: Palolo Deep: site 2; quadrat 1.



Species identification:

1. *Porites cylindrica*
2. *Porites rus*

Fig. 25: *Palolo Deep: site 2; quadrat 2*

Species identifications:

1. *Acropora nobilis*
2. *Jania sp.*
3. *Porites cylindrica*
4. *Porites rus*

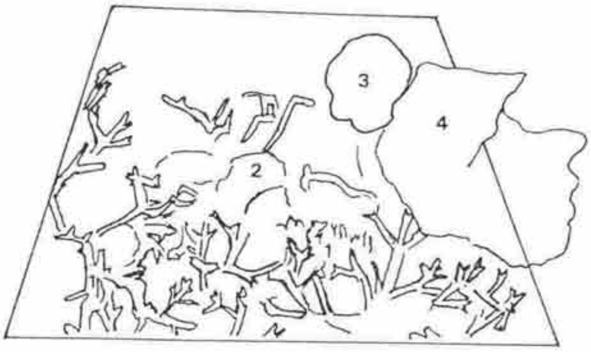


Fig. 26: *Palolo Deep: site 2; quadrat 3.*

Species identifications:

1. *Acropora nobilis*
2. *Cladophoropsis sp.*

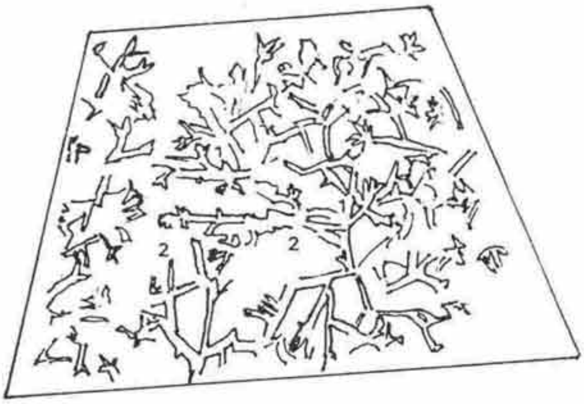
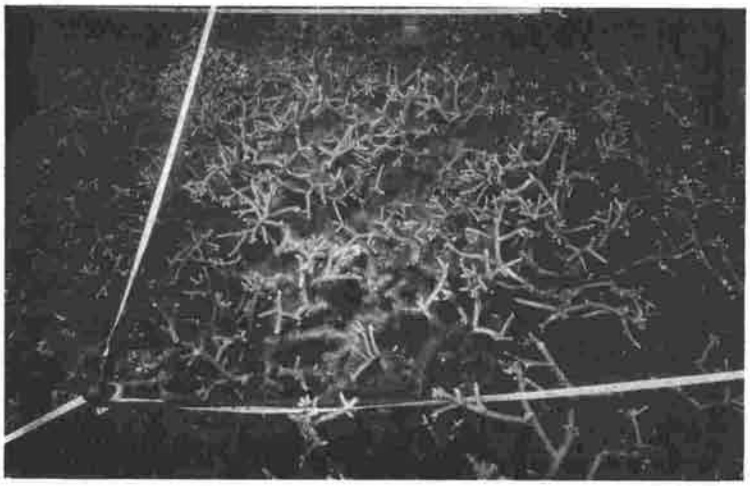


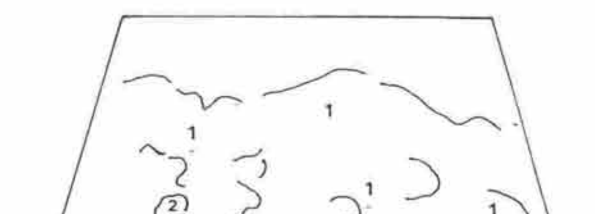
Fig. 27: Palolo Deep: site 2; quadrat 4.



Species identifications:

1. *Acropora nobilis*
2. *Cladophoropsis sp.*
3. *Porites rus*

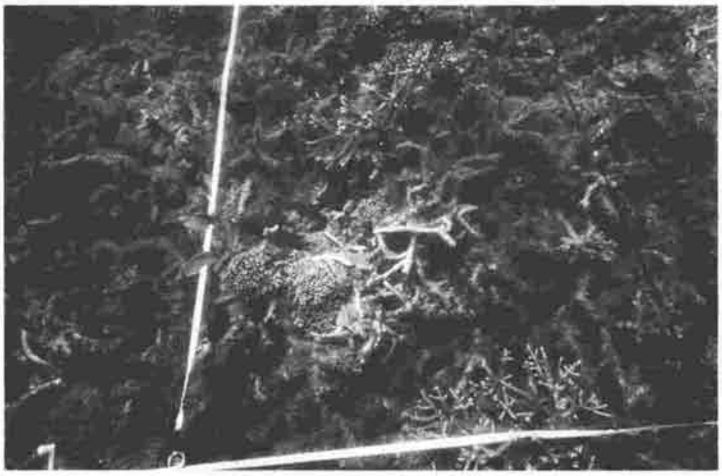
Fig. 28: Palolo Deep: site 2; quadrat 5.

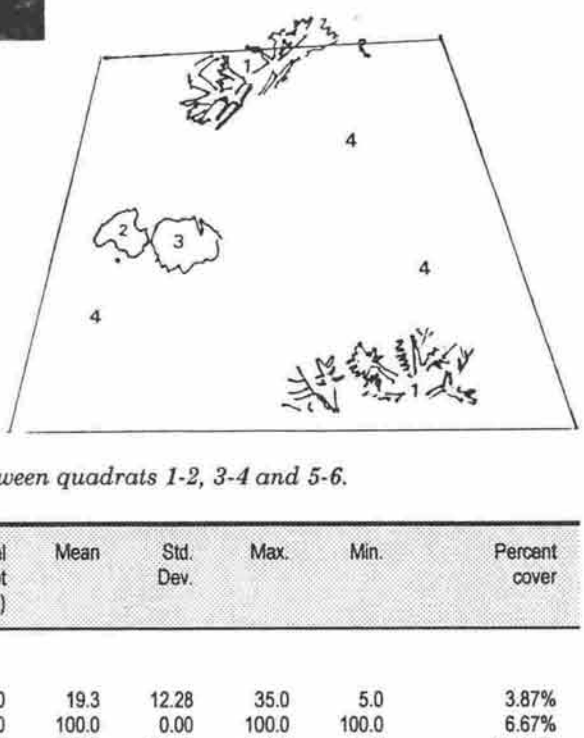


Species identifications:

1. *Jania sp.*
2. *Pavona decussata*
3. *Halimeda sp.*

Fig. 29: Palolo Deep: site 2; quadrat 6.





Species identifications:

1. *Acropora nobilis*
2. *Pocillopora damicornis*
3. *Seriatopora hystrix*
4. *Cladophoropsis sp.*

***Table 20: Monitoring site 2: Transects A, B and C** run between quadrats 1-2, 3-4 and 5-6.*

	Taxa	N	Total Intercept (cm)	Mean	Std. Dev.	Max.	Min.	Percent cover
Transect A								
Coral	Acropora nobilis	3	58.0	19.3	12.28	35.0	5.0	3.87%
	Porites cylindrica	1	100.0	100.0	0.00	100.0	100.0	6.67%
	Porites rus	3	520.0	173.3	78.78	250.0	65.0	34.67%
	Seriatopora hystrix	1	685.0	685.0	0.00	685.0	685.0	45.67%
						Total		**90.88%**
Substrate	Rubble	3	77.0	25.7	11.73	42.0	15.0	5.13%
	Sand	2	60.0	30.0	10.00	40.0	20.0	4.00%
						Total		**9.13%**
Transect B								
Coral	Acropora nobilis	2	775.0	387.5	232.50	620.0	155.0	77.50%
	Seriatopora hystrix	1	195.0	195.0	0.00	195.0	195.0	19.50%
						Total		**97.00%**
Substrate	Rubble	1	30.0	30.0	0.00	30.0	30.0	3.00%
						Total		**3.00%**
Transect C								
Coral	Acropora nobilis	3	45.0	15.0	10.80	30.0	5.0	4.50%
	Porites cylindrica	2	110.0	55.0	5.00	60.0	50.0	11.00%
	Porites rus	1	150.0	150.0	0.00	150.0	150.0	15.00%
	Seriatopora hystrix	1	5.0	5.0	0.00	5.0	5.0	0.50%
						Total		**31.00%**
Substrate	Rubble	1	150.0	150.0	0.00	150.0	150.0	15.00%
						Total		**15.00%**

Table 21: Comparative fish abundance between the monitoring quadrats at site 2. (The segments are 10m.)

Site: 2 Quadrat section:	1-3	3-5	>5	2-4	4-6	>6
Family:						
Holocentridae	0	0	4	0	0	3
Serranidae	0	0	1	2	0	1
Mullidae	0	0	4	0	0	1
Chaetodontidae	10	4	0	4	11	2
Pomacentridae	32	0	0	14	8	27
Labridae	0	3	0	0	0	5
Acanthuridae	0	4	0	2	0	4
Siganidae	1	0	0	3	3	10
Balistidae	2	1	0	0	1	0

Fig. 30: Reef Slope: site 3; quadrat 1.

Species identifications:

1. *Acropora sp.*
2. brown algae
3. *Montipora sp.*
4. *Pocillopora eydouxi*

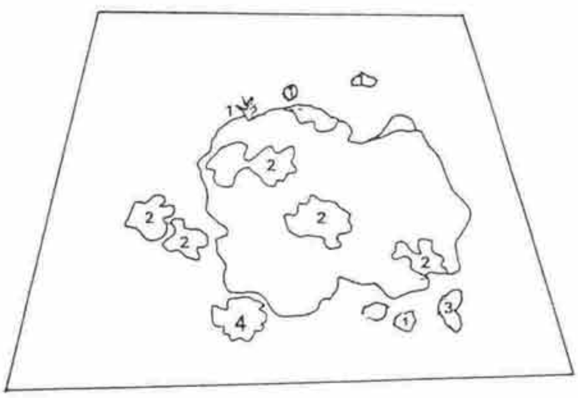
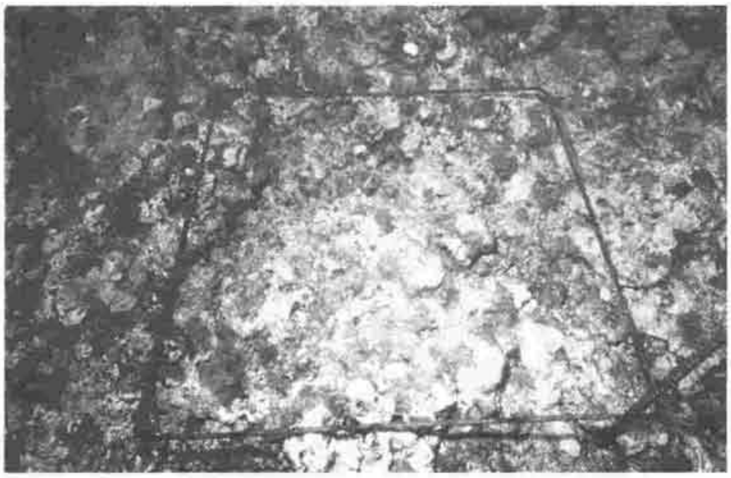


Fig. 31: Reef Slope: site 3; quadrat 2.



Species identification:

1. *Acropora sp.*
2. brown algae
3. *Montipora sp.*
4. *Pocillopora eydouxi*

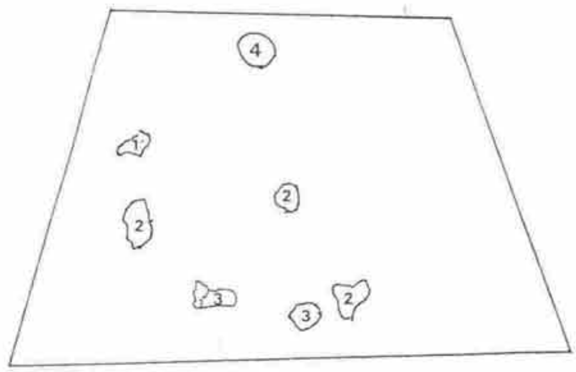
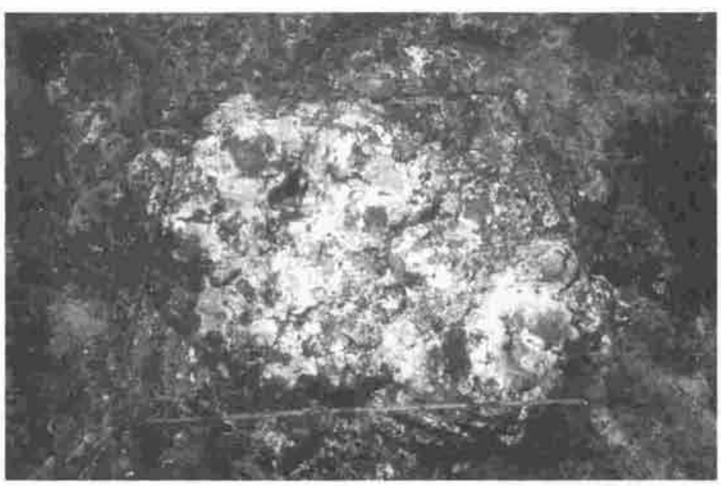


Fig. 32: Reef Slope: site 3; quadrat 3.



Species identification:

1. *Acropora sp.*
2. brown algae
3. *Dictyosphaeria cavernosa*
4. *Montipora sp.*
5. *Porites sp.*

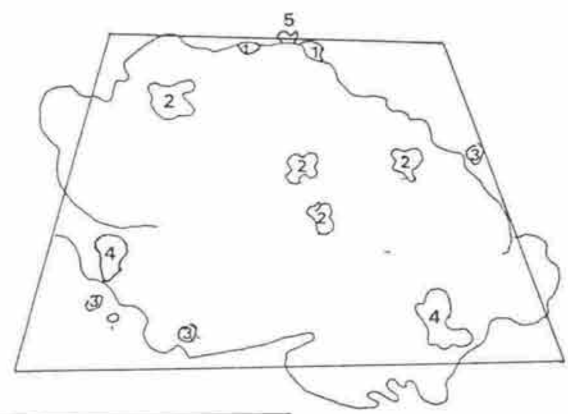


Table 22: Monitoring site 3: Reef slope transect adjacent quadrat on eastside.

	Taxa	N	Total Intercept (cm)	Mean	Std. Dev.	Max.	Min.	Percent cover
Coral	Acropora sp.	9	58.0	6.4	2.75	12.0	3.0	2.90%
	Montipora sp.	4	20.0	5.0	2.74	9.0	2.0	1.00%
	Porites sp.	1	3.0	3.0	0.00	3.0	3.0	0.15%
						Total:		**4.05%**
Algae								
	Coralline algae	17	1915.0	112.6	80.58	315.0	9.0	95.75%
	Halimeda	1	4.0	4.0	0.00	4.0	4.0	0.20%
		Total:	**2000**			**Total:**		**95.95%**

Table 23: Monitoring site 3: Reef slope transect adjacent quadrat on westside.

