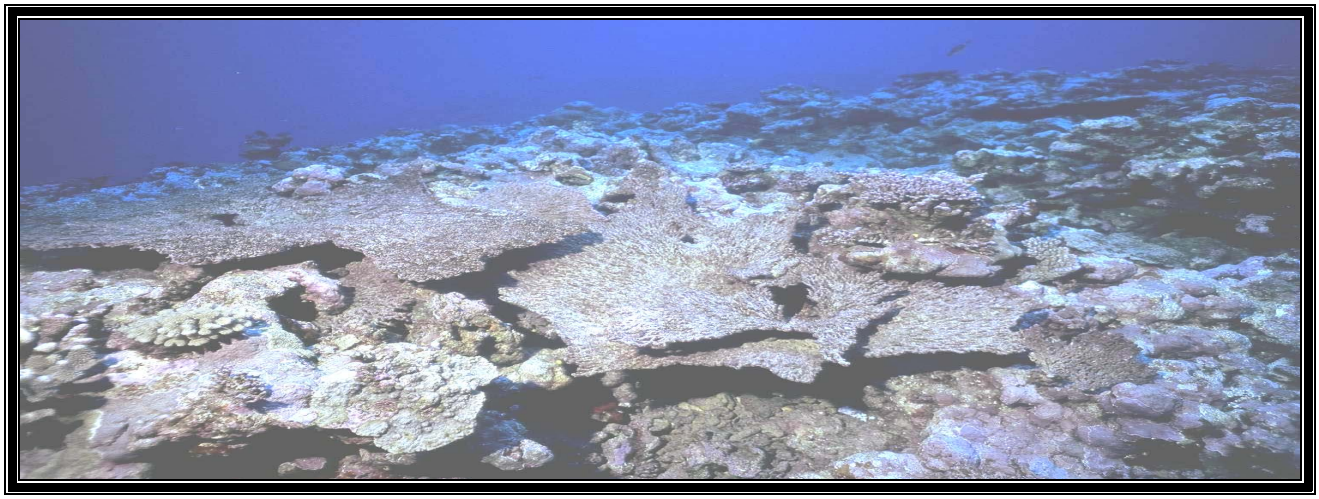
BASELINE BIOLOGICAL SURVEY
OF
TO'ATUGA REEF
(5 Mile Reef)



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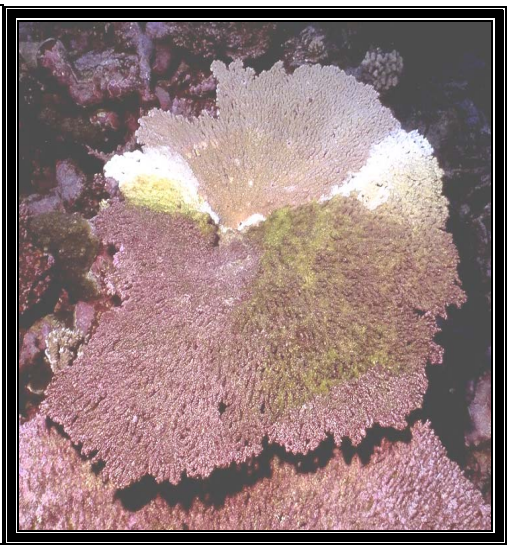
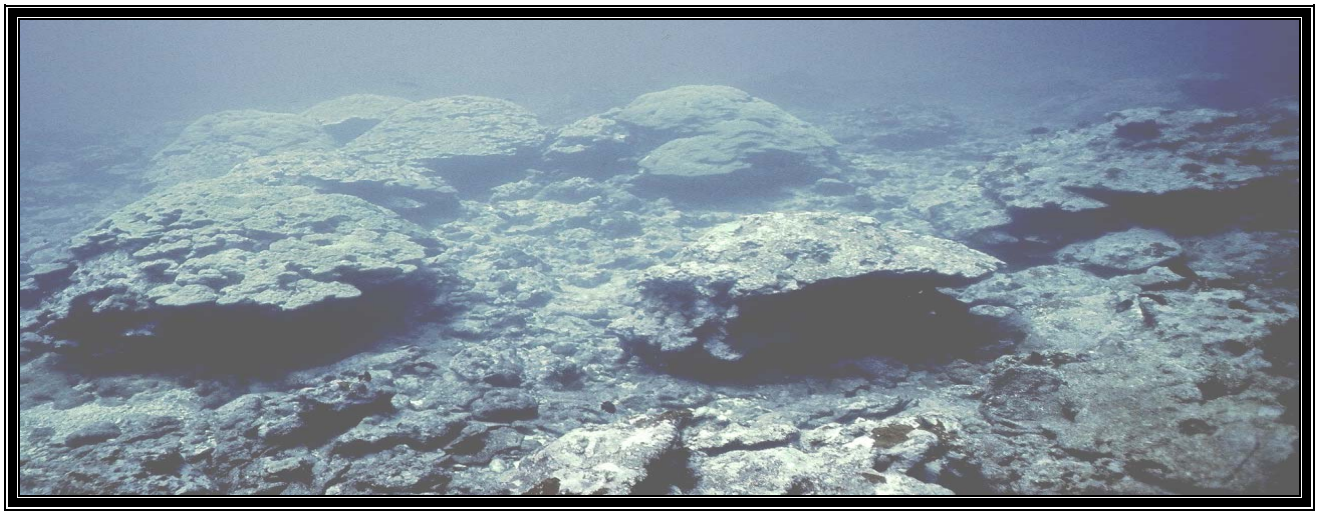
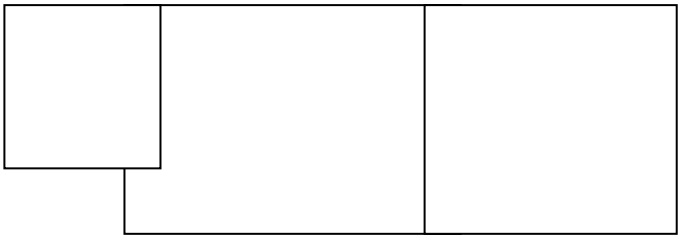




Photos

A)

B) **C)** **D)**



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B) Title

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1.0 Summary

1.1 Introduction

To'atuga Reef is located between 6.5-7.4 km (3.5-4.0 nautical miles) north or seaward of Apia Harbour (middle) on the north coast of Upolo Island, Samoa. It is an elongate ridge of reef extending in a NW–SE axis, with a broad reef top which ranges between 15-22m descending on a slope of 30^0-45^0 with vertical sections to a sand and rubble bottom at 35-40m. The reef top is characterised by a low topographic relief with the undulating contours of small ridges and depressions.

This report provides a baseline description of the major habitat types and dominant fauna present on the reef. A basic inventory and description of the To'atuga marine environment is undertaken. Transects were used to detail the occurrence primarily of fish, coral, algae, mobile invertebrates and physical substrate types. Preliminary species inventories were compiled for hard coral and fish, with records of other benthos. General features of the habitat such as the surge environment, current, depth, bathymetric profile, community type and dynamics are described. Bathymetric assessment was aided by the profiling of the reef by South Pacific Applied Geoscience Commission (SOPAC) which provided a framework for site position and general reef assessment. Impacts of storms, coral bleaching, disease and the human impacts of recreational diving, fishing and anchoring are discussed and management recommendations made.