	Taxa	N	Total Intercept (cm)	Mean	Std. Dev.	Max.	Min.	Percent cover
Coral	Acropora sp.	11	60.0	5.5	0.89	8.0	5.0	3.00%
	Montipora sp.	2	10.0	5.0	0.00	5.0	5.0	0.50%
	Porites sp.	2	13.0	6.5	1.50	8.0	5.0	0.65%
						Total:		4.15%
Algae	Coralline algae	14	1903.0	135.9	115.47	397.0	6.0	95.15%
	Dictyosphaeria sp.	1	14.0	14.0	0.00	14.0	14.0	0.7.%
		Total:	**2000**			**Total:**		**95.85%**

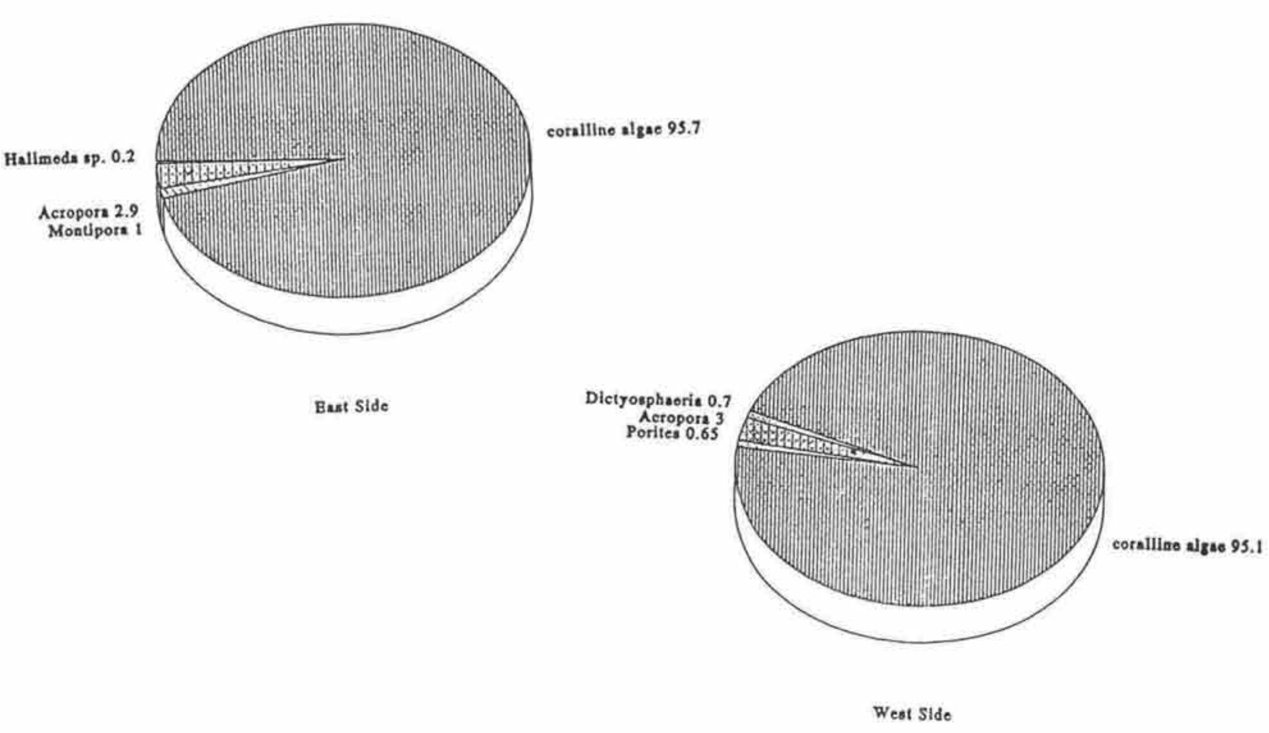


Fig. 33: Graphs of the composition of the site 3 transects: east and west side.

6. Natural History

The following is information on the natural history of selected species found in the Palolo Deep.

Fig. 34a: *Echinometra mathaei:* Burrowing sea urchin on coral rock.

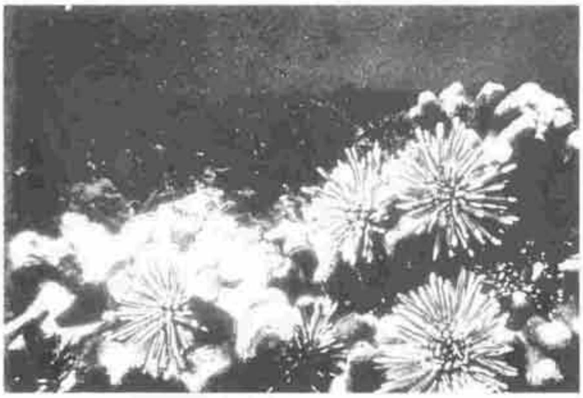
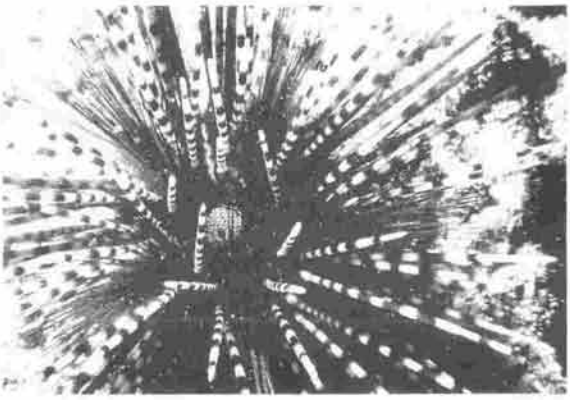


Fig. 34 b: *Echinothrix calamaris:* The nocturnal, banded sea urchin.



Echinometra mathaei

The common name is **Mathae's Sea Urchin** or the **Burrowing Sea Urchin**.

In adults, the upper spines vary from a uniform grey to red, black or a dark green, occasionally with white tips. Juveniles can be brown, pink, green or purple but the spines usually have a white ring at the base. Adult size is about 8.5cm in diameter including the spines.

One of the most common sea urchins on the reef, they range from the Red Sea to the South-west Pacific. Usually found under slabs of dead coral in shallow water areas (0-5m) of the reef flat often in exposed situations such as the reef crest. They are found to reside in cup-like excavations or burrowed out grooves which serve as protection. They make these excavations by abrading away limestone material with their stout spines. Often the excavations represent many generations of effort.

The urchin is a herbivore, scraping algae from boulders and rubble close to its hollow at night, and catching drifting algae.

At the Palolo Deep 'burrowing sea urchins' are common on the reef flat where they inhabit coral boulders. Numbers up to $51/m^2$ were recorded, though the average is between 5-10 urchins/m^2. Their abundance is related to the presence of coral boulders, which provide shelter and on which their food source is found.

Echinothrix calamaris

Commonly known as the **banded or striped sea urchin** because of its white and black banded primary spines. Adult size is about 25cm in diameter (spine length included). Juveniles often have pure white primary spines. It has a spotted bubble-like anal cone.

It has been found from the Indian Ocean to the Red sea, and from Hawaii to Tahiti. This striking sea urchin is confined to shadowy recesses within the reef during the day, and feeds on algae and detrital deposits at night. A night dive in the Palolo Deep will reveal a surprising number of urchins grazing the surface of the rocks.

Extreme caution should be taken when encountering this species as its secondary spines are very sharp, poisonous and cause painful wounds. Along with the long spined sea urchin (*Echinothrix diadema*) they may be considered the most dangerous creatures on the reef, as the careless reef observer will attest.

Fig. 34 c: *Stegastes lividus:* The territorial Bluntsnout Gregory giving rise to coral/algal relationship in next photo.

Photo: Fishes of the GBR: Randall, Allen, and Steene.

Fig. 34 d: *Acropora nobilis* with the algae *?Cladophoropsis* sp.

Stegastes lividus

A member of the Pomacentridae (Damsel fishes), this fish is known as the **Bluntsnout Gregory**. It can be identified by its overall brown colour, frequently with an ill-defined blackish area below the soft part of the dorsal fins.

Adult size reaches 17cm, total length. A very aggressive and pugnacious fish, it occurs in colonies that can emit staccato sounds. An average density of 4 individuals/square metre was observed in the *Acropora nobilis* beds in the Southern Palolo Deep.

The species occurs from South Africa and the Red Sea to the Society Islands and Line Islands. They usually reside among staghorn corals in depths of 1-5m. They defend territories against all intruders, including nipping the legs of divers. As a result of keeping the herbivores at bay, algae tends to proliferate at the base of the coral colonies.

Coral with algal growth

The coral *Acropora* is commensal with the dense algal growth which is a result of the territorial behaviour of the damselfish, *Stegastes lividus*. Many damselfish on coral reef are territorial and some defend the area for months or years. Strongly territorial fish are often rasping or browsing herbivores whose territoriality seems based primarily on the defence of food resources.

The aggressive behaviour reduces total grazing pressure to such an extent that a dense mat of algae develops within their territories. In some instances, this could shade the coral thereby reducing coral growth itself. In the Palolo Deep there is a balance. The coral growth occurs in an open manner above the algae. This allows enough light to penetrate allowing algal development and the colony surface to be cleaned by the current of the constant rain of sediments.

Fig. 34 e: *Chaetodon auriga*: Threadfin Butterfly fish.

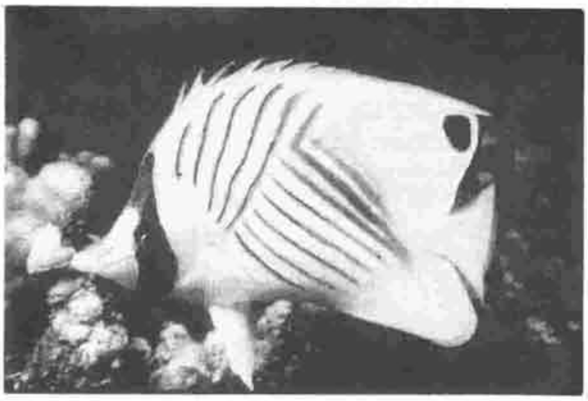
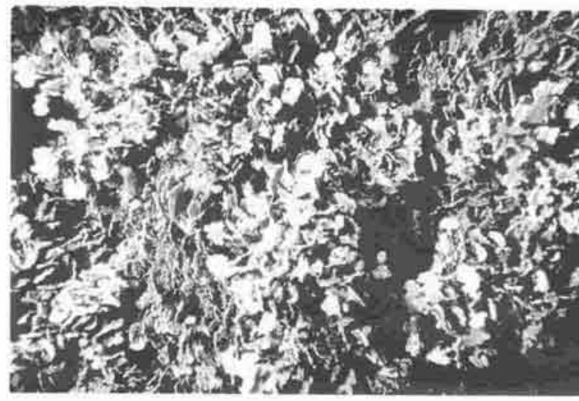


Fig. 34 f: *Halimeda* sp.: This algae is a principal contributor in the sand cycle.



Chaetodon auriga

Also known as the **threadfin butterflyfish**. It can be identified by its converging black stripes (chevron-like) on its sides. It has yellow dorsal, caudal and anal fins posteriorly, and a black spot on the softer part of its dorsal fin with a black band through the eye. Adults usually have a long pennant type filament extension of the dorsal fin, just after the black spot, which is used in territorial defence. Juveniles lack the filamentous trailing. Adults grow up to 20cm in total length.

Occurring from East Africa and the Red Sea to the Indo-Pacific and Polynesia, they can be found singularly or in pairs on shallow protected reefs, and also on outer reefs to 30m.

The Threadfin butterflyfish does not seem to be territorial during the day but at night expects to sleep in its own spot, and beware any fish that gets in the way. It feeds on algae, polychaetes, prawns and coral polyps. In the Palolo Deep, it occurs in the proximity of the large stands of *Acropora*.

Halimeda discoidea

Belonging to the calcified green algae (Chlorophyta), this genus can be easily identified by its distinctive chains of little hard segments made of green kidney-shaped disks. It occurs profusely in both the Caribbean and the Indo-Pacific region and is usually found on the leeward side of the reef. It is found around the margin of the Palolo Deep from the rim to <10m. It is also found on the reef flat but is less abundant due to unsuitable substrate and wave action. It flourishes on the outer reef slope, particularly in the shelter of the cracks and shallow crevices.

The *Halimeda* plays an important part in the sand cycle. The plant deposits limestone within its disks and each chain may add an entire disk everyday. Although the disks are hard, their connections are fragile so that water movement or disturbance from browsing or grazing animals breaks them off quite easily. The disks soon become part of the sand and eventually become minute grains.

Sand not only forms cays, beaches, and lagoon floors, but also fills in the spaces between the coral framework of the main reef structure.

Fig. 34 g: *Acanthaster planci*: The crown-of-thorns starfish enjoys a meal.

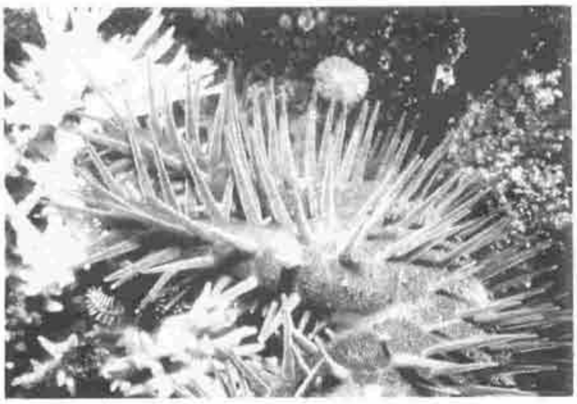
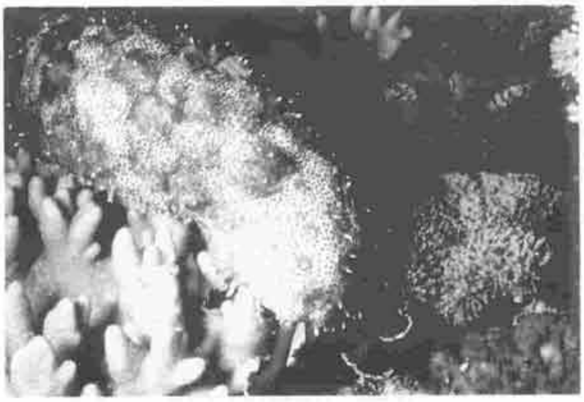


Fig. 34 h: *Bohadschia graeffei*: A grazing sea cucumber.



Acanthaster planci

(see Section 7.3: Crown-of-thorns Starfish.)

Commonly known as the **crown-of-thorns starfish**. This starfish can grow up to 60cm in diameter with 13-16 arms. There are many sharp spines on the dorsal surface that can cause severe injuries and should be avoided or handled with care. The colour range can be quite variable from bright red to deep purple or shades of green. In the Palolo Deep, Acanthaster is particularly colourful with bright orange spines.

It occurs throughout the tropical Pacific region, usually among the corals. It has separate sexes and spawns during the summer months (Birkeland and Lucas 1990). A single female may spawn many millions of eggs. The larval stage may last up to 25 days and travel 500km (Moran 1986).

This spiny starfish feeds on living coral polyps by turning its stomach outwards, pressing it against the coral and digesting it. Upon settlement, the cryptic juvenile feeds on coralline algae. Within 6-12 months, it begins to feed on coral. It reproduces after its third year and lives to a maximum of 9 years (Zann et al. 1987; 1990).

Known predators include the puffer fish, the giant triton, and recently it has been suggested that xanthid crabs may help to protect their host corals by nipping the crown-of-thorns' tube feet thereby causing it to withdraw.

Bohadschia graeffei

Commonly known as **Graeffe's sea cucumber**. The species varies in colour but generally has short white tipped papillae, covered in dark spots with larger mottled brown areas. Adults grow up to 30cm in length. The holothurian's body is relatively firm to touch but it must be treated carefully as it throws out its guts and associated organs (which will be regenerated) as a vigorous defensive action.

It occurs throughout the Indian Ocean and West Pacific. It can be found on the sand or rubble areas of the coral reef, usually in sheltered back reef or lagoon areas. At the Palolo Deep, its occurrence is limited to the sandy, silty bottom of the lagoon.

It is a detrital feeder. Feeding occurs through the intake of sediments and small animals caught up in the soft, sticky 'catching pads' of its feeding tentacles. In some areas, this species has been found to 'clean' detritus that settled on fronds of living algae.

Fig 34 i: *Pterois volitans*: The Firefish or Turkeyfish.

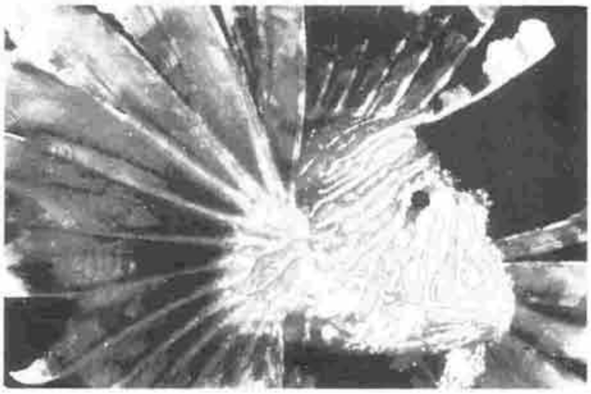
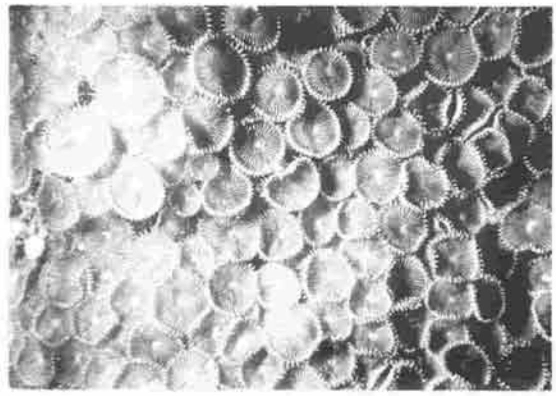


Fig. 34 j: *Palythoa heideri*: At depth in the Palolo Deep, the very common zooanthid.



Pterois volitans

Commonly known as **firefish** or **turkeyfish**. Looking similar to the butterfly scorpionfish, this fish can be distinguished by its separated pectoral fin rays. Colour ranges from pink to black, the body being crossed with pairs of white bands. Adult size is approximately 38cm in length.

It ranges from Western Australia and Malaysia to south-eastern Polynesia and north to Japan. It can be found about lagoon reefs and around coral heads. This firefish usually occurs in a pair or group and inhabits the same cave, ledge or overhang for a number of years. It is mainly found in the southern portion of the Palolo Deep or along the southeast margin of the main Deep.

Although it is known to hunt during day or night, higher activity occurs around twilight and darkness, where it feeds on shrimps. A painful and poisonous sting, that usually subsides in 6 to 12 hours, can result from the penetration of the dorsal spines.

Palythoa heideri

Known commonly as **Heidi's Zoanthid**. These animals appear as stalked anemones and are intermediate in structure between anemones and hard coral. They appear as a dense colonial veneer of brown polyps, each up to a centimetre in diameter. The colour ranges from green to brown.

They are found in rocky habitats below the turbulence of the surf zone to 10m in the warm temperate regions. They occur throughout the tropics from the Indian Ocean to the Pacific. In the Palolo Deep, they monopolise surfaces below the proliferation of hard coral. They are abundant as carpet-like colonies on dead coral bommies in deeper areas. Here there are few benthic organisms. Their proliferation in such an environment indicates less dependence on light and/or a tolerance of persistent siltation.

They feed on plankton and suspended sediments. The polyps are not very sensitive to touch.

Fig. 34 k: *Fungia fungites*: A free living or unattached mushroom coral with tentacles expanded.

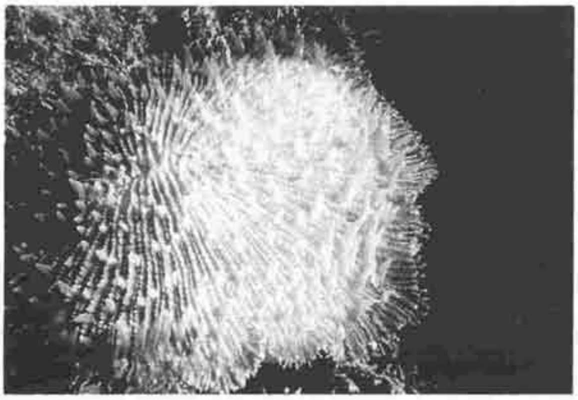


Fig. 34 l: *Amphiprion ocellaris*: Anemonefish commensal with *Stoichactis* sp.

Fungia fungites

One of the many solitary, free living corals which are generally known as **mushroom coral**. A solitary polyp can be up to 28cm in diameter. The corallite, which is usually somewhat oval in outline with a convex upper surface, has a large number of vertical radiating septal ridges. The dent in its centre is the position of the polyp mouth. Unlike most corals, the polyps do not divide to form colonies. The mushroom coral also do not cement themselves to the reef. At the time of larval settlement, they attach and grow to a size of three to five centimetres before breaking free to assume the adult mode.

In the Palolo Deep many of these larval stages can be seen to be attached to the rubble, clustered in depressions along the rim. The occurrence of the adults indicates a preference for this area. The specimen pictured is unusual in its bright colouration.

The species ranges from Eastern Africa and the Red Sea to the Pacific region. This coral is very common on some reefs, and has been confused with *F. danai* which is more circular. Mushroom coral because of its unattached nature generally prefers the quiet waters of the pools, lagoons or the deeper water. It seems very tolerant to silty environments often seen in abundance. In the Palolo Deep it is not very common.

Amphiprion ocellaris

Common name is **Clown Anemonefish**. They are only associated with large sea anemone such as *Radianthus ritteri* and *Stoichactis giganteum*. They can be easily identified by their bright orange colour with 3 white stripes running dorsal-ventrally. Adults grow up to 7cm in total length.

Clown Anemonefish occur from the Tropical Indian Ocean to the Western Pacific. They are found on inshore and offshore reefs, in up to 20m depth. Commensal with the anemone, they are immune to the stinging cell of their host.

They are omnivorous feeders. At night, many anemones close and enfold the Clown Anemonefish. The species breeds in summer, with both adults protecting the eggs. They normally occur as an adult pair, the female being larger with several juveniles occupying the same anemone.

Fig. 34 m: *Millepora platyphylla*: "Fire coral or stinging coral" is actually a Hydrozoan.

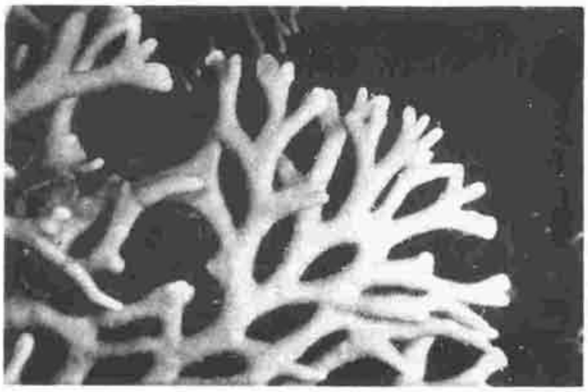


Fig. 34 n: *Tridacna squamosa*: Giant Fluted Clam.

Millepora platyphylla

More commonly known as the **fire coral** or the **stinging coral** because of the burning sensation it causes when touched. *Millepora* are colonial and hermatypic but are not a true or stony coral belonging to the class Hydrozoa.

Colonies are arborescent, platelike, columnar or encrusting with a smooth surface covered by near-microscopic pores. Tentacles project from the colony surface. Visible as fine straight hairs, the tentacles connect with the mouth or gastropore. Sexual reproduction is accomplished through a phase involving minute medusae. These sturdy colonies are capable of withstanding the strongest wave action. Although several different growth forms occur, it is now believed that only one species exists.

This genus ranges from east Africa to the Tuamotus and Marquesas. This species is normally found on projecting parts of the reef where tidal currents are strong. It is also abundant on upper reef slopes and in lagoons and may be a dominant component of some coral communities. In the Palolo Deep, its occurrence is limited to the upper rim area.

Tridacna squamosa

Commonly known as the **giant fluted clam**. It can be easily identified in field by its relatively large size and the characteristic sculpture of its leaf-like flutes. The giant fluted clam has beautiful mottled mantle lobes with variation in colour including blue, green, brown and black. Adult clams can grow up to 40cm in length.

It occurs from low tide mark to 20m. This species ranges from the Red Sea to South Africa and from the Tropical Indian Ocean to the Western Pacific. It occurs in the Palolo Deep as well as on the reef flat.

During low tide when the mantles are exposed, it produces a mucous cover that prevents dehydration. The giant clam has a unique symbiotic relationship with single celled microscopic algae, zooxanthellae. The minute algae in the mantle produce carbohydrates using the sun's energy and provide some of the clam's food. This hermatypic clam is also a filter feeder.

Fig. 34 o: *Carpilius maculata*: Three Spot Crab.

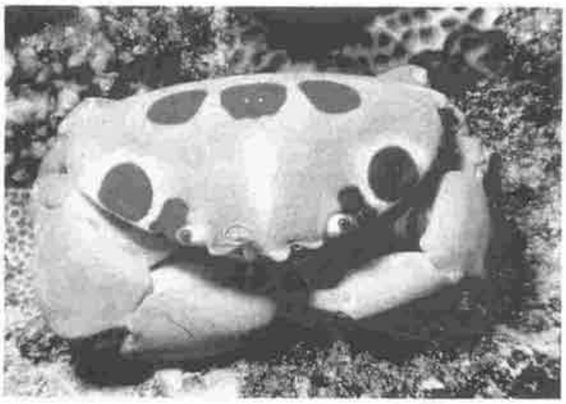
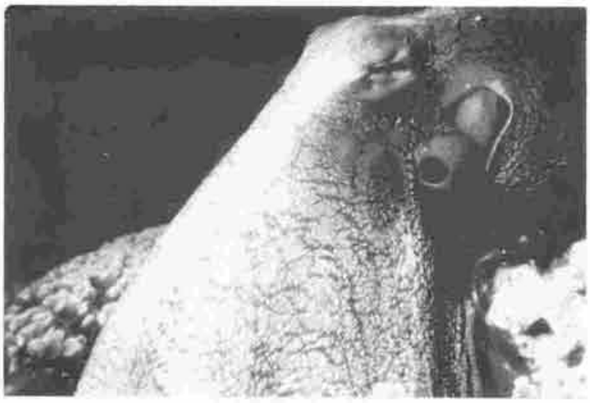


Fig. 34 p: *Octopus cyaneus*: Blue octopus: generally noctural, this one was seen late afternoon.



Carpilius maculata

Also known as the **three spot crab**. Its body is oval in shape and more broad than long. It is generally a light brown or fawn colour with three conspicuous deep red spots on the carapace and two behind each eye. The pincers are large in proportion to the body and the fingers can be tipped with black. This species can often be found in crevices on the reef where it wedges itself in backwards with its strong, spine-tipped walking legs to face the world with its pincers.

They range throughout the western Pacific. In the Palolo Deep, they are seen mainly at night when they come out to forage. They are herbivorous and scavengers.

Octopus cyaneus

The common name is **Blue Octopus**. Can be identified by its large head with a pair of eyes that bear a remarkable resemblance to vertebrate eyes. It has 8 arms covered with two rows of suckers. Usually weighing up to 4kg. The octopus with its arms extended has a diameter ranging up to 50cm with a length up to 1m. Like other members of the family it has the ability to change its colour to blend with its background. The colour ranges from dark brown to pink. The species can be seen at dusk or dawn, and is generally nocturnal.

Its distribution is throughout the tropical Indo-west Pacific ocean. Octopus live in a liar comprising coral rubble, a crevice or overhang surrounded by dead shells of molluscs. They are carnivorous, feeding on other molluscs. The mouth has a beak resembling that of a parrot which is strong enough to fracture thick shells such as that of the robust *Turbo* sp. Their saliva is toxic inactivating their prey.

Fig. 34 q: *Daldorfia horrida*: A rare and unusual crab.

Fig. 34 r: *Padina commessoni*: Fan-like brown algae.

Daldorfia horrida

This is one of the largest crabs on the coral reef. A specimen collected in the Palolo Deep had a carapace diameter of 15cm with the distance between the end of the pincers 75cm.

It has been described as grotesque with its mass of lumps and knobs but it is these features that allow it to blend so well with its rubble environment. It has a stippled, cream to ruddy red colouration. Slender antennae, eyes that withdraw into sockets and a claw in which the moveable portion is angled, are other features.

Its distribution is tropical, extending to Australia. In the Palolo Deep, it is rare. It inhabits burrows in the coral rubble. This nocturnal species is an omnivore, feeding as a scavenger as well as a grazer.

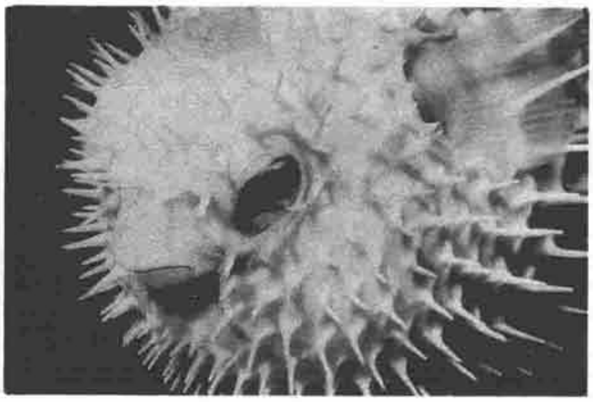
Padina commessoni

The **fan-like brown algae** (Phaeophyta) is very common on the reef flat and inshore. It usually grows in a cluster. The genus *Padina* is of particular interest as it is the only brown algae that deposits limestone.

The base or thallus branches out into one plane with an inroll of growth towards the lower side. Concentric lines of hairs mark the reproductive organs of this algae.

Fig. 34 s: *Diodon liturosus*: Black-blotched porcupine fish.

Fig 34 t: *Diodon liturosus*: Black-blotched porcupine fish.



Diodon liturosus

Commonly known as the **black-blotched porcupine fish**. It is characterised by its large head and spines. Its colouration is light brown to cream on the body with black blotches extending from the eyes and forming a saddle across the back. This colouration disappears upon inflation. The pectoral fins are yellow. The fish can reach a total length of 50cm.

They are found in the Indo-Pacific, mainly on the reef on sandy or muddy bottom. They are carnivorous and feed on crustacean, molluscs and echinoderms usually in the early hours of the morning. Their hard dental plates and strong jaws are well suited to crushing the tests and shells of their prey. They are poor swimmers and can only move in short bursts over small distances.

Diodon liturosus

The **porcupine fish** presents a formidable sight to any predator. In stress, when camouflage and evasive swimming fails, it has a specialised defence system. Embedded in the skin are dozens of erectile spines, which in the relaxed position lie backwards along the body.

By pumping water (or air when at the surface) into the abdomen the skin cavity is inflated and the spines stand rigidly up. These spines are needle sharp and can cause painful, slow-healing wounds. The flesh of this fish may contain tetraodontoxin making it very poisonous. It can also inflict a serious bite.

Fig. 34 u: *Chaetodon ephippium*: Saddled butterfly fish.

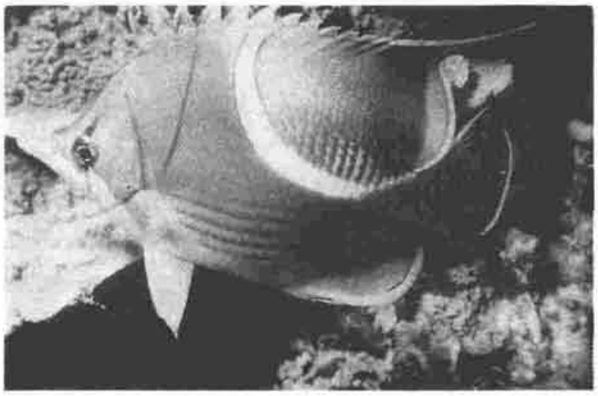
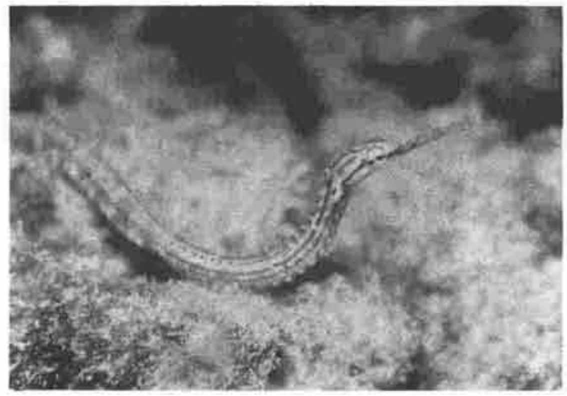


Fig. 34 v: *Corythoichtys schultzi*: Schultz's pipefish.



Chaetodon ephippium

Commonly known as the **saddled butterflyfish**. They have a yellow snout and pectoral fins. A large black area exists posteriorly and on the adjacent dorsal and caudal fins. Adults have a long filament extending back from the dorsal fin. They grow up to 23cm in length.

This species is widespread in the Pacific Ocean as far north as Japan and Hawaii to the Polynesian groups in the east and Papua New Guinea and Cocos-Keeling in the west. They are common in depths of less than 10m. Their diet is composed of coral polyps, algae, shrimp and polychaetes. In the Palolo Deep, they occur throughout the extensive beds of *Acropora nobilis*. They usually occur in pairs.

Corythoichthys schultzi

Commonly known as **Schultz's pipefish**, they are relatives of the sea-horses. They have a very small gill opening, no spines in the fins, no pelvic, pectoral or anal fins and only a single dorsal fin. Their maximum size is about 16cm in length.

They can be found from the Red Sea to the Society Islands. Though most often observed among the corals of the shallow reef, they occur in depths up to 30m.

Peculiar to this group, the female deposits her eggs on the ventral surface of the male. The males incubate the eggs in a pouch or specialised area, carrying them until hatching.

Fig. 34 w: *Parribacus antarcticus*: Slipper or spanish lobster.