1.2 General Assessment

To'atuga Reef is a prolific coral reef. The nature of the reefs is influenced by depth, oceanic swell and intermittent disturbance due to storms conditions. The proximity to Apia subjects the reef to human use such as dive sites and fishing. Unlike the coastal shallow fringing reefs, impacts from freshwater runoff, sedimentation, and the crown-of-thorns starfish are not important. Primary influences are: isolation from the coastal environment, depth, wave environment (cyclonic and distant storm), coral bleaching and disease. The damage from cyclone Heta was observed. To'atuga Reef is generally consolidated by coralline algae with a reduced coral assemblage. Evidence of recruitment is common with the presence of small colonies.

1.3 Environmental Impacts

1.3.1 Location

The reef occurs in a location which must limit recruitment due to the lack of proximity to other reefs, it's depth and exposure to the wave surge. It is removed from the coastal fringing reefs. The prevailing westerly current further isolates the reef from similar reefs. Though there are a few small patches north of Upolu, the coasts tends southeasterly. Generally, American Samoa may serve as a recruitment source. More easterly are the scattered Northern Cook Islands at 750 miles, the Tuamotu Islands, French Polynesia at 900miles. Recruitment observed may result from self-seeding.

1.3.2 Wave environment

The Samoa Islands are subject to a wave environment generated by prevailing tradewind conditions or distant storms. Extreme manifestations of wave influence are cyclones. The wave action influences the habitats of To'atuga Reef through an ambient surge environment, which at times can be destructive at times. The major cyclones Ofa and Valerie (1990, 1991) must have had a pronounced effect on the reef with the living cover of the adjacent Palolo Deep being damaged and,

in some cases, the living reef surface being totally removed by these strong storms (Lovell and Toloa, 1993). Storm deposition existing as moraines of rubble are still evident on the inshore reefs.

1.3.3 Depth

Coral reefs generally occur in shallow waters. In exposed shallow areas, wave action is vigourous giving rise to a pronounced zonation based on intensity. Depths to 30m are not uncommon, though the attenuation of light influences the abundance of corals and ameliorates coral bleaching.

1.3.4 Coral bleaching

Coral bleaching has had a prominent effect on Samoan reefs and there is ample evidence in the form of dead standing coral of the 2002 coral bleaching episode on To'atuga Reef. For the reef top, dead Acropora plates indicate bleaching death. On the southwest portion of the reef, the coral assemblage is dominated by large Porites colonies. Many of these are dead, the expected result from a coral bleaching event. For the dead tabulate coral, the degrading of the skeletal material through bio-erosion and surge-induced damage provides increased fragmented material which, when wave-borne, creates additional coral damage and loose rubble material.

1.3.5 Disease

The presence of white-band disease (WBD) on To'atuga Reef is common in the Acropora table colonies. The substantial amount of the dead standing coral may have resulted from the progressive death of the corals which survived the coral bleaching. It is hypothesized that the stress from the coral bleaching precipitated the WBD outbreak as this disease has not been recorded in Samoa.

1.3.6 Diving and fishing

The principal influences from human activities are from diving and fishing. In both cases, anchoring is required which has the potential for limited damage. Data on the frequency of diving and the intensity of fishing is required as is the assessment of activities on the reef by the users .

1.3.7 Anchor damage

Anchoring is a necessity when visiting To'atuga Reef by boat. Submerged moorings (>8m) may be a solution for dive operations and fishing vessels.

2.0 Methods

2.1 Field Methods

Initial reconnaissance was assisted by charted and bathymetric information of To'atuga Reef. This allowed an overview to be made of the general habitats. The survey strategy was then developed to best describe these environments. 13 stations were selected as representative samples for the area. Survey was by SCUBA. In most cases, two dives were made at each site. Due to depths of ~ 20m or more, bottom time was limited. Data was recorded on plastic slates.

Qualitative and quantitative description was obtained by general inspection, photography, conducting point-intercept transects and some belt transects (Marsh, Bradbury and Reichelt 1984, De Vantier et. al., 1985; English et. al. 1997). The methods were adapted to the survey of marine benthos after Done (1981, 1989, and 1991).

2.1.1 Point Intercept Transect (PIT)

A 40 metre transect line is laid within which three 10m point long intersect transects, separated by 5m, were measured at each site. The transect line was positioned where it would best describe the habitat features. The point-intercept transects (PIT) were used at almost every site to assess the benthic composition of the reef.

Abbreviations of the names of benthic items or attributes were used to provide consistency and facilitate data entry. The PIT readings were taken every .5m within the 10m segments. Attributes noted comprised hard coral, soft coral, sponge, coralline algae, fleshy seaweed, turf algae, encrusting red algae, dead standing coral, living coral fragments, coral colony damage, recently killed coral, rock, rubble, sand, silt and other (see Figure 1).

2.1.2 Bathymetry and Currents

The bathymetry was detailed from SOPAC bathymetric assessment, nautical charts and confirmed by transect records and depth sounding.

The assessment of the current structure in To'atuga Reef is of a qualitative nature. Information is derived, generally, from pilot charts (DMAHTC, 1981) and field inspection as part of the transect information. Reference to seasonality is derived from anecdotal information.

2.1.3 Underwater Photography

Habitat and specimen shots were taken with an Ikelite-housed Coolpix 990 digital camera. The unit had auto focus and exposure as well as wide angle and macro capability. A Nikonos camera with a 15mm lens was used for habitat and specimen shots. Ikelite strobes were used for both units.