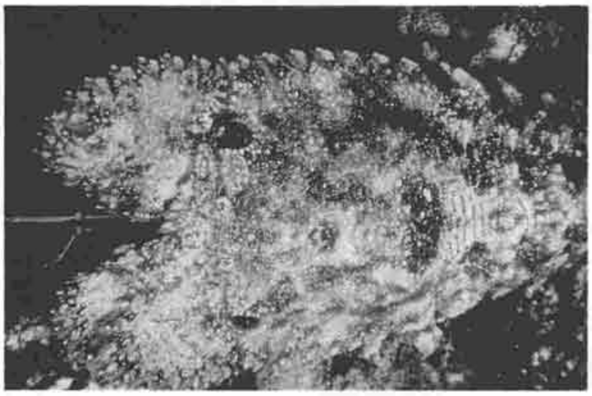
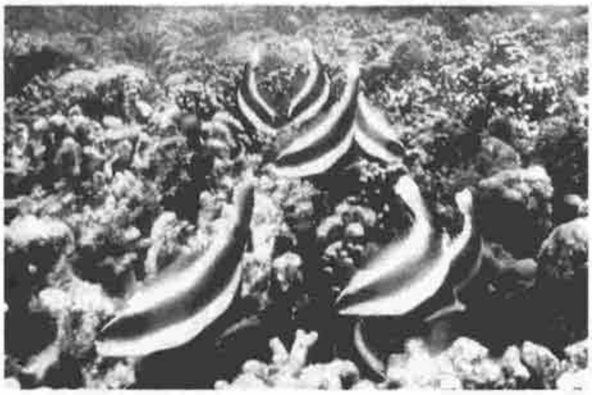


Fig. 34 x: *Heniochus chrysostomus*: Pennant bannerfish feeding.



Parribacus antarcticus

Commonly known as the **Antarctic Slipper** or **Spanish lobster**. The slipper lobster has a knobbly carapace with short, flat plate-like antennae. Its camouflage colouration is a mottling of cream, black and brown. It is large, up to 25cm in length, and is slow moving. Females can sometimes be determined by the presence of an egg mass held by swimmerets under the tail.

They occur from the Indo-Pacific to the Caribbean inhabiting rock and coral reefs in the tropics and sub-tropics. They secret themselves in crevices amongst the coral and rubble by day but can be found foraging at night.

They are carnivorous, feeding on molluscs and small invertebrates. At times, they prey on giant clams.

Heniochus chrysostomus

Known as the **Pennant Bannerfish** because of their elongated dorsal spine with an expanded pennant-like margin. They are characterised by two prominent alternating brown and white vertical stripes with a yellow snout. Adults can reach 25cm in length. They are usually found in solitary or small groups.

They occur from Cocos-Keeling Islands to Pitcairn Island. This species is one of the most commonly seen fish on the reefs in depths of less than 20m. In the Palolo Deep, they occur on the eastern reef flat and in the coral areas of the Deep. They feed mainly on coral polyps but also on zooplankton and other benthic invertebrates.

7. Species Inventory

7.1 Scleractinia (Hard Coral)

The Scleractinian or hard coral fauna of the Palolo Deep is unique by virtue of its varied environment and its recent history involving two major cyclones. Though a wide variety of species is present, predominance in the habitat zones is the result of a history of recolonisation after major cyclones and environmental considerations such as tolerance to exposure, unstable substrates and sedimentation.

The Reef Slope is in the process of recolonisation with a predominately *Acropora* assemblage. Affected by wave action and current, the Western Reef Flat is relatively impoverished, dominated by large *Porites lutea* colonies. The protected Eastern Reef Flat is co-dominated by two species of *Porites* (*P. rus* and *P. cylindrica*) and *Pocillopora damicornis*.

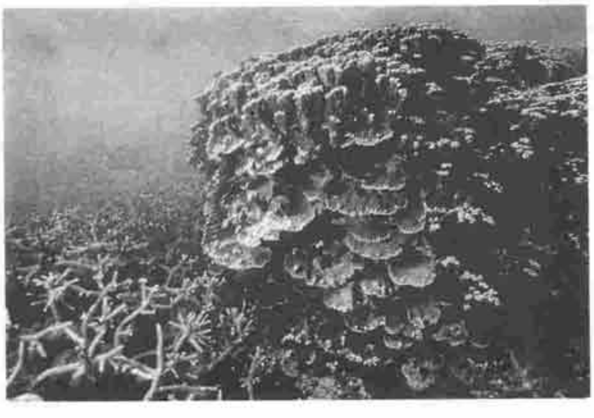
The Palolo Deep is monopolised by areas of sprawling *Acropora nobilis* as well as large colonies of *Porites rus* and *Porites cylindrica*. Chronic sedimentation affects this area. The Main Deep is characterised by relic coral bommies (>5m depth) in the silty environment with the principal coral growth along the south-east perimeter. The inshore area is depauperate due to tidal exposure and substrate limitations.

A reference collection was compiled. Identifications of the predominant genus *Acropora* were carried out by Dr. Wallace of the Museum of Tropical Queensland, Townsville. Other identifications were made using the *Scleractinia of Eastern Australia* (Veron et al. 1976-1984). A taxonomic listing was compiled as well as a reference list of the specimens with such details as reference numbers, collection site, museum numbers and *in situ* photographs.

An interesting feature of the collection is the presence of possible endemic species, or those whose occurrence is confined to a restricted part of the Pacific. The identification of some specimens remains to be finalised as they are unusual in comparison with species occurring more centrally in their range. The collection contains 11 families, 32 genera and 48 species. A maximum generic number for the Samoas, based on world-wide distributional data, is between 50 and 60 (Veron 1993). Forty-nine genera have been recorded from American Samoa (Birkeland et al. 1992). This compares with 58 genera and 148 species from Fiji.

Fig. 35: Hard Corals of Palolo Deep.

a) Porites rus

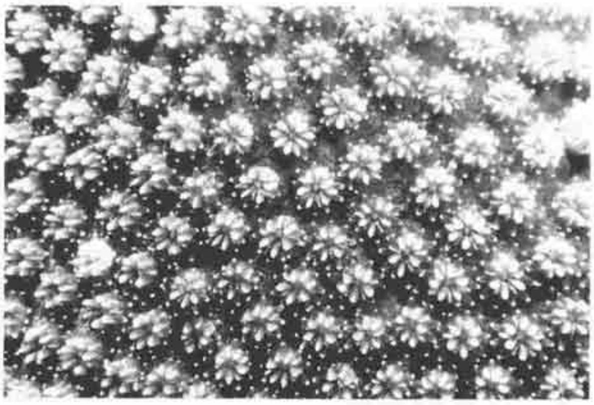


b) Porites cylindrica

Fig. 35: Hard Corals of Palolo Deep (cont'd).

c) Acropora nobilis

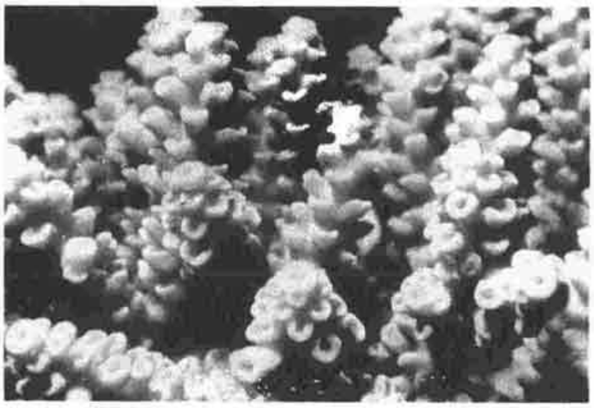
f) Galaxea fascicularis



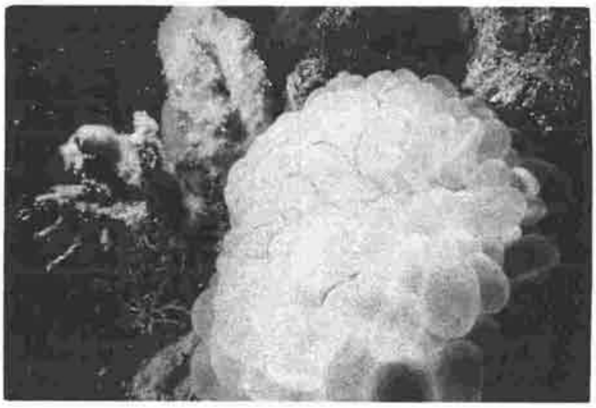
d) Porites lutea

g) Fungia fungites

e) Acropora nasuta



h) Plerogyra sinuosa



7.1.1 Scleractinia: taxonomic listing

POCILLOPORIDAE

Pocillopora damicornis
Pocillopora eydouxi
Pocillopora verrucosa
Seriatopora hystrix

ACROPORIDAE

Acropora aspera
Acropora carduus
Acropora cerealis
Acropora cf. grandis
Acropora cf. aculeus
Acropora sp.
Acropora cuneata
Acropora cytherea
Acropora cf. cytherea
Acropora danai
Acropora cf. danai
Acropora divaricata
Acropora sp.
Acropora formosa
Acropora gemmifera
Acropora humilis
Acropora hyacinthus
Acropora sp.
Acropora sp.
Acropora nasuta
Acropora nobilis
Acropora cf. nobilis
Acropora paniculata
Acropora robusta
Acropora cf. samoensis
Acropora secale
Acropora valida
Acropora sp.
Astreopora listeri
Astreopora myriophthalma
Montipora cf. australiensis
Montipora turgescens

PORITIDAE

Alveopora cf. allingi
Goniopora lobata
Porites cylindrica
Porites lobata
Porites lutea
Porites nigrescens
Porites rus

SIDERASTREIDAE

Coscinaraea columna
Psammocora contigua
Psammocora haimeana

AGARICIIDAE

Leptoseris mycetoseroides
Leptoseris purpurea
Pachyseris speciosa
Pavona decussata
Pavona varians

FUNGIIDAE

Fungia fungites
Fungia repanda
Fungia scruposa
Herpolitha limax

OCULINIDAE

Galaxea fascicularis

PECTINIIDAE

Echinophyllia aspera
Oxypora sp.

MUSSIDAE

Lobophyllia sp.

MERULINIDAE

Merulina ampliata

FAVIIDAE

Diploastrea heliopora
Favia matthaii
Favites cf. flexuosa
Favites halicora
Leptastrea purpurea
Leptoria phrygia
Leptoria phrygia

7.1.2 Scleractinia: reference collection

Ref. No.	Species	Collection site	Museum or photographed specimens
48)	*Acropora sp. ('mystery')*	Palolo Deep	G43472
12)	*Acropora aspera*	Palolo Deep	G43464 Photo
13)	*Acropora carduus*	Palolo Deep	G43461
43)	*Acropora cerealis*	Mulinu'u Pt.	G43478
54)	*Acropora cerealis*	Palolo Deep	G43471 Photo
60)	*Acropora cerealis*	Palolo Deep	G43468
44)	*Acropora cf. grandis*	Palolo Deep	G43495
66a)	*Acropora cf. aculeus*	Palolo Deep	G43482
28)	*Acropora sp. ('fine aculeus 3')*	Mulinu'u Pt.	G43473
31)	*Acropora cuneata*	Palolo Deep	G43491
33)	*Acropora cuneata*	Mulinu'u Pt.	G43492
53a)	*Acropora cytherea*	Palolo Deep	G43470 ND*
57)	*Acropora cytherea*	Palolo Deep	G43487
38)	*Acropora cf. cytherea*	Palolo Deep	G43484
59)	*Acropora danai*	Aleipata	G43489
35)	*Acropora cf. danai*	Mulinu'u Pt.	G43490
40)	*Acropora cf. danai*	Aleipata	G43493
30)	*Acropora divaricata*	Palolo Deep	

Ref. No.	Species	Collection site	Museum or photographed specimens
65)	*Acropora sp. ('echinata -like')*	Palolo Deep	G43477
63)	*Acropora formosa*	Palolo Deep	G43497
55)	*Acropora gemmifera*	Palolo Deep	G43469
39)	*Acropora humilis*	Aleipata	G43462
34)	*Acropora hyacinthus*	Mulinu'u Pt.	G43481 Photo*
32)	*Acropora hyacinthus*	Mulinu'u Pt.	G43467
15)	*Acropora sp. ('listeri-like')*	Palolo Deep	G43475
58)	*Acropora nasuta*	Palolo Deep	G43466
26)	*Acropora nasuta*	Mulinu'u Pt.	G43457
67)	*Acropora nasuta*	Palolo Deep	G43458
37)	*Acropora nobilis*	Palolo Deep	G43465
62)	*Acropora nobilis*	Palolo Deep	G43460 Photo
61)	*Acropora nobilis*	Palolo Deep	G43463
36)	*Acropora nobilis (thick)*	Aleipata	G43498
64)	*Acropora nobilis (thick)*	Aleipata	G43496
52)	*Acropora paniculata*	Palolo Deep	G43459 ND
45)	*Acropora paniculata*	Palolo Deep	
3)	*Acropora paniculata*	Palolo Deep	
8)	*Acropora robusta*	Palolo Deep	G43494
69)	*Acropora cf. samoensis*	Palolo Deep	G43476 Photo
47)	*Acropora secale*	Aleipata	G43486
50)	*Acropora secale*	Mulinu'u Pt.	G43479
66b)	*Acropora sp.*	Palolo Deep	Photo
41)	*Acropora sp.*	Palolo Deep	
49)	*Acropora valida*	Mulinu'u Pt.	G43485
68)	*Acropora valida*	Palolo Deep	G43488
51)	*Acropora sp. ('Samoan valida')*	Aleipata	G43480
53b)	*Acropora sp. ('Samoan valida')*	Aleipata	G43474
10)	*Alveopora cf. allingi*	Palolo Deep	
27)	*Astreopora listeri*	Palolo Deep	
24)	*Astreopora myriophthalma*	Palolo Deep	
1)	*Coscinaraea columna*	Palolo Deep	
14)	*Diploastrea heliopora*	Palolo Deep	
42)	*Echinophyllia aspera*	Mulinu'u Pt.	
88)	*Favia matthaii*	Palolo Deep	
90)	*Favites cf. flexuosa*	Palolo Deep	
89)	*Favites halicora*	Palolo Deep	
29)	*Fungia fungites*	Palolo Deep	
22)	*Fungia repanda*	Mulinu'u Pt.	
20)	*Fungia scruposa*	Mulinu'u Pt.	
86)	*Galaxea fascicularis*	Palolo Deep	

Ref. No.	Species	Collection site	Museum or photographed specimens
87)	*Goniopora lobata*	Palolo Deep	
56)	*Herpolitha limax*	Palolo Deep	
11)	*Leptastrea purpurea*	Palolo Deep	
83)	*Leptoria phrygia*	Palolo Deep	
25)	*Leptoria phrygia*	Palolo Deep	
85)	*Leptoseris mycetoseroides*	Palolo Deep	
71)	*Leptoseris purpurea*	Palolo Deep	
84)	*Lobophyllia sp.*	Palolo Deep	
19)	*Merulina ampliata*	Mulinu'u Pt.	
9)	*Montipora cf. australiensis*	Palolo Deep	
46)	*Montipora turgescens*	Palolo Deep	
17)	*Montipora turgescens*	Palolo Deep	
20)	*Montipora turgescens*	Mulinu'u Pt.	
72)	*Oxypora sp.*	Palolo Deep	
2)	*Pachyseris speciosa*	Palolo Deep	
74)	*Pavona decussata*	Palolo Deep	
5)	*Pavona decussata*	Palolo Deep	Photo
7)	*Pavona varians*	Palolo Deep	Photo
79)	*Pocillopora damicornis*	Palolo Deep	Photo
4)	*Pocillopora eydouxi*	Palolo Deep	
23)	*Pocillopora eydouxi*	Mulinu'u Pt.	
77)	*Pocillopora eydouxi*	Palolo Deep	Photo
75)	*Pocillopora verrucosa*	Palolo Deep	
16)	*Porites cylindrica*	Palolo Deep	
80)	*Porites lobata*	Palolo Deep	Photo
21)	*Porites lutea*	Mulinu'u Pt.	Photo
76)	*Porites nigrescens*	Palolo Deep	Photo
78)	*Porites rus*	Palolo Deep	Photo
6)	*Porites rus*	Palolo Deep	
18)	*Porites rus*	Palolo Deep	
70)	*Psammocora contigua*	Palolo Deep	
73)	*Psammocora cf. haimeana*	Palolo Deep	
82)	*Seriatopora hystrix*	Palolo Deep	Photo
81)	*Seriatopora hystrix*	Palolo Deep	

Index:

Photo: Refers to a file photo of the species.

ND: No duplicate specimen existing in the reference material.

The Palolo Deep material was collected during the period of 20 April to 31 May 1993.

7.2 Molluscs

Name	Locality
GASTROPODA	
CONIDAE	
Conus textile	Palolo Deep
Conus vexillum	Reef flat
Conus cf. frigidus	Reef flat
Conus tulipa	Reef flat
VASIDAE	
Vasa ceramicum	Reef slope
VERMETIDAE	
Dendropoma maximum	Porites colonies
LITTERINIDAE	
Litterina coccinea	Intertidal shore
Cerithium nodulosum	Reef flat
Distorsio sp.	
MURICIDAE	
Morula granulata	
CYMATIIDAE	
Cabestana cf. spengleri	
CYPRAEIDAE	
Cypraea tigris	
Cypraea moneta	
STROMBIDAE	
Strombus luhuanus	Reef flat
Lambis scorpius	Palolo Deep
Lambis (Lambis) truncata	
TURBINIDAE	
Turbo petholatus	Reef flat
Turbo sp.	
TROCHIDAE	
Trochus pyramis	Palolo Deep
MITRIDAE	
Strigatella sp.	Palolo Deep
Mitra cucumerina	Palolo Deep
Vexillum sp.	Palolo Deep
TEREBRIDAE	
Terebra dimidiata	Palolo Deep
NASSARIDAE	
Nassarius albescens	Shoreline
NERITIDAE	
Nerita undata	Shoreline
Nerita plicata	Shoreline
OPISTHOBRANCH - Phyllidae	
Phyllidia ocellata	Palolo Deep

7.3 Fishes of Palolo Deep

Scientific Names	English	Samoan
ACANTHURIDAE	**Surgeonfish**	**Pone, palagi**
Acanthurus auranticavus	Orange-socket surgeonfish	-
A. guttatus	White-spotted surgeonfish	Maogo
A. lineatus	Stripped surgeonfish	Alogo
A. nigricans	-	-
A. nigricauda	Blackstreak surgeonfish	Pone-i'usina
A. nigroris	Bluelined surgeonfish	Ponepone
A. olivaceus	Orangeband surgeonfish	Ponepone
A. triostegus	Convict surgeonfish	Manini
Ctenochaetus striatus	Bristle-toothed surgeonfish	Pone
Naso annulatus	Whitemargin unicornfish	-
N. lituratus	Smooth-head unicornfish	Ili'ilia
N. unicornis	Brown unicornfish	Ume-isu
Zebrasoma scopas	Brown tang	Pitopito
Z. veliferum	Sailfish surgeonfish	Iliu
APOGONIDAE	**Cardinalfishes**	Fo
Apogon angustatus	Stripped cardinalfish	Fo-tusiloloa
Cheilodipterus macrodon	Tiger cardinalfish	Fo-taoto, tuganini
ATHERINIDAE	**Silverfishes**	**Sali**
Atherinomorus lacunosus	Robust hardyhead	-
AULOSTOMIDAE	**Trumpetfishes**	**Taoto, taotito**
Aulostomus chinensis	Trumpetfish	Taoto-ena
BALISTIDAE	**Triggerfishes**	**Sumu**
Balistapus undulatus	Orangelined triggerfish	Sumu-aimaunu
Rhinecanthus aculeatus	Whitebanded triggerfish	Sumu-uo'uo
Sufflamen freanatus	Bridle triggerfish	Sumu-gase'ele'ele
CAESIONIDAE	**Fusiliers**	**Atule-toto, ulisega**
Caesio caerulaureus	Blue and gold fusiliers	Atule-toto
CARANGIDAE	**Trevally**	-
Caranx melampygus	Bluefin trevally	Malauli-apamoana
CHAETODONTDAE	**Butterflyfish**	**Tifitifi**
C. auriga	Threadfin butterflyfish	Siu
C. ephippium	Saddled butterflyfish	Tifitifi tuauli
C. melannotus	Blackback butterflyfish	Tifitifi pa'ipa'i
C. reticulatus	Reticulated butterflyfish	Tifitifi maona
C. trifasciatus	Redfin butterflyfish	Tifitifi manifi
C. ulietensis	Double-saddle butterflyfish	Tifitifi gutu'uli
C. unimaculatus	Teardrop butterflyfish	Tifitifi pulesama
Heniochus chrysostomus	Pennant bannerfish	Laulaufau laumea

Scientific Names	English	Samoan
CIRRHITIDAE	**Hawkfish**	**La'o, lausiva**
Paracirrhites arcatus	Arc-eye hawkfish	Lausiva
P. forsteri	Blackside hawkfish	Lausiva
DIODONTIDAE	**Porcupinefishes**	**Tauto**
Diodon hystrix	Porcupinefish	Tauta, tautu
D. liturosus	Black-bloched Porcupinefish	Tauta, tautu
FISTULARIIDAE	**Flutemouth**	**Taotao**
Fistularia commersonii	Smooth flutemouth	Taoto-ama, taotao
GOBIIDAE	**Gobies**	**Mano'o**
Valenciennae strigata	Blueband goby	Mano'o-sina
HAEMULIDAE	**Sweetlips**	-
Plectorhynchus chaetodonoides	Many-spotted sweetlips	I'amai-moana
P. pictus	Dotted sweetlips	-
HOLOCENTRIDAE	**Squirrelfishes and Soldierfish**	**Malau**
Myripristis adustus	Shadowfin soldierfish	Malau tuavela
Neoniphon opercularis	Blackfin squirrelfish	Malau loa
N. sammara	Spotfin squirrelfish	Malau tui
LABRIDAE	**Wrasses**	**Sugale**
Cheilinus chlorourus	Floral maori-wrasse	Lalafi-matapua'a
C. trilobatus	Tripletail maori wrasse	Lalafi-matamumu
C. unifasciatus	Redbreasted wrasse	Lalafi, tagafa, malakea
Epibulus insidiator	Slingjaw wrasse	Si'umutu, lalafi-tua'au
Gomphosus varius	Bird wrasse	Gutusi'o, sugale-lupe
Halichoeres margaritaceus	Pink belly wrasse	Sugale uluvela
H. trimaculatus	Threespot wrasse	Lape, sugale-pagota
Hemigymnus melapterus	Blackeye thicklip	Sugale-laugutu
Labrichthys unilineatus	Tubelip wrasse	Sugale-tafuti
Labroides bicolor	Bicolor cleaner wrasse	Sugale i'usina
L. dimidiatus	Bluestreak cleaner wrasse	Sugale mo'otai
Lobropsis xanthonota	Yellowback tubelip	-
Macropharyngodon negrosensis	Black wrasse	-
Thalassoma hardwickii	Sixbar wrasse	Sugale-a'au
LETHRINIDAE	**Emperors**	**Mata'ele'ele, filoa**
Lethrinus harak	Thumbprint emperor	Filoa-vai
L. cf. nebulosus	Spangled emperor	Ulusa'o, mulogo
Monotaxis grandoculus	Big-eye bream	Mu-matavaivai, matamu

Scientific Names	English	Samoan
LUTJANIDAE	**Snappers**	**Mu**
Lutjanus fulvus	Yellow-margined seaperch	Tamala, taiva
L. gibbus	Paddletail	Malai
L. kas	-	-
Macolor niger	Black and white seaperch	Matala'oa
MICRODESMIDAE	**Dartfishes**	**Mano'o-ui**
Ptereleotris evides	Twotone dartfish	Mano'o-ui
MONACANTHIDAE	**Leatherjacket**	**Pa'umalo**
Oxymonacanthus longirostris	Beaked leatherjacket	Pa'umalo-gutuumi
Monacanthus chinensis	Fan-bellied leatherjacket	-
Cantherhines dumerilii	Yelloweyed leatherjacket	Pa'umalo
MULLIDAE	**Goatfishes**	-
Mulloides flavolineatus	Yellowstripe goatfish	I'asina (<8cm), vete
Parupeneus barberinus	Dash-and-dot goatfish	Tusia
P. cyclostomus	Goldsaddle goatfish	Moana
P. indicus	Indian goatfish	Ta'uleia
NEMIPTERIDAE	**Bream**	-
Scolopsis trilineatus	Threelined monocle bream	Tivao
OSTRACIIDAE	**Boxfishes**	**Moamoa**
Ostracion cubicus	Yellow boxfish	Moamoa-lega
O. meleagris	Spotted boxfish	Moamoa-uli, moamoa-sama
POMACANTHIDAE	**Angelfishes**	**Tu'u'u**
Centropyge flavissimus	Lemonpeel angelfish	Tu'u'u-sama
Pomacanthus imperator	Emperor angelfish	Tu'u'u-moana
Pygoplites diacanthus	Regal angelfish	Tu'u'u-moana
POMACENTRIDAE	**Damselfishes**	**Tu'u'u**
Abudefduf septemfasciatus	Banded sergeant	Mutu
A. sexfasciatus	Scissor-tail sergeant	Mamo
A. vaigiensis	Indo-pacific	Mamo
Amphiprion melanopus	Red and black anemonefish	Tu'u'u-lumane
Chromis atriopectroalis	Black-axil chromis	Tu'u'u-segasega
C. viridis	Blue-green chromis	I'alanumoana
Dascyllus aruanus	Humbug dascyllus	Mamo
Pomacentrus pavo	Blue damsel	Tu'u'u-segasega, teatea

Scientific Names	English	Samoan
SCARIDAE	**Parrotfishes**	**Fuga, laea, galo**
Hipposcarus longiceps	Pacific longnose parrotfish	Ulapokea
Scarus dimidiatus	Yellowbarred parrotfish	Fuga-alosama
S. oviseps	Egghead parrotfish	Fuga-alosina
S. sordidus	Bullethead parrotfish	Fugausi-tuavela
SERRANIDAE	**Groupers and Sea Basses**	**Gatala, 'ata'ata**
Cephalopholis argus	Blue-spotted grouper	Gatala-uli, loi
E. hexagonatus	Hexagon rockcod	Gatala-a'au
E. merra	Dwarf spotted rockcod	Gatala-aloalo
E. tauvina	Greasy rockcod	Gatala-tane
Anthias dispar	Redfin anthias	Segasega-moana
A. pascalus	Amethyst anthias	Segasega-moana
Pseudanthias hypselosoma	Stocky anthias	-
SIGANIDAE	**Rabbitfishes**	Lo
Siganus argenteus	Forktail rabbitfish	Loloa
S. fuscescens	Dusky rabbitfish	-
S. spinus	Scribbled rabbitfish	Anefe, pa'ulu
SYNGNATHIDAE	**Pipefishes**	-
Corythoichthys intestinalis	Banded pipefish	-
SYNODONTIDAE	**Lizardfishes**	**Ta'oto**
Saurida gracilis	Slander lizardfish	Ta'oto
TERAPONTIDAE	**Terapon Perches**	**Avaava**
Terapon jarbua	Crescent grunter	Avaava
TETRAODONTIDAE	**Puffers**	**Sue**
Arothron nigropunctatus	Blackspotted puffer	Sue-uli, sue-lega
C. amboinensis	Ambon toby	Sue-lape
C. bennetti	Bennett's toby	Sue-'afa
C. solandri	Solanders toby	Sue-mimi
C. valentini	Black-saddled toby	Sue-mu
ZANCLIDAE	**Moorish Idols**	-
Zanclus cornutus	Moorish idol	Pe'ape'a, laulaufau

7.4 Algae

CHLOROPHYTA

Codiales

Halimeda opuntia
H. macroloba
Chlorodesmus fastigiata
Caulerpa racemosa
Codium sp.

Siphonocladales

Valonia ventricosa
Cladophoropsis sp.
Dictyosphaeria cavernosa

PHAEOPHYTA

Ectocarpales

Hydroclathrus sp.
Colpomenia sp.
Padina commersoni

Dictyotales

Dictyota dichotoma

Fucales

Sargassum cristaefolium
Turbinaria ornata

RHODOPHYTA

Crytonemiales

Peyssonelia sp.
Amphiroa sp.
Jania sp.
Hildenbrandtia sp.
Lithophyllum sp.
Porolithon sp.

8. Environmental Impacts

From a coral reef perspective, the Palolo Deep Marine Reserve is an area of contrast. History and circumstance have developed a variety of habitats which have been differentially storm affected and are now changing as the result of sedimentation. The reef fauna has developed within this framework to give rise to a distinct reef zonation.

The most well developed and luxuriant parts of the reef, in terms of coral development, occur in the embedded lagoon and on the Eastern Reef Flat. The reef flat to the east of this area has greater diversity but is constrained by depth and the period of development. Due to cyclone damage there are virtually no large coral colonies on the reef slope. Recolonisation of this area is prolific, with high densities of small colonies developing. Rubble banks and slopes reflect the recent history of cyclone effect.

Following is a discussion of some of the events and processes which have been influential in the conditioning of the biological and physical aspects of the reef as it is today.

8.1 Cyclones

The most significant natural occurrence capable of causing immediate catastrophic coral mortality on reefs is a tropical cyclone or hurricane. The effects of extreme wave action as well as the reduction in salinity, increased turbidity, the change in the reef morphology and current structure, result in the alteration of the reef communities and, at times, wholesale destruction.

These community changes involve the reduction of monopolising species, the dispersal of coral fragments which may develop into new colonies, and new substrate becoming available for settlement. As part of the system within which coral reefs have evolved, cyclones have many beneficial effects on their growth and development. Literature concerning the effects of cyclones on coral reefs is found in the suggested reading portion of the references.

8.1.1 Cyclones Ofa and Val

Between 1 and 5 February 1990, tropical cyclone Ofa, the strongest cyclone in 150 years, devastated Western Samoa. A year later in January, another strong cyclone, Val, also occurred. These two cyclones have greatly affected the present nature of the Palolo Deep Marine Reserve. Cyclone Ofa stripped the seaward reef slope of its coral which, together with older rubble, was deposited shoreward. The subsequent cyclone, Val, degraded the storm banks, spreading them across the reef flat and moving more material into the Deep. Details of the storms' path and general effect on Western Samoa is found in Zann and Sua (1991).

The effects of cyclones depend on their intensity and direction, and the nature of the reef community. The northern coast is generally protected from the prevailing winds and is subject to greater damage as the coral growth is less robust. The storm banks were largely made of rubble formed prior to the cyclone and dislodged and carried on to the reef flat.

Storms have different effects on different parts of the reef system. It is this feature which allows the coral reef to respond successfully to catastrophic events. The Palolo Deep is a good example of the ability of the system to respond in terms of recolonisation and regrowth. The presence of the Deep provides a protective environment in which the reef fauna and flora can survive the devastating nature of storm waves. It is from this reservoir of living material that the reef is subsequently restored.

8.1.2 Devastation and Recovery

The type of catastrophic coral mortality as witnessed by cyclone Ofa is impressive as it represents nearly the complete removal of benthos from the outer reef slope, the deposition of extensive rubble banks on the seaward reef flat and major alteration of the reef flat fauna. On the geological time scale, this is not an uncommon event and has occurred many times during the reef's existence. The tropical phenomenon of coral reefs and cyclones represents proof enough that they can survive and even thrive as the result of their interaction.

Records of such devastation provide an understanding as to the nature of the destruction and subsequent redevelopment of the coral reef assemblage. In the Caribbean, British Honduras reefs were stripped of living corals over a zone 8km wide during a hurricane in 1961. The barrier reef spur and groove system was stripped in an area of over 40km in width (Stoddart 1963).

At Rendezvous Reef, affected by the center of the storm, the only coral to survive was the massive *Montastrea annularis*. It was the massive coral *Diploastrea* which was one of two species which survived the reef slope devastation at Palolo Deep. A similar effect occurred with the total disappearance of the more fragile branching *Acroporas* at both Palolo Deep and Rendezvous Reef. Devastation by Cyclone Ofa, however, represented destruction of a greater magnitude. Unlike the Honduras situation where corals survived with depth, there were almost no corals left alive. Rather than the reef surface and slope being mantled with rubble (Ball, Shinn & Stockman 1967), at Palolo Deep it was deposited in large ridges on the reef crest.

The degree of exposure to the storm force is important in reef survival. At Jaluit Atoll (Marshall Islands), massive quantities of rubble were an indication of the coral destruction on the seaward reef, while the more delicate branching and foliose corals survived unharmed in the lagoon (Blumenstock 1958, 1961).

A range of recovery rates has been proposed by various authors (Shinn 1972 {1-4 yrs}; Stephenson et al. 1958 {10-20yrs}; Stoddart 1969a {20-25 yrs}) which reflects the variability in a reef's response to storm damage. Grigg and Maragos (1974), in examining lava flows of known age, found the recovery time for the types of reef communities in exposed conditions to be 20 years, while 50 years may be required for the more complex reefs found in sheltered areas.

The 1965 resurvey of the British Honduras reefs showed little reef recovery in the area of greatest damage. The only corals occurring in any numbers were those which survived the storm itself, with large areas colonised by the algaes *Padina* and *Halimeda*. Substantial recovery had occurred in areas where damage had been slight. The survey of 1972 revealed little or no recovery in areas of extreme damage ten years later but complete recovery in areas of moderate damage.

Shinn (1972) found that coral recovery following hurricanes Donna and Betsy in Florida was relatively quick. Despite apparent extensive damage, within one year the damage was barely noticeable. In four years repair was total.

A more remarkable example of rapid recovery is in Indonesia. Here a situation occurred where destruction was total as the result of a reef being overlaid by lava. The bare substrate experienced remarkable recruitment and general recovery in five years (Tomascik, in press). As with the Palolo Deep, it is an *Acropora* dominated assemblage which has settled prolifically on a totally denuded reef.