2.2 Data Analysis

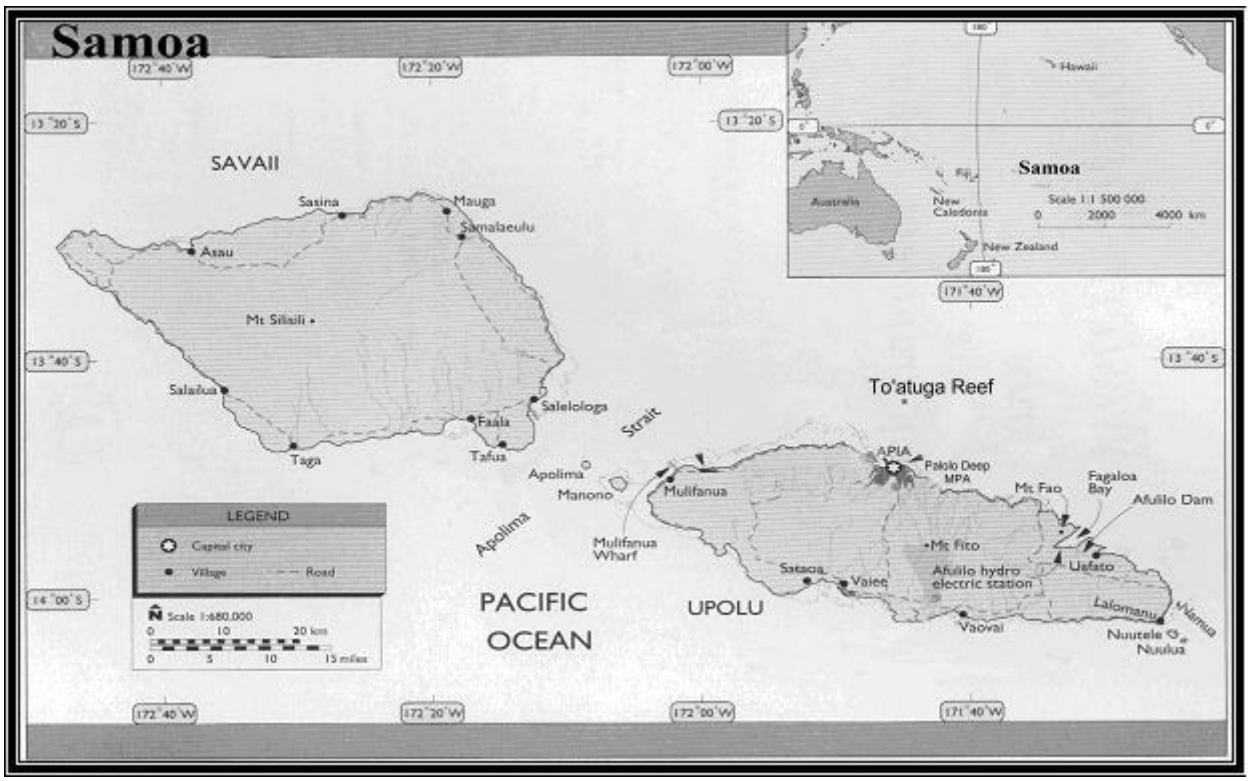
Information from the point transects were entered into an Excel spreadsheet program and was processed with respect to relative coverage and composition with site mean and standard deviation. The benthic items assessed are listed in Figure 1. The pie charts of the percentage composition is taken from the table summaries. Hard coral occurrences are tabled.

Table 1. Substrate code as applicable to the benthic items assessed.

Substrate Code	
HC	hard coral
CF	living coral Fragments
SC	soft coral
SP	sponge
FS	fleshy seaweed
TA	turf algae
EN	encrusting algae
CA	coralline algae
CD	coral damage
RKC	recently killed coral fragments
DSC	dead standing

	coral w algae
RC	rock
RB	rubble
SD	sand
SI	silt/clay
OT	other

Figure 1. Location of To'atuga Reef, Upolu, Samoa.



Adapted from the Western Samoa SOE State of the Environment Report, SPREP 1993.

3.0 The Nature of To'atuga Reef (Five Mile Reef)

The nature of the reef system is unique due to its offshore location, depth and chronic surge environment. Its lack of zonation conforms to general reef development within the context of an exposed reef system, with a relatively deep reef top (15-22m) and a prominent peripheral depth gradient, and subject to periodic disturbance. This disturbance includes short-term considerations such as storm wave action and the much longer-term processes of eustacy and tectonism (Connell 1973; Chappell 1980, 1981; Purdy 1974).

The reef is isolated from the mainland and occurs in relatively deep water for coral reef development. It represents an uncommon shelf habitat. There are a few small reef areas 5 miles eastward from To'atuga Reef that shallow to 20-24m which most probably are similar to To'atuga Reef. The shelf is deeper ranging from 68-100m, with fewer shallow areas on the northeastern seaward shelf of Upolu. A series of shallow areas exist to the west of To'atuga Reef, seaward of

Cape Faleula but are adjacent the broad fringing reef. Many shallow near coast areas exist adjacent the fringing reefs on the western end of the island near the airport.

The presence of constant surge provides an environment that gives rise to an unusual balance of physical and biological processes. Both features protect the reef environment from the influences of the island such as freshwater run-off and sedimentation. The occurrence of the largest cyclone in 150 years (Ofa: Feb., 1990), followed by a major one (Valerie) the following year, must have affected the reef as it did in Palolo Deep (Lovell and Toloa, 1993) but this is not discernable more than a decade later. Evidence of recent events on the reef includes coral bleaching and damage from the most recent cyclone, Heta.

Figures 1 and 3 A,B shows the location of To'atuga Reef in Samoa. The position of the sample stations are shown in Figure 6. The bathymetry of the reef is shown in Figure 4, 5.

The following sections describe the 13 assessment stations on the reef. Site information with habitat photos describe representative areas of the reef. The overview description comprises the details of location, exposure, depth, profile, physical substrate, algae, coral, community type, biological and physical dynamics. For each site, point and qualitative transect information is incorporated in the text as well as in a summary table. A pie chart diagram details the percentage composition of the benthos.

Figure 2 A, B. A) Chart of central northern Upolu showing the location and bathymetry of To'atuga Reef. B) Large scale chart showing To'atuga Reef in relation to Apia Harbour.

A **B**

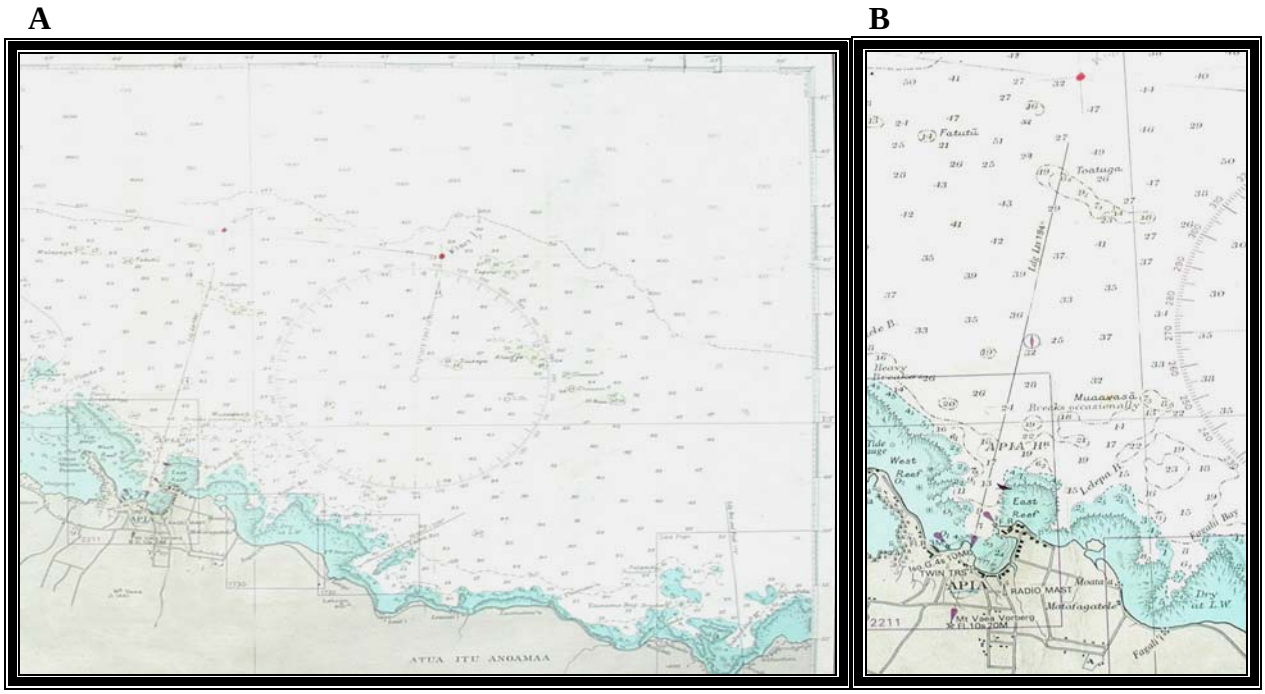


Figure 3. Bathymetry of To'atuga Reef*

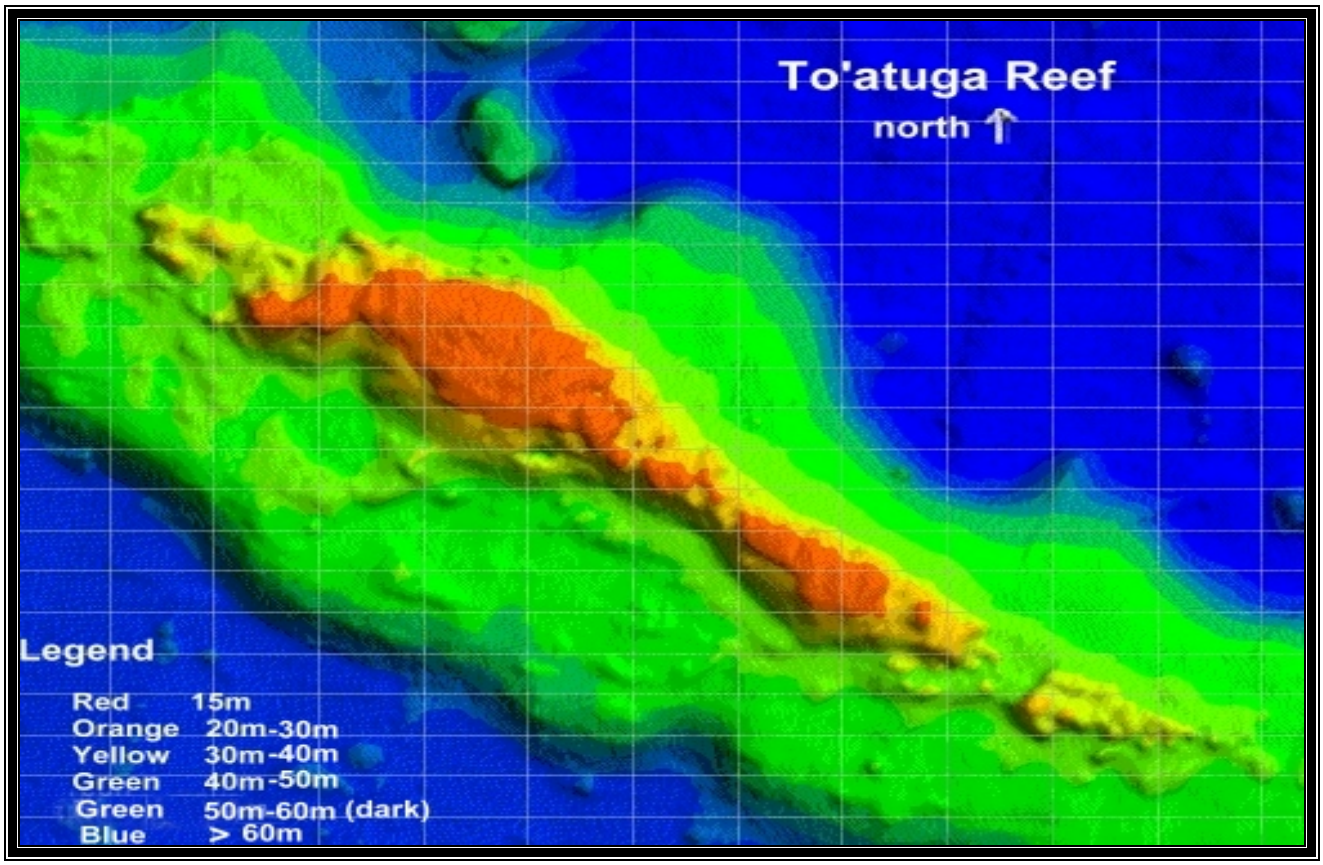
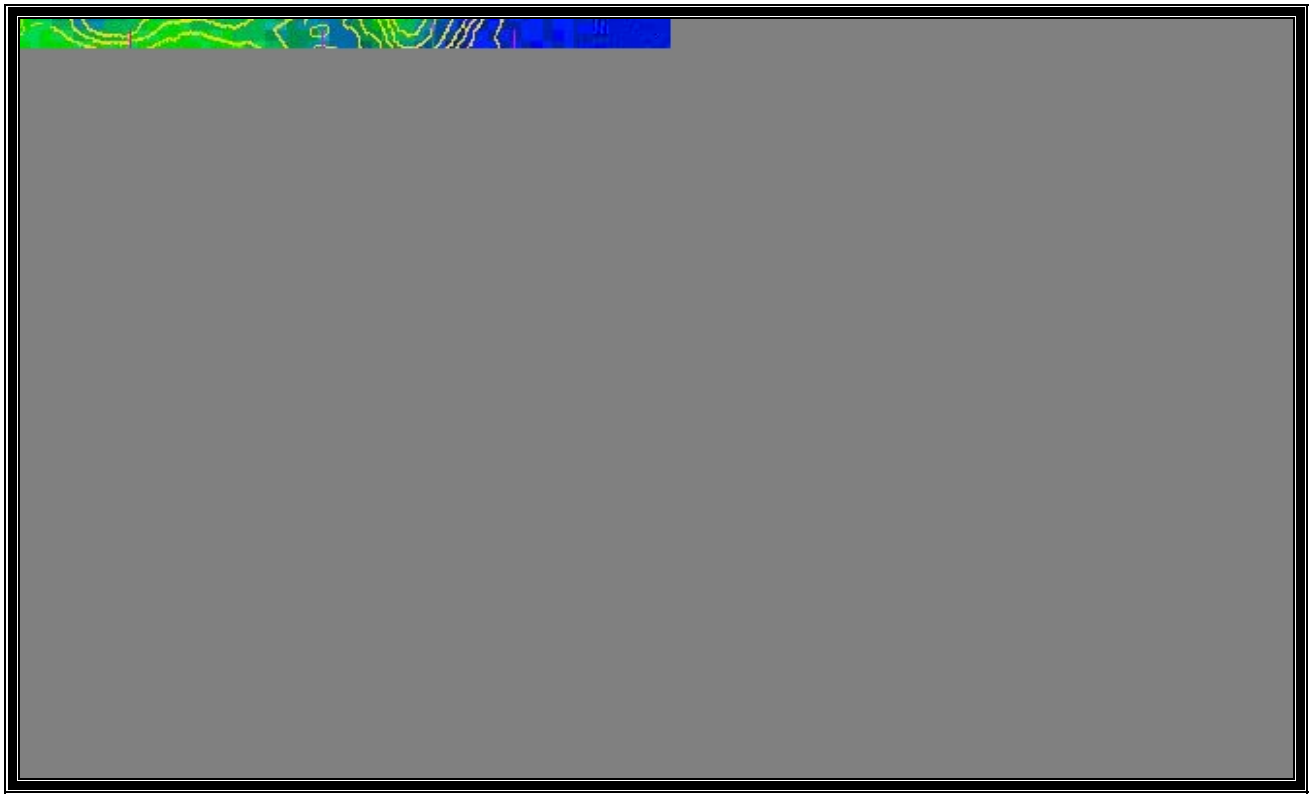