Stephenson et al. (1958) suggested that settlement of planulae larvae is inhibited by the mobility of debris formed by the storms, and their estimate of recovery following the Low Isles, Great Barrier Reef storm is minimal. In the Palolo Deep situation the rubble on the reef slope was largely removed due to the steep slope, and wave action.

Endean (1971) discussed the theoretical considerations which affect the rate of recovery of devastated reefs. These include the availability of planulae larvae and their survival rates, competition with other organisms and corals, substrate conditions, rates of growth and the succession of successful colonisers. Certainly the frequency of cyclones affects the nature of a coral reef's development. It may account for major regional differences between cyclonic and non-cyclonic areas (Stoddart 1969e, 1974).

The prolific settlement on the reef slope at Palolo Deep is indicative of a reef well on the way to recovery. Fish occur in abundance. The hard coral assemblage is represented by three annual periods of settlement since cyclone Ofa. The origin of this settlement is probably from the Deep itself. The benthos is dominated by encrusting algal colonies. The substrate has been consolidated by coralline algae. With the coral developing an ever increasing relief, it is estimated that in another four to six years substantial coral cover will occur, creating a flourishing reef.

The eastern reef flat is a good example of the re-establishment of hard coral with 10-17% occurring overall, and an astonishing 83% coverage in one localised area. The size of the colonies indicates that they are the result of fragmentation.

The substrate is coral rubble which has only moderate stability. As a result, many of the colonies are adapted to a semi-mobile existence, unattached, with their growth form conditioned by periodic over turning. In the context of a shallow reef flat situation, coral growth is flourishing. By contrast the paucity of the western reef flat provides evidence that the Palolo Deep offers both shelter and, most probably, living fragments assisting in the re-establishment of the hard coral assemblage.

8.2 Sedimentation

The origins of sedimentation in the Palolo Deep are from two principal sources: run-off carrying topsoil and landfill, and the degradation of reef rubble following two major cyclones. The most important long-term source is soil carried by run-off, caused by the clearing of the watershed, the general development of Apia and the port. The deposition of many tons of reefal material resulting from cyclone Ofa, and its subsequent degradation have given rise to an abundance of silt. The finer component is responsible for the persistent turbidity present in the Deep. It is speculated that the principal sedimentary influence on the marine environment is of terrestrial origin. An increase in suspended sediments and general siltation occurs during times of flood and is persistent as general run-off. The nature of the Palolo Deep as an enclosed lagoon in the reef flat facilitates the deposition of silt. The current structure in and about the Deep creates a sink situation, into which transported silt is continuously deposited.

It is well known that siltation directly affects species diversity and the degree of living cover. Bull (1982) in comparing two bays on Magnetic Island, North Queensland, found a marked reduction in the number of species in the site most affected by siltation.

The Palolo Deep is characterised by limited species with a co-dominance of three coral species in the Deep, where the siltation is greatest. Roy and Smith (1971) found a 50% lower coverage in turbid areas of the Fanning Island lagoon. Porter (1972a,b) attributed diversity reduction in back shelf regions of Caribbean reefs to sedimentation.

Loya (1972) concluded that heavy sedimentation may be a very significant factor in determining Scleractinian community structure. He attributed a reduction in species abundance and percentage cover in areas on Eilat Reefs, Red Sea, to this agent. He points out that the few massive species found in this zone have probably evolved cleaning mechanisms. Marshall and Orr (1931), in studying the effects of sedimentation at Low Isles, Queensland, found the predominant bay genera to be those most tolerant to siltation.

Deposited sediment may limit the establishment of sessile organisms such as coral. Motoda (1940) explained the paucity of reef corals in certain areas in Palau being due to unfavourable substrates. This is certainly the case in the bottom of the Deep where burial is evident and there are expanses of sand between relic coral bommies. The rubble slopes also present an area devoid of coral growth. Kissling (1965) found substrate to be the prime factor in regulating coral distributions in the shallow water environment at Spanish Harbour.

Lovell (1989), in comparing the underlying subfossil reef corals with the recent assemblage, found a marked change in composition had occurred. The hypothesis for this change included, as a major factor, the chronic presence of suspended sediment and silty substrates in the present environment.

Given this persistent silt load, the reef system has become pre-conditioned to some extent. The presence of persistent silt is characteristic of a coastal environment. Lovell (1989) has shown that a reef subject to periodic catastrophic flooding can survive. If the environment returns to its pre-flood state, species number and to a lesser extent, diversity are maintained when re-colonised. It may be presumed that if the period of heavy siltation is a short-term event, then any alteration to the reef may be temporary. If the suspended sediment becomes chronic, and heavy silting a permanent feature, then the coral reef assemblages will be dramatically reduced. This seems to be the case at the Palolo Deep where turbidity is significant.

8.3 Crown-of-Thorns Starfish or alamea (*Acanthaster planci*)

(See also Section 6: Natural History, Fig. 34 g)

The periodic increase in the population of this coral-eating starfish has made it an influential feature of the reef community. During periods when there are large numbers of these starfish, areas of the coral reef are denuded of living coral. Infestations cause a dramatic change to the coral reef community. With the removal of the coral's tissue, the skeleton is initially colonised by algae. The associated fauna changes, particularly with respect to the fish assemblage which becomes largely herbivorous. Monopolising species are reduced, making substrate available for recolonisation by other species. Species diversity has been shown to increase as the result of an infestation (Porter 1972b). The occurrence of terrestrial run-off has been linked to *Acanthaster* outbreaks (Birkeland 1982).

Documented outbreaks have been recorded five times on Upolu (1932-33, 1950s, 1969-70, 1977-80, 1980s), though the infestations haven't necessarily occurred in the Palolo Deep during these periods (Zann and Bell 1991). With normal population densities at six specimens per kilometre of reef (Endean 1982), the number of crown-of-thorns in the Palolo Deep is higher than normal.

On this basis eight specimens would be expected for the entire Reserve; twice that number were observed in the Southern Palolo Deep, though rarely elsewhere. Little coral had been eaten with feeding scars usually evident in the proximity of the individuals. No threat to the coral from these starfish is perceived in the immediate future. A large and colourful animal and one which has been a focus of interest from the scientific community over the past 30 years, makes its presence of particular value to the Reserve from a tourist point of view. If the population numbers and consequent coral destruction were to become unacceptable then collecting would be appropriate. This strategy lends itself to the Deep where the habitat is confined and easily collected.

Seven specimens were collected as samples for research purposes. The size of observed individuals varied between 18.5-25.5cm. The largest specimen, a female, had a large ovary indicating readiness for a second annual spawning.

8.4 Sewage Outfall

A proposal is being investigated for the offshore disposal of effluent from the Apia sewerage system. The location of the outfall is 1300m from Mulinu'u Pt. at a depth of 40m. It is 2.5km to the northwest of the Palolo Deep (GKW Consultants et al. 1984).

Advisability of this scheme, from the standpoint of pollution of the Marine Reserve, warrants further investigation. Of concern is contamination by the sewage effluent which comprises a host of waste products including faeces, toxins from domestic cleaners, and all manner of material for which the domestic sewer is considered a common receptacle. Contamination by faecal coliforms provides the potential for disease. Nutrient enrichment in the Reserve will lead to a suppression of coral growth and a marked change in the benthic community.

As the Deep acts as a sink accumulating material by virtue of its current structure, the nature and transportability of the effluent needs to be considered. Nutrient elevation, particularly phosphorus, is known to affect the ability of corals to calcify and lead to a progressive degradation of the coral community (Kinsey 1988) and inshore areas (Rasmussan 1988). A sewage plume is developed as the largely freshwater effluent is carried to the surface where the wind driven current distributes it for some distance.

Feasibility studies have indicated that current flow is consistently to the west (GWK Consultants et al. 1984) as the result of southerly winds which predominate in the winter months. The sampling period failed to take seasonality into account whereby the wind and surface current directions reverse. Winds in the summer months blow from the northwest and are likely to convey contaminated water into the Reserve.

When all costs are counted, dumping sewage at sea can prove the most expensive option. General categories of expense would have to include the discharge facility and effluent pipe construction, maintenance and the unaccounted but often unacceptible costs of chronic pollution leading to both potential health hazards and environmental degradation. In a region where tropical cyclones are frequent, the budget for replacement costs would be hard to assess. The alternative of a secondary or tertiary treatment plant whereby the solid waste can be sold as fertilizer may prove more attractive.

An environmental impact that can be predicted is that there will be a change in the benthic community as algal cover will be reduced as a result of reduction in light around the outfall. Deposit feeders proliferate with the settlement of large quantities of particulate material. The extent of the effects of the plume is dependent on two factors: quantity of effluent and the current structure (Dr. Hutchings pers. comm.).

What is apparent is that Palolo Deep is a silt trap into which a continuous current feeds from seaward. If the plume encroaches on the Deep, as it most probably will due to the prevailing summer winds, there will be deposition. Faecal contamination may render the Deep unhealthy for public use. The continuous input of nutrient material may change the nature of the benthos in the Reserve with a flow-on affecting the fauna and fish. Nutrient loading has a most pronounced effect on reef corals. Effluent concentrations are seen to greatly enhance the growth of algae at the expense of the corals. Coral morbidity and mortality may not be related to effluent toxicity, but are the result of competition with algae for space and light (Marszalek 1981b). If degradation does occur then the value of the Reserve as a reservoir for recruitment, recreation and tourist attraction will be greatly diminished.

9. Management Recommendations

9.1 Features and Improvements

The successful development and operation of the Palolo Deep Marine Reserve is the result of the efforts and resources of Mr. Siaki (Jack) Laban Toomalatai and his family. Their efforts are responsible for the development of the visitor facility and the policing of the Reserve. There has been some monetary and material support from the Government.

Despite its proximity to the capital, it has a secluded atmosphere about it. It is quiet, uncommercial and has the feeling of personal discovery. The family run business is unassuming and friendly. Recommendations to improve the Reserve must necessarily be integrated into the existing formula of success, where appeal has been found in modest development.

Improvements to the Palolo Deep could involve two areas:

☑ Improvement of the financial base of the Reserve operation. Without increasing the entrance fee, revenue should be generated within the facility to provide a more adequate cash flow for promotional and maintenance requirements.

There is a need for municipal and national bodies (i.e. the Visitors' Bureau) to appreciate the value of the Palolo Deep National Marine Reserve and to provide assistance in its promotion and the development of interpretive material.

☑ Development of public information within the facility and implementating measures required to conserve the Deep and enhance visitors' experience.

9.2 Recommendations

1. Provide information about the Deep.

Information about the Palolo Deep should be provided to visitors:

a. At the entrance, a general summary of the varied aspects of the Deep should be provided on admission. Acquainting visitors with the Reserve at this point would provide a more informed basis for their subsequent experience.

Presented in the form of a fact sheet this information should include:

➲ Map, habitat descriptions, history of the Palolo Deep

➲ Cautions against habitat disturbance, coral collection and breakage

➲ Detail hazards: urchin, cone shells, coral cuts, currents, general water and sun safety

b. Interpretive information should be provided in the form of displays within the Reserve which should include:

➲ Dynamics of the coral reef system: trophic relationships; processes of reef building; destructive processes

➲ Threats: siltation; freshwater; dilution; pollution; Crown-of-Thorns starfish; cyclones; other effects of man

➲ Description of cyclone Ofa and its effects

2. Develop a commercial shop

Visitors will be better catered for and revenue will be generated by the presence of a shop. Commercial items, such as educational and souvenir material, could be sold: for example, an expanded and more elaborate version of the information on the fact sheet in a booklet. It should include a summary of material similar to that presented as interpretive display information. Memorabilia of the Palolo Deep and coral reefs to include clothing, photographs and postcards showing the Deep, its habitats and inhabitants are examples. Cold drinks and snacks should be available.

3. Promote the Deep as an ecotourism venue

A formal programme should be developed to cater for groups. The Visitors' Bureau should be approached for their advice and participation.

With regard to the Deep, visitors' experience would be enhanced by the redevelopment of the underwater trail. As detailed in the visitors' fact sheet, an appreciation of the main features of the Reserve as identified in the field, should include dominate species, ecological zones and unusual features.

4. Pond development

The possibility of developing a pond near the shore for viewing by people unable or unwilling to trek to the Deep has been proposed by Mr. Laban. This is an interesting idea with good potential and should be pursued.

Fundamental to robust coral development is adequate circulation. This is characteristic of the inshore area. Live coral could be brought in to create a habitat which would attract its own assemblage, providing an example of the larger ecosystem. The inshore reef flat is impoverished but would be enhanced by creating a deeper habitat with varied relief. However there would be initial difficulties such as establishing corals amenable to transplantation and the stabilisation of substrate. The development of a stable and viable display would rely on initiative, industry, experimentation and continued maintenance.

5. Regulate visitor access and usage

Unregulated visitor usage with time could result in the degrading of aspects of the Reserve. An example is access to the Deep, which at present is generally by wading across the inshore flat. The presence of boulders, coral colonies, and other reef inhabitants makes approaching the Deep hazardous for visitors. Marine life, to a limited extent, is also damaged. The approach to the Deep should be confined to a cleared and marked path. The access route would be designated on the fact sheet and by a sign at shore's edge.

Damage from reef walking in the more luxuriant areas behind the Platform (Fig.3) could easily occur as the assemblage has good relief and is composed largely of young (< 3.5 yrs) branching corals. It should be recommended as an ideal snorkelling area at high or mid-tide. Though there is no evidence of a problem thus far, its shallow depth presents a hazard to the area over time if care is not taken.

6. Improve the Platform

Renovate the platform to provide a partially covered facility which will allow visitors to escape the sun if they desire.

7. Police facilities

The task of policing the Reserve against such activities as illegal fishing has been a job assumed by the proprietor Mr. Laban and the DEC park ranger Kelati. To make this task more effective, a punt and binoculars should be provided.

8. Research and educational opportunities

To develop a progressive understanding of the Palolo Deep, the Reserve's advantages as an area of research opportunities should be promoted. It has easy access and shore facilities. Good baseline information is available with a variety of environments. Emphasis should be placed on the sheltered, secure nature of the Palolo Deep for conducting experiments.

The site should be used for field excursions by secondary schools to provide education on the importance of the coastal environment and the conservation of coral reefs. Discussions should be conducted between the park management, DEC, and the Education Department to facilitate this.

9. Monitor the Deep

A monitoring programme is essential to provide a more complete understanding of the dynamics of the Deep. Baseline information is fundamental to the assessment changes experienced in the Reserve which are the result of natural causes or otherwise (see Section 8).

10. Review Proposed Sewage Outfall

All important to maintaining the natural state of the Reserve is the prevention of pollution from the proposed sewage outfall. As the feasibility study failed to monitor the seasonal variation in current direction, further investigation is required. It is suggested that SOPAC be approached to conduct such a study.

10. References

Agassiz, A. 1894. A reconnaissance of the Bahamas and the elevated reefs of Cuba in the steam yacht *Wild Duck*, January to April 1893. *Harvard University Museum, Zoollogical Bulletin*, 26(1).

Andrews, G.J. and Holthus, P.F. 1989. Marine environment survey: Proposed Aleipata Islands national park, Western Samoa. *SPREP. South Pacific Commission, Noumea, New Caledonia.* 68pp.

Babcock, R.C., Bull, G.D., Harrison, P.L., Heyward A.J., Oliver, J.K., Wallace C.C., & Willis, B.L. 1986. Synchronous spawning of 105 scleractinian coral species on the Great Barrier Reef. *Mar. Biol.*, **90:** 394-397.

Bachshall D.G., Barnett J., Davies P.J., Duncan D.C., Harvey N., Hopley D., Isdale P.J., Jennings J.N. and Moss, R. 1979. Drowned dolines - the blue holes of the Pompey Reefs, Great Barrier Reef. *B.M.R. J. Aust. Geology & Geophysics* 4: 99-109.

Ball, M.H., Shinn, E.A. and Stockman, K.W. 1967. The geologic effects of Hurricane Donna in south Florida. *J. Geology* 75: 583-597.

Birkeland, C. 1982. Terrestial runoff as a cause of outbreaks of Acanthaster planci (Echinodermata: Asteroidea). *Mar. Biol.* 69: 175-185.

Birkeland, C. and Lucas, J.S. 1990. *Acanthaster planci: major management problem of coral reefs.* Boca Raton, LA: CRC Press, 257 pp.

Birkeland, C., Randall, R.J. and Amesbury, S.S. 1992. Coral and Reef-Fish Assessment of the Fagatele Bay National Marine Sanctuary. *NOAA Tech. Memo. NOS MEND* 232 pp.