Figure 4. 10m contour profile of To'atuga Reef*



***SOPAC 2004 Multi-beam bathymetric survey of Samoa. South Pacific Applied Geoscience Commission – European Union project (SOPAC/EU EDF8), Jan.-Feb. 2004.**

Table 6. Benthic composition at site 3.

Grand total	N	Mean	SD
Hard coral	6	2.0	1.0
Soft coral	0	0.0	0.0
Coral Fragments	5	1.7	2.9
Recently dead coral	0	0.0	0.0
Dead standing coral	0	6.3	2.1
Turf algae	1	0.3	0.6
Coralline algae	19	6.3	2.1
Sponge	0	0.0	0.0
Rock	2	0.7	0.6
Rubble	7	2.3	2.3
Sand	0	0.0	0.0

Figure 13. Percentage of benthic cover at site 3.

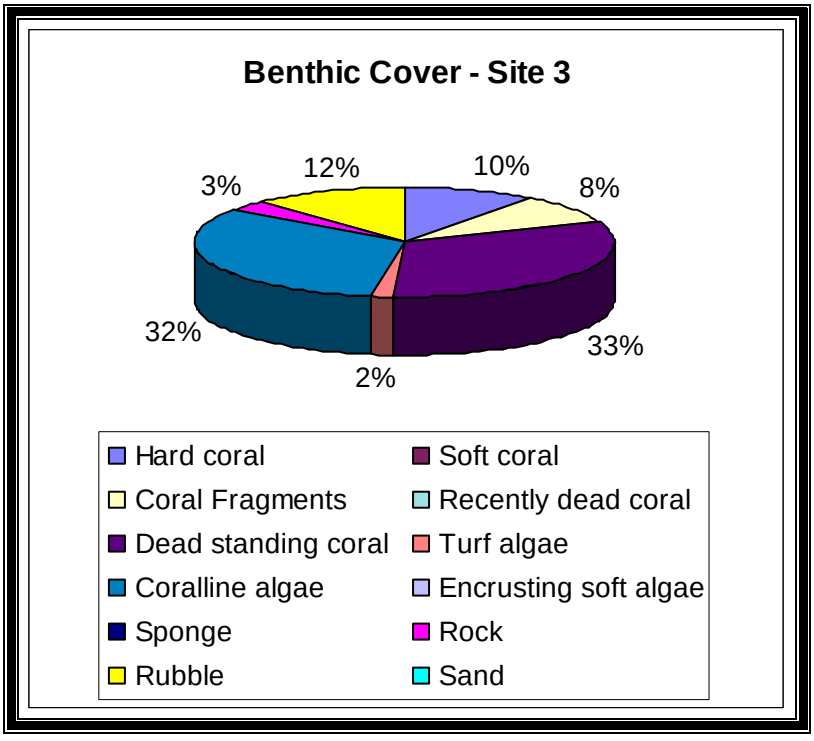


Table 7. Coral present in 30m transect.

Hard coral	Occurrence in 30m
Acropora humulis	2
Acropora secale	1
Montipora sp.	1

Pavona sp.	1
Echinopora gemmacea	1

Figure 14. Dead standing tabulate corals with a live colony (left of centre) with long dead coral (right bottom).

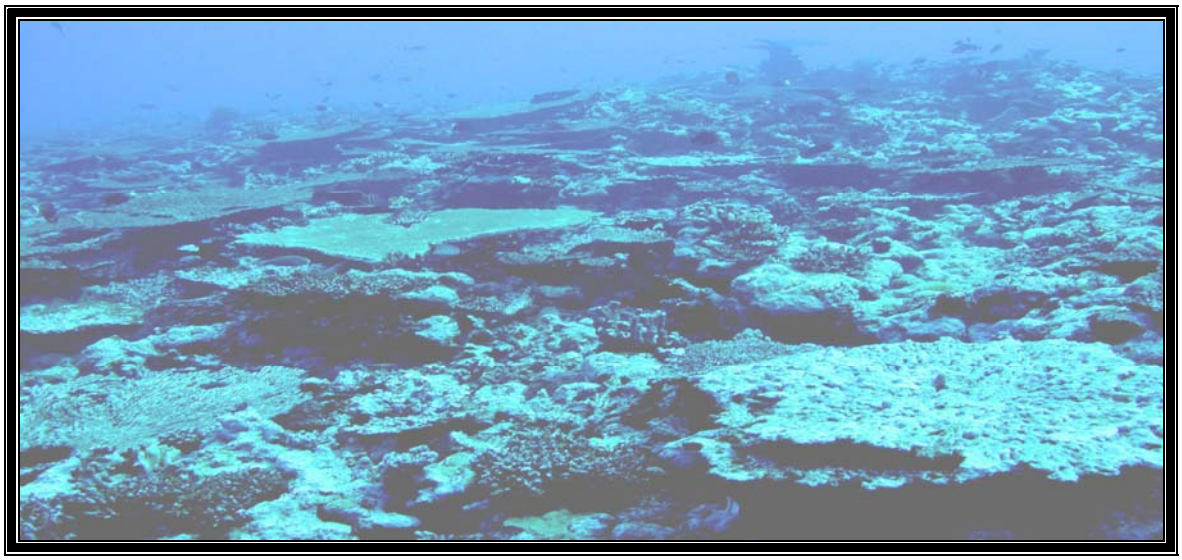
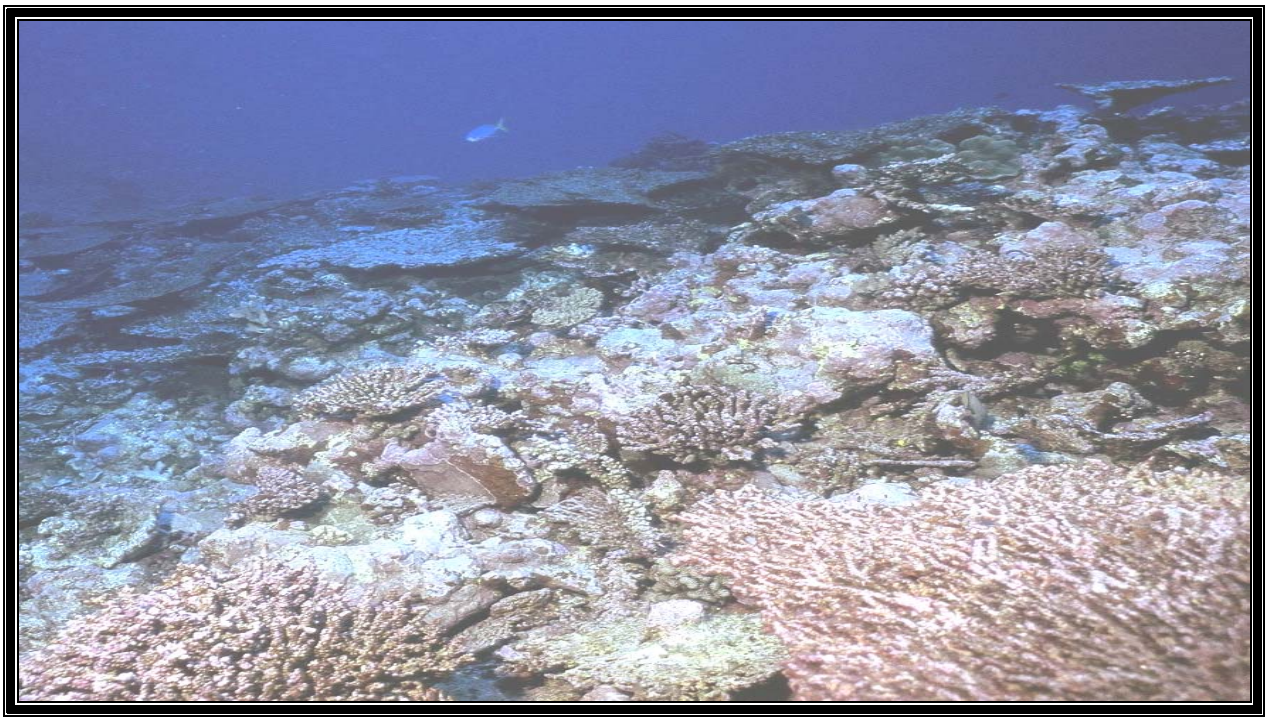