Blumenstock, D.I. 1958. Typhoon effects at Jaluit Atoll in the Marshall Islands. *Nature* 182: 1267-1269.

Blumenstock, D.I. (ed.) 1961. A report of typhoon effects upon Jaluit Atoll. *Atoll Res. Bull.* 75: 1- 105.

Bull, G.D. 1982. Scleractinian coral communities of two inshore high island fringing reefs at Magnetic Island, North Queensland. *Mar. Ecol. Prog. Ser.* 7(3): 267-272.

Chappell, J. 1980. Coral morphology, diversity and reef growth. *Nature* 286: 249-252.

Chappell, J. 1981. Relative and average sea level changes, and endo-, epi-, and exogenic processes on the earth. In: *Sea level , ice, and climatic change.* Int. Ass. Hydrol. Sci. Publ. No. 131.

Connell, J.H. 1973. Population ecology of reef building corals. In: Jones, O.A. and Endean, R. (eds) *Biology and Geology of Coral Reefs* 2 pp. 47-75. Academic Press, London.

Dahl, A.L. 1978. Report on assistance to Western Samoa with national parks and conservation. *SPC* manuscript.

De Vantier, L.M., Barnes G.R., Daniel P.A., Johnson D.B. 1985. Assessment protocol. In Bradbury, R.H. and Reichelt, R.E. (eds), *Studies in the assessment of coral reef ecosystems.* Australian Institute of Marine Science, Townsville.

Dill, R.F. 1977. The Blue Holes - Geologically significant submerged sink holes and caves off British Honduras and Andros, Bahama Islands. *Proc. 3th Int. Coral Reef Symp. Miami.* pp 237-242.

Done, T.J., Kenchington, R.A. and Zell, L.D. 1981. Rapid, large area, resource surveys using manta board. *Proc. 4th Int. Coral Reef Symposium.* 2: 299-308.

Done, T.J. 1989. Classification and assessment of some coral reefs in Mauritius. *COMARAF Serie Documentaire No. 2.* UNESCO/UNDP publication 36pp.

Done, T.J. 1991. The coral reef at Balaclava, Mauritius: a pilot study and a comparison of methods. *COMARAF Serie Documentaire No. 6.* UNESCO/UNDP publication 35pp.

Emery, K.O., Tracey, J.I., and Ladd, H.D. 1954 Geology of Bikini and nearby atolls. *United States Geological Survey, Professional Paper* 260-A.

Endean, R. 1971. The recovery of coral reefs devastated by catastrophic events with particular reference to the current *Acanthaster planci* plagues in the tropical Indo-West Pacific region. *J. Mar. Biol. Ass. India*, **13**: 1-13.

Endean, R. 1982. *Australia's Great Barrier Reef*. University of Queensland Press, St. Lucia, Queensland, Australia.

GKW Consultants, Murray-North Partners, and GM Meredith 1984. *Apia water supply and sanitation project. Phase 111. Master plan for sewage and storm water drainage*. Public Works Dept. Govt. Western Samoa.

Grigg, R.W. and Maragos, J.E. 1974. Recolonization of hermatypic corals on submerged lava flows in Hawaii. *Ecology* **55:** pp. 387-395.

Jordan G.F. 1954. Large sinkholes in the straits of Florida. *Amer. Ass. of Petrl Geol. Bull.* 38: 1810-17.

Kear, D. and Wood, B.L. 1959. *The Geology and Hydrology of Western Samoa*. Government Printer, Wellington. NewZealand. Geological Survey Bulletin n.s. 63: 92p.; 5maps

Kinsey, D.W. 1988. Responses of coral reef systems to elevated nutrients. 55-65pp. In: *(Baldwin, C.L. ed) Nutrients in the Great Barrier Reef Region Workshop Series 10.* Great Barrier Reef Marine Park Authority, Townsville, Australia.

Kissling, D.L. 1965. Coral distribution on a shoal in Spanish Harbour, Florida Keys. *Bull. Mar. Sci.* 15: 600-611.

Lovell, E.R. 1989. Coral assemblages of Moreton Bay, Queensland, Australia, before and after a major flood. *Mem. Qd Mus.* 27(2): 535-550.

Loya, Y. 1972. Community structure and species diversity of hermatypic corals at Eilat, Red Sea. *Mar. Biol.* 13(2): 100-123.

Loya, Y. 1976. Effects of water turbidity and sedimentation on the community structure of Puerto Rican corals. *Bull. Mar. Sci.* 26(4): 450-466.

Marsh, L.M., Bradbury, R.H. and Reichelt, R.E. 1984. Determination of the physical parameters of coral distribution using the line transect data. *Coral Reefs 2*: 175-180.

Marshall, S.M. and Orr, A.P. 1931. Sedimentation on Low Isles and its relation to coral growth. *Sci. Rep. Gt Barrier Reef Exped.* 1(5): 1928-1929.

Marszalek, D.S. 1981b. Effects of sewage effluents on reef corals. *Proc. 4th Int. Coral Reef Symp.* 1 abstr.

Moran, P. 1986. The *Acanthaster* phenomenon. *Oceanogr. Mar. Biol. Annu. Rev.* 24, 379-480.

Moreton, J., Richards, M., Mildner, S. and Bell, L. 1989. *The shore ecology of Upolu, Western Samoa*. 168 pp. MS.

Motoda, S. 1940. The environment and life of the massive reef coral *Goniastrea aspera* Verrill, inhabiting the reef flat in Palao. *Palao Trop. Biol. Stn Stud.* 2: 1-6.

Palmer, A.N. 1984. Geomorphic interpretation of karst features. In: LaFleur, R.G. (ed) *Groundwater as a geomorphic agent.* Boston, Allen & Unwin.

Porter, J. 1972a. Patterns of species diversity in Caribbean Reef corals. *Ecology* 53(4): 745-748.

Porter, J. 1972b. Ecology and species diversity of coral reefs on opposite sites of the Isthmus of Panama. *Bull. Biol. Soc. Wash.* 2: 89-116.

Potts, D.C. 1977. Suppression of coral populations by filamentous algae within damselfish territories. *J. Exp. Mar. Biol. Ecol.* 28: 207-216.

Purdy, E.G. 1974. Reef configuration: cause and effect. *Society of Economic Palaeontologists and Mineralogists. Special publication* **18:** 9-76.

Randall, J.E., Allen, G.R., Steene, R.C. 1990. *Complete Divers and Fisherman's Guide to the Great Barrier Reef and Coral Sea.* Crawford House Press, Australia; ISBN 1863330127.

Rasmussan, C. 1988. Effect of nutrients carried by mainland run-off on reefs in Cairns area. 66-91pp In: *Nutrients in the Great Barrier Reef region.* Workshop series no.10. Great Barrier Reef Marine Park Authority.

Roy, K.J. and Smith, S.V. 1971. Sedimentation and coral reef development in turbid water, Fanning Lagoon. *Pac. Sci.* 25: 234-247.

Shinn, E.A. 1972. *Coral reef recovery in Florida and the Persian Gulf.* Houston: Shell Oil Company, Environmental Conservation Department. 9pp.

Stearns, H.T. 1944. The geology of the Samoan Islands. *Bull. Geol. Soc. America* 1277-1332.

Stephenson, W., Endean, R. and Bennett, I. 1958. An ecological survey of the marine fauna of Low Isles, Queensland. *Aust. J. mar. Freshwat. Res.* 9: 261-318.

Stoddart, D.R. 1962. A short account on catastrophic storm effects on the British Honduras reefs and cays. *Nature* 196 No. 4854: 512-515.

Stoddart, D.R. 1963. Effects of Hurricane Hattie on the British Honduras reefs and cays, October 30-31, 1961. *Atoll Res. Bull.* 95: 1-142.

Stoddart, D.R. 1969a. Ecology and morphology of recent coral reefs. *Biol. Rev.* 44, pp. 433-498.

Stoddart, D.R. 1969e. Post-hurricane changes on the British Honduras reefs and cays: resurvey of 1956. *Atoll Res. Bull.* 131: 1-25.

Stoddart, D.R. 1974. Post-hurricane changes on the British Honduras Reefs: Re-survey of 1972. *Proc. 2th Int. Coral Reef Symp.* 2: 473-483.

Veron, J.E.N. 1986. *Coral of Australia and the Indo-Pacific*. Angus and Robertson. ISBN 0 207 15116 4.

Veron, J.E.N. 1993. A Biogeographic Database of Hermatypic Coral. *Aust Ins. Mar. Sci. Monogr. Ser. 10,* 433pp.

Veron, J.E.N. and Pichon, M. 1976. *Scleractinia of eastern Australia, Part 1: Families Thamnasteriidae, Astrocoenidae, Pocilloporidae*. Aust. Ins. Mar. Sci., Monogr. Ser. 1, 86pp.

Veron, J.E.N. and Pichon, M. 1980. *Scleractinia of eastern Australia, Part 3: Families Agariciidae, Siderastreidae, Fungiidae, Oculinidae, Merulinidae, Mussidae, Pectinidae, Caryophyllidae, Dendrophylliidae*. Aust. Inst. Mar. Sci., Monogr. Ser. 4, 422pp. 86pp.

Veron, J.E.N., Pichon, M. and Wijsman-Best, M. 1977. *Scleractinia of eastern Australia, Part 2: Families Faviidae, Trachyphyllidae*. Aust. Ins. Mar. Sci., Monogr. Ser. 3, 232pp.

Veron, J.E.N. and Wallace, C.C. 1984. *Scleractinia of eastern Australia, Part 4: Families Acroporidae*. Aust. Ins. Mar. Sci., Monogr. Ser. 6, 485pp.

Wallace, C.C. and Bull, G.D. 1981. Patterns of juvenile coral recruitment on a reef front during a Spring-Summer spawning period. *Proc. 4th Int. Coral Reef Symp. Manila.* 2: 345-350.

Wallace, C.C. 1985a. Reproduction recruitment and fragmentation in nine sympatric species of the coral genus *Acropora*. *Mar. Biol.* **88**: 217-233.

Wallace, C.C. 1985b. *Seasonal peaks and annual fluctuations in recruitment of juvenile scleractinian corals.* Mar. Ecol. Prog. Ser. **21**: 289-298.

Williams, E.H. Jr., and Bunkley- Williams, L. 1990. The world-wide coral bleaching cycle and related sources of coral reef mortality. *Atoll Res. Bull* 335: 1-71.

Zann, L.P. and Bell, L. 1991. *The effects of the Crown-Of-Thorns Starfish (Alamea) on Samoan Reefs.* FAO/UNDP SAM/89/002 Field Report No. 8.

Zann, L.P., Brodie, J. and Vuki, V. 1990. History and dynamics of crown-of-thorns starfish, *Acanthaster planci* (L.) in the Suva area, Fiji. *Coral reefs* 9: 135-144.

Zann, L. and Eager, E. 1987. The Crown of Thorns Starfish. *Aust. Science Mag.* 24: 13-54.

Zann, L.P. and Sua, T. 1991. *Effects of cyclone Ofa on the fisheries and coral reefs of Upolu, Western Samoa in 1990.* FAO/UNDP, Apia, Western Samoa. SAM/89/002. Field Report No. 2.

10.1 Suggested Reading

10.1.1 Hurricanes:

Anthes, R.A. 1982. *Tropical cyclones; their evolution, structure and effects.* 208pp. American Meteorological Society, Boston.

Antonius, A. 1972. Hurricane Laura, witnessed in British Honduras. *Atoll Res. Bull. 162: 11-12.*

Aigner, T. 1985. *Storm depositional systems.* Springer-Verlag, New York, 174pp.

Baines, G.B.K. and McLean, R.F. 1976. Sequential studies of hurricane deposit evolution at Funafuti Atoll. *Mar. Geol.* 21: M1-M8.

Baines, G.B.K. and Beveridge, P.J. Storms and island building at Funafuti atoll. Ellice Islands. *Proc. Second Intn'l Coral Reefs Symp.* 2: 485-496.

Behrens, E.W. 1969. Hurricane effects on a hypersaline bay. *Memoir, Int. Symp. on Coastal Lagoons.* UNAM-UNESCO: 301-312.

Cooper, M.J. 1966. The destruction of marine fauna and flora in Fiji caused by the hurricane of February 1965. *Pac. Sci.* 20: 137-141.

Cowan, G. and Utanga, A. 1991. The effects of cyclone Sally on Rarotonga, Cook Islands. In: *Workshop on coastal processes in the South Pacific island nations, Lae, Papua New Guinea.* SOPAC Tech. Bull. 7: 127-128.

Danitofea, S. and Baines, G.B.K. 1991. *Cyclone Namu and the North Guadalcanal coast, Solomon Islands: implications for economic development.* SOPAC Tech. Bull. 7: 125-127.

Dutton, I.D. (ed.) *The effects of cyclone Winifred.* Workshop Series 7. 111pp. Great Barrier Reef Marine Park Authority, Townsville, Australia.

Hayes, M.O. 1967. Hurricanes as geologic agents, south Texas coast. *Amer. Assoc. Petroleum Geol. Bull.* 51: 937-956.

Highsmith, R.C., Riggs, A.C. and D'Antonio, C.M. 1980. Survival of hurricane-generated coral fragments and a disturbance model of reef calcification/growth rates. *Oecologia* 36: 322-329.

Hopley, D. and Isdale, P. 1977. Coral micro-atolls, tropical cyclones and reef flat morphology: a North Queensland example. *Search* 8,3: 79-81.

Howorth, R. and Greene, G. 1991. Effects of cyclones Ursula, Carlotta and Uma in the Port Vila - Mele Bay area, Vanuatu. In: Workshop on coastal processes in the South Pacific island nations, Lae, Papua New Guinea. *SOPAC Tech. Bull.* 7: 123-124.

Kjerfve, B., Magill, K.E., Porter, J.W. and Woodley, J.D. 1986. Hindcasting of hurricane characteristics and observed storm damage on a fringing reef, Jamaica, West Indies. *J. Mar. Res.* 44: 119-148.

Kobluk, D.R. and Lysenko, M.A. 1987. Impact of two sequential Pacific hurricanes on subrubble cryptic corals: the possible role of cryptic organisms in maintenance of coral reef communities. *J. Paleontology* 61: 663-675.

McKee, E.D. 1959. Storm sediments on a Pacific atoll. *J. Sediment. Petrol.* 29: 354-364.

McLean, R.F. 1974. Morphology of hurricane banks at Funafuti Atoll, Ellice Islands. In, *Proc. Int. Geogr. Union Reg. Conf.* and *8th N.Z. Geogr. Conf.*: 269-277.

Moorehouse, F.W. 1936. The cyclone of 1936 and its effects on Low Isles, with special observations on Porites. *Rep. Gt. Barrier Reef Comm.* 4: 37-44.

Perkins, R.D. and Enos, P. 1968. Hurricane Betsy in the Florida-Bahama area: geologic effects and comparison with Hurricane Donna. *J. Geology* 76: 710-717.

Rogers, C.S., Suchanek, T.H., Pecora, F.A. Effects of hurricanes David and Frederic (1979) on shallow *Acropora palmata* communities: St. Croix, US Virgin Islands. *Bull. Mar. Sci.*: 32A: 532-548.

Stephens, P.R., Trustrum, N.A. and Fletcher, J.R. 1986. *Reconnaissance of the physical impact of cyclone Namu -Guadalcanal and Malaita, Solomon Islands.* N.Z. Soil Conservation Centre

Stoddart, D.R. 1962. A short account on catastrophic storm effects on the British Honduras reefs and cays. *Nature* 196 No. 4854: 512-515.

Stoddart, D.R. 1963. Effects of Hurricane Hattie on the British Honduras reefs and cays, October 30-31, 1961. *Atoll Res. Bull.* 95: 142.

Stoddart, D.R. 1969. Ecology and morphology of recent coral reefs. *Biol. Rev.* 44, pp. 433-498.

Stoddart, D.R. 1974. Post-hurricane changes in the British Honduras reefs: resurvey of 1972. *Proc. Second Internat Coral Reef Symposium*: 473-482.

10.1.2 Sedimentation:

Aller, R.C. and Dodge, R.F. 1974. Animal-sediment relations in tropical lagoon: Discovery Bay, Jamaica. *J. Mar Res.* 32: 209-232.

Amesbry, S.S. 1981. Effects of turbidity on shallow-water reef fish assemblages in Truk, Eastern Caroline Islands. *Proc. 4th Int. Coral Reef Symp.* 1: 155-160.

Bak, R.P.M. 1978. Lethal and sublethal effects of dredging on coral reefs. *Mar. Poll. Bull.* 9: 14-16.

Bakus, G.J. 1968. Sedimentation and benthic invertebrates of Fanning Island, Central Pacific. *Mar. Geol.* 6: 45-51.