Figure 15. Slope ascending to the crest of the eastern margin. Dead standing coral on the crest with living coral in the fore and middle view.



4.1.4 Site 4 a, b

This area is located on the reef top of the To'atuga Reef (Lat. 13 45' 55"; Long. 171 45' 04"). The station is located at 18-19m depth.

Table 8. Benthic composition at site 4a.

Grand total	N	Mean	SD
Hard coral	14	4.7	1.5
Soft coral	0	0.0	0.0
Coral fragments	5	1.7	0.6
Recently dead coral	0	0.0	0.0
Dead standing coral	11	7.0	0.6
Turf algae	0	0.0	0.0
Coralline algae	18	6.0	2.6
Sponge	0	0.0	0.0
Rock	9	3.0	2.0
Rubble	2	0.7	0.6
Sand	0	0.0	0.0

Figure 16. Percentage of benthic cover at site 4a.

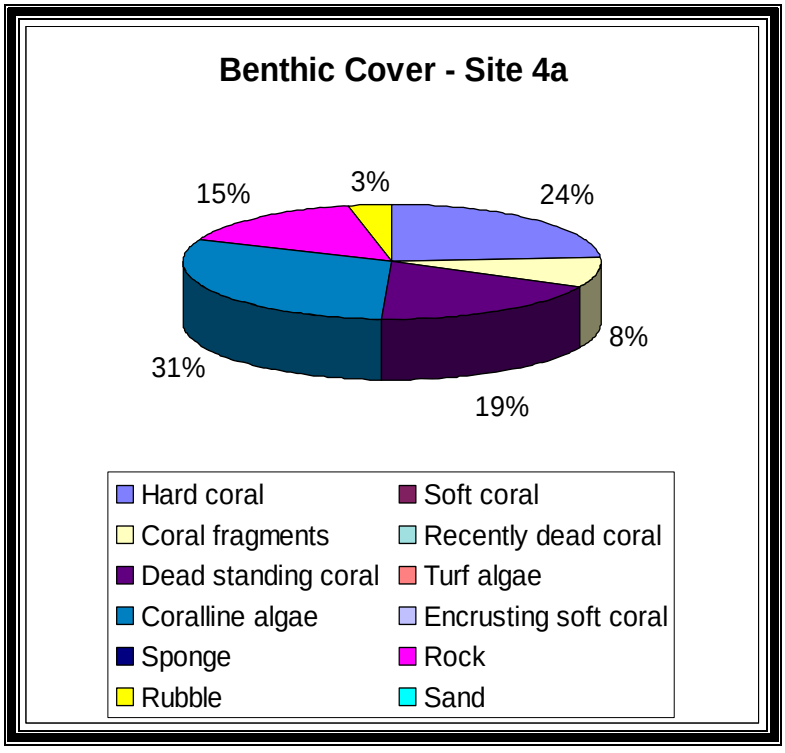


Table 9. Benthic composition at site 4b.

Grand total	N	Mean	SD
Hard coral	13	4.3	2.5
Soft coral	0	0.0	0.0
Coral fragments	5	1.7	1.5
Recently dead coral	0	0.0	0.0
Dead standing coral	7	6.0	1.2
Turf algae	0	0.0	0.0
Coralline algae	26	8.7	1.2
Sponge	0	0.0	0.0
Rock	2	0.7	1.2
Rubble	7	2.3	1.5
Sand	0	0.0	0.0

Figure 17. Percentage of benthic cover at site 4b.

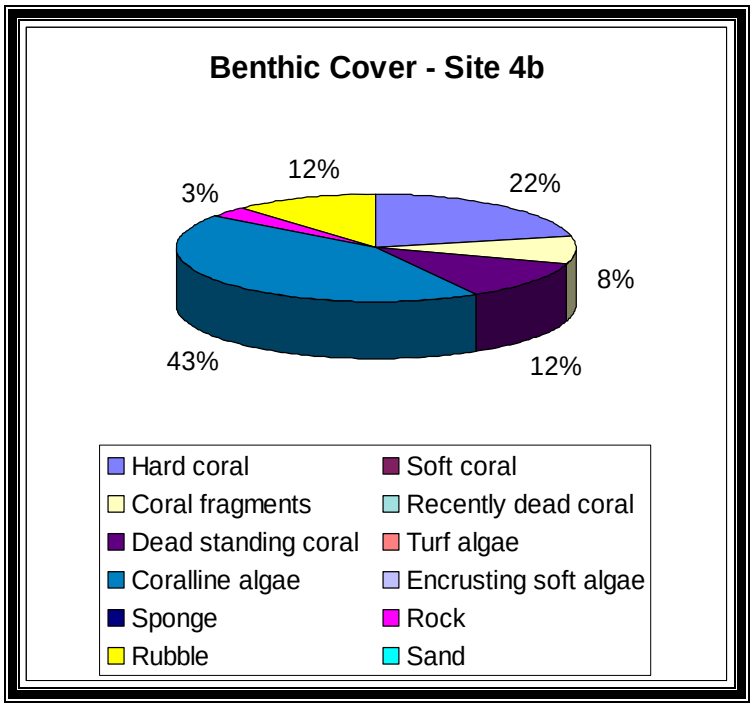


Table 10. Coral composition in a 30m transect.

Hard coral	Pocillopora meandrina	5
	P. eydouxi	1
	Acropora valida	1
	Leptastrea purpurea	1
	Pavona varians	1

Montipora sp.	2

Figure 18. Old and recent dead standing coral. Uncommon soft coral (left foreground, centre). Light areas are coralline algal covered areas.

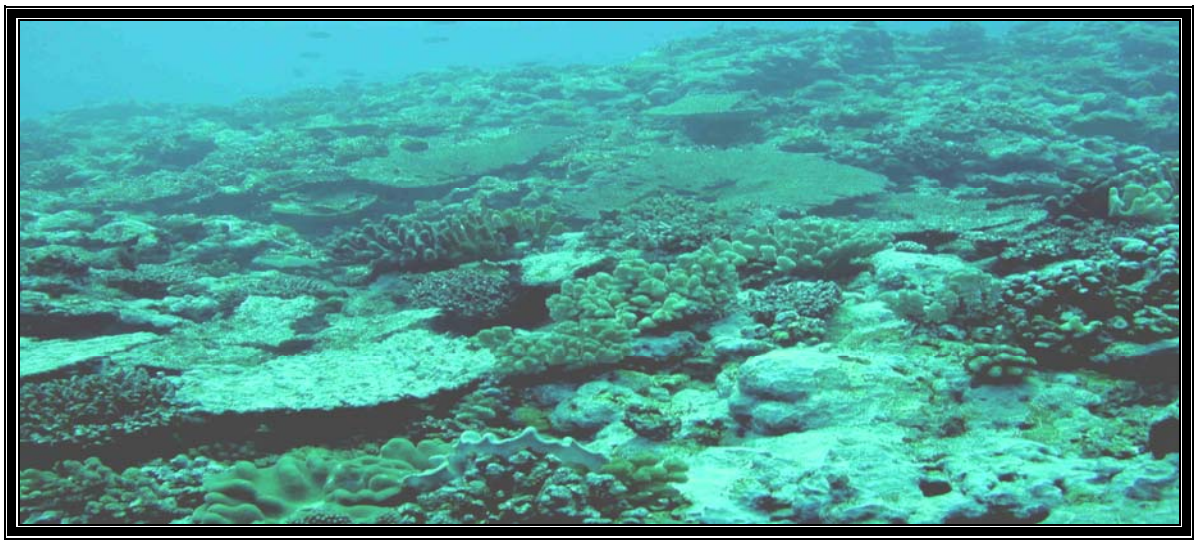
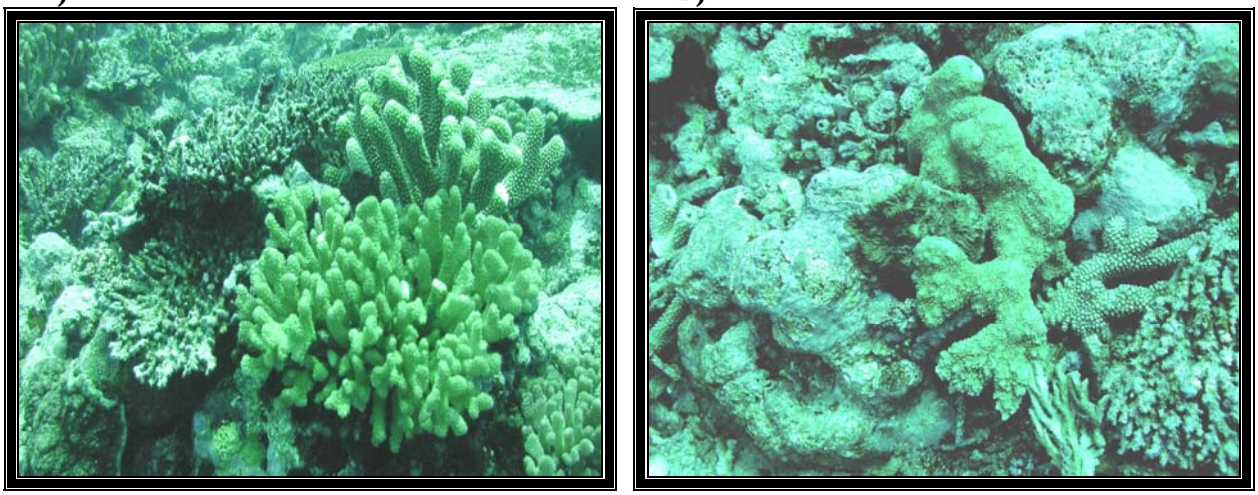


Figure 19. A) *Pocillopora eydouxi* and *P. meandrina* adjacent dead standing Acropora colonies. B) Rubble accumulation in the hollow of the reef top. Montipora fragment (center) has continued to grow as a loose colony. Other fragments have died and are coralline algal covered.

A) **B)**



4.1.5 Site 5

This area is located on the reef top of the To'atuga Reef (Lat. 13^0 45' 56"; Long. 171^0 45' 01"). The station is located at 19-20m depth.

Table 11. Benthic composition at site 5.

Grand total	N	Mean	SD
Hard coral	28	9.3	0.6
Soft coral	0	0.0	0.0
Coral Fragments	10	3.3	1.5
Recently dead coral	0	0.0	0.0
Dead standing coral	0	4.7	1.2
Turf algae	0	0.0	0.0
Coralline algae	49	16.3	3.8
Encrusting soft algae	3	4.7	1.0
Sponge	1	0.3	0.6
Rock	4	1.3	1.2
Rubble	10	3.3	2.1
Sand	0	0.0	0.0

Figure 20. Percentage of benthic cover at site 5.

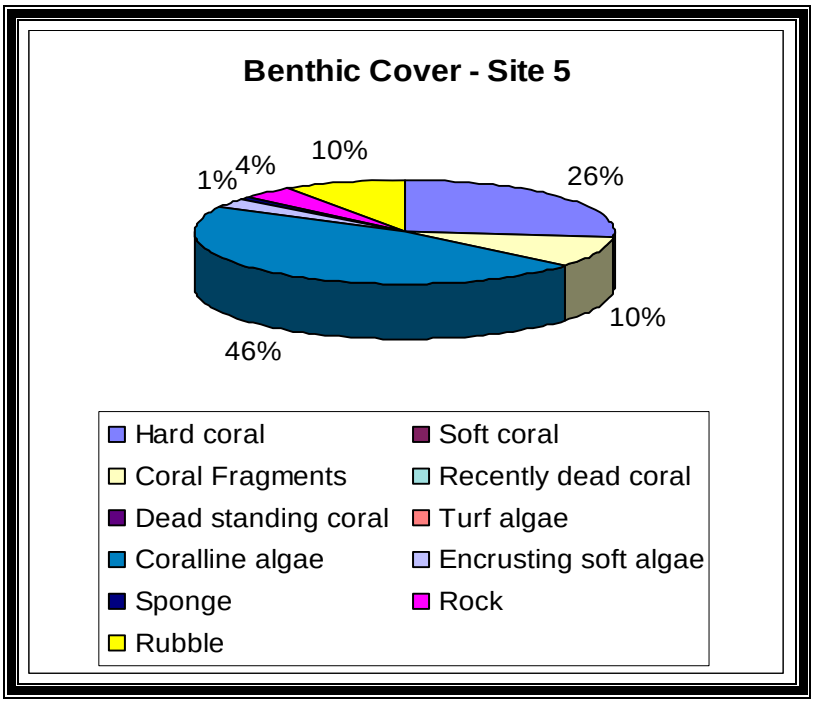


Table 12. Coral composition in a 30m transect.