Chansang, H., Booyanate, P., Charuchinda, M. 1983. Effects of sedimentation from coastal mining on coral reefs on the northwestern coast of Phuket, Thailand. *Proc. 4^{th} Int. Coral Reef Symp.*, 1, 129-136.

Cortes, N.J. and Risk, M.J. 1985. A reef under siltation stress: Cahuita, Costa Rica. *Bull. Mar. Sci.* 36(2): 339-356.

Dodge, R.E. and Vaisnys, J.R. 1977. Coral populations and growth patterns: responses to sedimentation and turbidity associated with dredging. *J. Mar. Res.* 35(4): 715-730.

Dodge, R.E., Aller, R.C. and Thomson, J. 1974. Coral growth related to resuspension of bottom sediments. *Nature* 247: 574-577.

Dollar, S.J. and Grigg, R.W. 1981. Impact of a Kaolin clay spill on a coral reef in Hawaii. *Mar. Biol.* 65:269-276.

Guicher, A. 1985. Natural and human change of sedimentation in lagoons behind barrier reefs in the humid tropics. *Proc. 5th Int. Coral Reef Congress* 4: 207-212.

Hubbard, D.K. 1986. Sedimentation as a control of reef development: St. Croix, US Virgin Islands. *Coral Reefs* 5: 117-125.

Hubbard, J.A.E.B. 1973. Sediment shifting experiments: a guide to functional behaviour in colonial corals. In: R.S. Boardman, A.H. Cheetham and W.A. Oliver, Jr. (eds). *Animal colonies.* Dowden, Hutchinson, and Ross, Inc., Stroudsburg, Pa.: 31-42..

Hubbard, J.A.E.B. and Pocock, Y.P. 1972. Sediment rejection by recent Scleractinian corals: a key to Paleo-environmental reconstruction. *Geologische Rundschau* 61:598-626.

Lasker, H.R. 1980. Sediment rejection by reef corals: the roles of behaviour and morphology in *Montastrea cavernosa* (Linnaeus). *J. Exp. Mar. Biol. and Ecol.* 47: 77-87.

Levin, J. 1970. *A literature review of the effects of sand removal on a coral reef community.* University of Hawaii, Dept. of Ocean Engineering. Univ. of Hawaii Sea Grant College Program Technical Report.

Motoda, S. 1939. Submarine illumination, silt content and quantity of food plankton on reef corals in the Iwayama Bay, Palao. *Palao Trop. Biol. Stn. Stud.* 1(4): 637-649.

Rogers, C.S. 1983. Sublethal and lethal effects of sediments applied to common Caribbean reef corals in the field. *Mar. Poll. Bull.* 14(10): 378-382.

10.1.3 Ecology:

Bak, R.P.M. and Criens, S.R. 1981. Survival after fragmentation of colonies of *Madracis mirabilis, Acropora palmata* and *A. cervicornis* (Scleractinia) and the subsequent impact of a coral disease. *Proc. 4th Int. Coral Reef Symp. Manila,* 2: 22-227.

Bazzaz, F.A. 1983. Characteristics of populations in relation to disturbance in natural and man-modified ecosystems. In Mooney, H.A. and Godron, M. (eds). *Disturbance and Ecosystems. Components of Response.* Springer-Verlag, Berlin, 258-275.

Birkeland, C. 1982. Terrestial runoff as a cause of outbreaks of *Acanthaster planci* (Echinodermata: Asteroidea). *Mar. Biol.* 69: 175-185.

Birkeland, C.and Lucas, J.S. 1990. Acanthaster planci: *Major management problem of coral reefs.* Boca Raton, LA: *CRC Press.* 257 pp.

Borowitzka, M.A. 1981. Algae and grazing in coral reef ecosystems. *Endeavour* 5: 99-106.

Brown B.E. 1987. Worldwide death of corals: natural cyclic events or man-made pollution? *Mar. Pollution Bull. 18: 9-13.*

Brown, B.E. and Howard, L.S. 1985. Assessing the effects of "stress" on reef corals. *Advances in Marine Biology* 22: 1-63.

Cairns, J. 1980. The recovery process in damaged ecosystems. *Ann Arbor Science,* Ann Arbor Michigan. *167pp.*

Choi, D.R. 1984. Ecological succession of reef cavity-dwellers (coelobites) in coral rubble. *Bull. Mar. Sci.* 35: 72-79.

Connell, J.H. 1973. Population ecology of reef building corals. In: Jones, O.A. and Endean, R. (eds) *Biology and Geology of Coral Reefs* 2 pp. 47-75. Academic Press, London.

Downing, N., El-Zahr, C.R. 1987. Gut evacuation rates in the rock-borrowing sea urchin, *Echinometra mathaei. Bull. Mar. Sci.* 41: 579-584.

Endean, R. 1976. Destruction and recovery of coral reef communities. In: O.A. Jones and R. Endean (eds). *Biology and geology of coral reefs.* 3: 215-254.

Hodges, L.T. 1977. Coral size and orientation relationships of the Key Largo Limestone of Florida. *Proc. 3rd Int. Coral Reef Symp. Miami, Florida* 2: 347-352.

Jackson, J.B. 1977. Competition on marine hard substrata: the adaptive significance of solitary and colonial strategies. *Amer. Nat.* 111: 743-767.

Kinsey, D.W. 1988. Responses of coral reef systems to elevated nutrients. 55-65pp. In: (Baldwin, C.L. ed) *Nutrients in the Great Barrier Reef Region.* Workshop Series 10. Great Barrier Reef Marine Park Authority, Townsville, Australia.

Pearson, R.G. 1973. Recovery of coral reefs on the Great Barrier Reef following attack by *Acanthaster. Micronesia:* 9:223

Pearson, R.G. 1981. Recovery and recolonization of coral reefs. *Mar. Ecol. Prog. Ser.* 4: 105-122.

Potts, D.C., Done T.J., Isdale, P.J. and Fisk, D.A. 1985. Dominance of a coral reef community by the genus *Porites* (Scleractinia). *Mar. Ecol. Prog. Ser.* 23: 79-84.

Randall, R.H. 1981. Morphologic diversity in the scleractinian genus *Acropora. Proc. 4th Int. Coral Reef Symp. Manila* 2: 157-164.

Sheppard, C.R.C. 1982. Coral populations on reef slopes and their major controls. *Mar. Ecol. Prog. Ser.* 7 pp. 83-115.

10.2 Field Reference Texts

10.2.1 Corals

Scleractinia of Eastern Australia *Aust. Inst. Mar. Sci. Monogr. Ser.* 1, 3-6 Vol I-V 1976-1985.

Veron, J.E.N. 1986. *Corals of Australia and the Indo-Pacific.* Angus & Robertson, Sydney, London. ISBN 0207 151164.

Veron, J.E.N. and Pichon, M. 1976. *Scleractinia of eastern Australia, Part 1: Families Thamnasteriidae, Astrocoenidae, Pocilloporidae.* Aust. Ins. Mar. Sci., Monogr. Ser. 1, 86pp.

Veron, J.E.N., Pichon, M. and Wijsman-Best, M. 1977. *Scleractinia of eastern Australia, Part 2: Families Faviidae, Trachyphyllidae.* Aust. Ins. Mar. Sci., Monogr. Ser. 3, 232pp.

Veron, J.E.N. and Pichon, M. 1980. *Scleractinia of eastern Australia, Part 3: Families Agariciidae, Siderastreidae, Fungiidae, Oculinidae, Merulinidae, Mussidae, Pectinidae, Caryophyllidae, Dendrophylliidae.* Aust. Inst. Mar. Sci., Monogr. Ser. 4, 422pp. 86pp.

Veron, J.E.N. and Wallace, C.C. 1984. *Scleractinia of eastern Australia, Part 4: Families Acroporidae.* Aust. Ins. Mar. Sci., Monogr. Ser. 6, 485pp.

10.2.2 Molluscs:

Wilson, B.R., and K. Gillett. *Australian Shells* A.H. & A.W. Reed, Sydney, Wellington, London.

Cernohorsky, W.O. 1967, 1972. *Marine Shells of the Pacific Vol. I,II.* Pacific Publications, Sydney.

Habe, T. 1964. *Shells of Western Pacific in Colour Vol. II.* Hoikusha Publishing Co. Osaka.

Kera, T. 1962. *Shells of the Western Pacific in Colour Vol. I.* Hoikusha Publishing Co. Osaka.

10.2.3 Fishes:

Grant, E.M. 1978. *Guide to Fishes.* Department of Harbours and Marine, Brisbane, Queensland. Australia.

Munro, I.S.R. 1967. *The Fishes of New Guinea.* Department of Agriculture, Stock and Fisheries, Port Moresby, PNG.

Randall, J.E., G.R. Allen, R.C. Steene. 1990. *Fishes of the Great Barrier Reef and Coral Sea* Crawford House Press. Bathurst, Australia. ISBN 1 86333 012 7

10.2.4 General:

Coleman, N. 1991. *Encyclopaedia of Marine Animals.* Angus & Robertson, Australia. ISBN 0 207 164 29 0.

Endean, R. 1982. *Australia's Great Barrier Reef.* University of Queensland Press, Australia ISBN 0 7022 1678 X.

George, D. and J. 1979. *Marine Life: An Illustrated Encyclopaedia of Invertebrates in the Sea.* Rigby Ltd., Australia, 1979. ISBN 0 7270 1107 3.

Annex:

Use of the Lotus-123 ver. 2.4 Spreadsheet Programme for Transect Analysis

Introduction

The translation of data from the field notes to the spreadsheet and its subsequent analysis is discussed in a step by step process. Macros are found in the macro library (section 12.1.2).

The field survey technique is discussed more fully in the methods section. Briefly, it involves recording benthic attributes under a transect line. The format for each entry, such as the coral *Porites lutea,* is to abbreviate it to Pl. Proceeding along the transect line, a measurement of the coral is taken from the line where its presence finishes. As an example, the format for *P. lutea* finishing at 235mm would be 235 pl. This figure is not a measure of extent but one of sequence which, through the programme, will be converted to a length measurement.

Inputing and Processing the Data

The method used for input and processing of the data in the Lotus spreadsheet is as follows:

- Create a spreadsheet file with titles to serve as a basis for the input of all transect (i.e. TFRAME.wk1). Set the column width for the taxa (column B) at 22 and that for the percent (column J) at 12: /WCS. Center the ^N. Right align the titles ": \.
- The titles appear as in the following:

Transect no. and description

Transect | Taxa Intercept | Value | N | Mean | Std.| Max.| Min.| %
Measurement Conversion Dev.

- Retrieve the file: /FR TFRAME.WK1.
- Rename the file to identify the transect: /FS.
- Add in the macro library: /A
- Input the data: Use \e macro.
- Combine files if several transects are to be used for a particular area: /FC.
- Edit problems or unusual entries: F2.
- Backup file: /FSB.
- Save the file under a new name so as to archive the original transect data and continue processing the original: /FS *.new.
- Write a formula which subtracts one measurement or cell from the next (i.e.+A5-A4) and place it adjacent to the first entry under the Intercept column.
- Copy it down the length of the column: /C.
- Edit inappropriate numbers such as those occurring as the result of combined transects: Delete.
- Convert the formula figures to absolute values: /RV.
- List them in the adjacent column: Value conversion.
- Total the value conversion, which is the true transect length and edit the percentage denominator in the data processing macro \x (F5AA1,/AAI,F2,save). It is the last line of that macro.
- Sort the taxa and the absolute values: /DS.
- Hide C column: /WCH.
- In the taxa column, type the name at the base of each grouping of similar attributes.
- Backup file: /FSB.
- To obtain the number of taxa (N), enter the taxa value ranges at the row of the attribute name using the function @count by employing the macros \c to enter the first cell in the range and \l to give the last cell in the range. The formula format is @count($cell..$cell). Use the $ to specify an absolute address.

- With the N formula highlighted, use the macro \x to calculate the values in the other columns.
- Continue calculating the @count function for each attribute name and employing the \x macro.
- Save and Backup: /FSR, /FSB.
- Use the absolute value function /RV to convert the formulae and to tranfer the data to a part of the spreadsheet where there is no row or column continuity.
- Hide the columns concerned with the transect measurement, the intercept length, and the formula conversion: /WCH.
- Remove the rows above the taxa names: macro \w or /wdr.
- Reorganise the table into alphabetically listed categories of corals, algae and substrate. Create an empty row, move in the appropriate entry and remove the empty rows to consolidate the table: \i,/m,\w.
- Insert the rows in the table to allow the headings Coral, Algae and Substrate: \i or /wir.
- Center the N column figures: \r.
- Calculate totals for the transect length, the percent cover per category: \u.
- Convert these values to absolutes and to percentage formats: /RV, /RFP.
- Save and Backup: /FSR, /FSB.
- Print the table: /PPR.\G.
- Printing the Graphs.

Graphics

The pie charts in the report have been developed using the programme **Slide**. This is a graphics programme which ports to Lotus and fulfils the same function as that of the graphics enhancement add-in WYSIWYG.

Keystroke and @ function macros used in the processessing of spreadsheet information

Keystroke	Macro function	Notes
\e	{?}~{right}{?}~{down}{left}/xg\z~	Data entry from field notes.
\c	@count($d	Used after the value conversion to calculate N and to establish absolute addresses.

The following is the principal macro used for calculations used in the transect analysis.
It is a combination of macros for the various functions listed below.
To start, the cursor needs to be at the N value or at the @count(..) column.

Keystroke	Macro function	Notes
		Calculates:
\x	/c~{right}~{right}{edit}{home}{right}sum{del 5}~/rff+1~~	Sum or total intercept
	/c~{right}~{right}{edit}{home}{right}AVG{del 3}~/rff+1~~	Mean
	/c~{right}~{right}{EDIT}{home}{right}std{del 3}~/rff~~	Standard deviation
	/c~{right}~{right}{edit}{home}{right}max{del 3}~/rff+1~~	Maximum value from transect value
	/c~{right}~{right}{edit}{home}{right}min{delete 3}~/rff+1~~{left 4}	Minimum value of transect entry
	/c~{right 5}~{right 5}/rv~~{edit}/12000~/rfp~~{left 7}	Percentage cover - requires editing of the transect length before use.
\o	/c~{right}~{right}{edit}{home}{right}sum{del 5}~/rff+1~~	Calculate sum
\u	@sum($d	Assist in sum calculation.
\l	..$d	To be used in association with \u

Keystroke	Macro function	Notes
Calculation of individual values:		Calculates:
\a	/c~{right 2}~{right 2}{edit}{home}{right}AVG{del 3}~/rff+1~~	mean
\m	/c~{right}~{right}{edit}{home}{right}max{del 3}~/rff+1~~	maximum
\n	/c~{right}~{right}{edit}{home}[right 2}in{delete 2}~/rff+1~~{left 5}	minimum
\p	/c~{right}~{right}/rv~~{edit}/4000~/rfp~~	percentage
\d	/wdr	Deletes rows.
\i	/wir	Inserts rows.
\f	/fs~{right}~	Saves file.
\r	{edit}{home}^~{down}	Centers numbers in cell and goes to the one below.
\t	{edit}{home}{del}~{down}	Deletes cell entry and goes to the one below.
\j	{edit}{home}{del}"~	Right aligns label. Used to center 'total' labels.

Acknowledgements

The Palolo Deep Marine Reserve Project was a cooperative effort between the Western Samoan Division of Environment and Conservation (DEC) and the South Pacific Regional Environment Programme (SPREP). Funding was provided by the Australian International Development Assistance Bureau (AIDAB).

The project was co-managed by Dr. Andrew Smith, Coastal Management Officer (SPREP) and Dr. Tony Robinson, Resource Management Officer (DEC). The co-consultants were Edward R. Lovell, Biological Consultants, Fiji, and Foua Toloa. Participants in the training and survey programme were Lavaasa Malua and Cedric Schuster (DEC) and Brendan Pasisi of the Department of Fisheries, Niue.

Many thanks to Dr. Carden Wallace who promptly identified the hard coral specimens and provided helpful comments on the assemblage, and to Dr. Leon Zann for his insights into the project.

Appreciation is expressed to Mr. Siaki (Jack) Laban Toomalatai who ably manages the Palolo Deep and to Kelati, the chief ranger, for valuable information and advice concerning the project. Many thanks to Michelle Lam, Liz Wilson and Antoine D.R. Nyeurt, University of the South Pacific, Fiji, for their valuable assistance and contribution to the report preparation.

Also thanks to Nancy Daschbach of the Fagatele Bay National Marine Sanctuary for information and material on the marine reserve, to Andrew Smith, Kelvin Passfield, Joy Heenan and Juana Lovell for editing the manuscript, and to R. B. Lovell for managing the colour photography.

The Authors.