Hard coral	Occurrence in 30m
Pocillopora eydouxi	6
Pocillopora meandrina	1
Acropora sp.	6

Montipora sp.	14
Pavona sp.	1

Figure 21. Pocillopora dominated reef top at station 5. Though live Acropora colonies occur there is an abundance of dead standing Acropora.

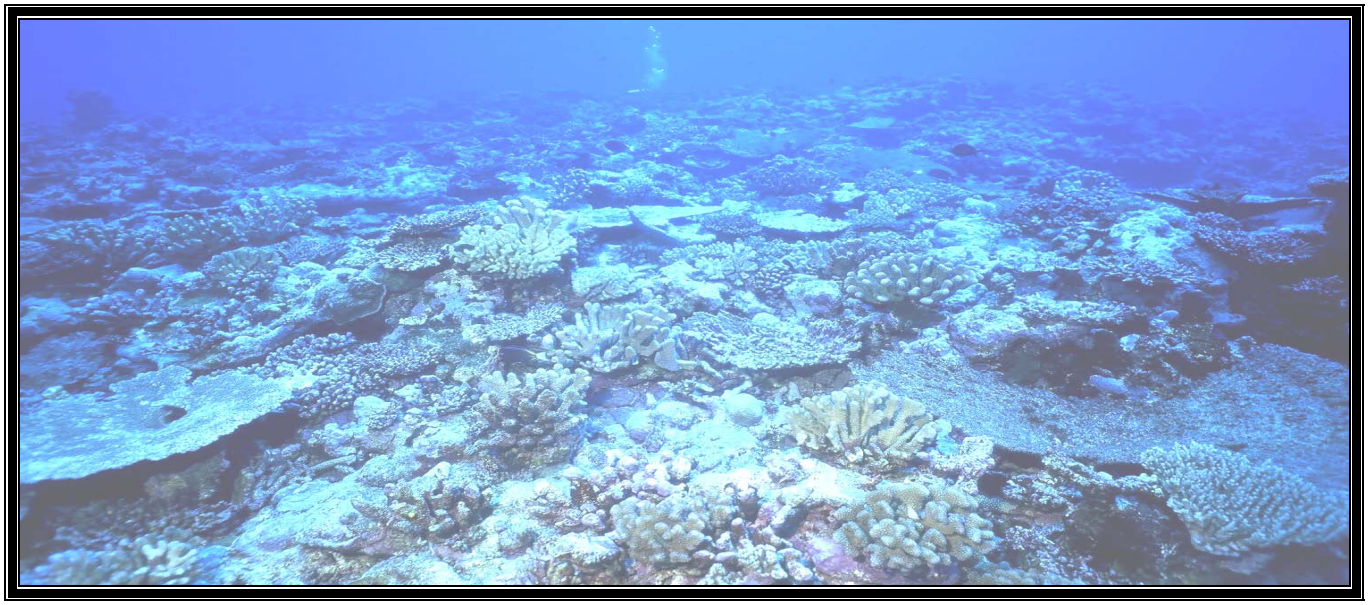
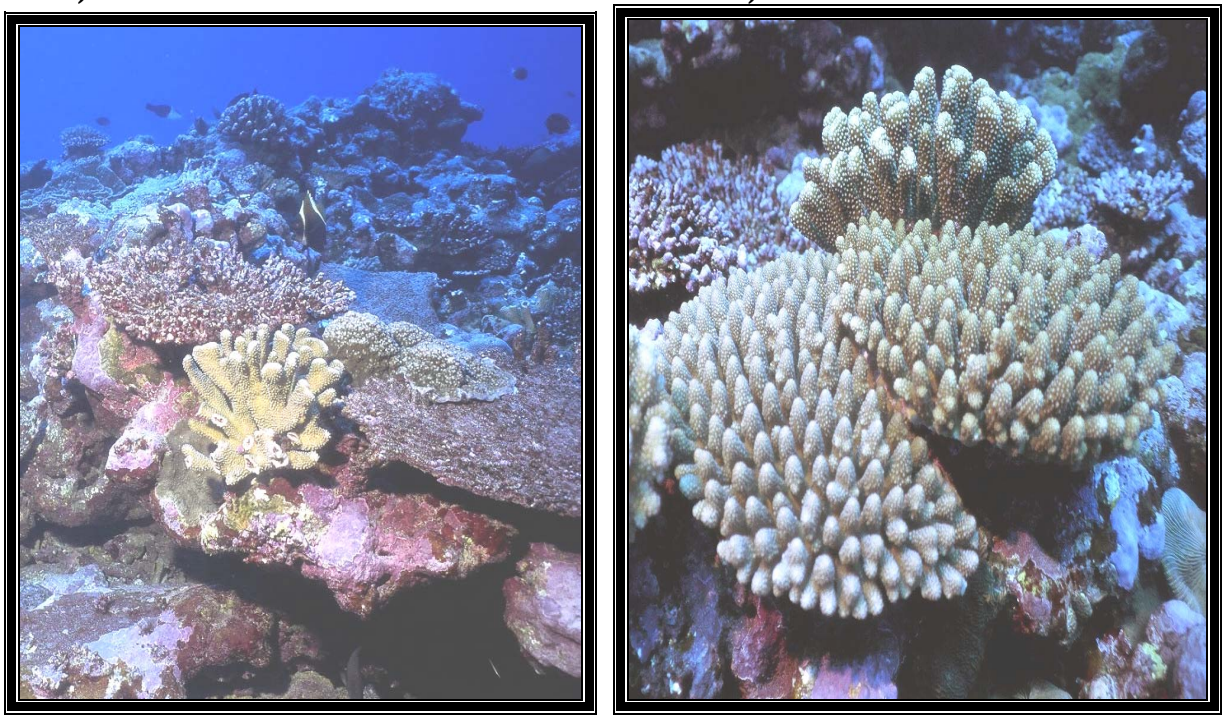


Figure 22. A) A broken *Pocillopora eydouxi* colony between dead standing Acropora coralla and surrounded below by coralline algae and behind by a Montipora colony. B) *Acropora monticulosa* colonies with a *Pocillopora eydouxi* colony (rear).

A) **B)**



4.1.6 Site 6

This area is located on the reef top of the To'atuga Reef (Lat. 13^0 45' 50"; Long. 171^0 44' 59"). The station is located at 17.5-21m depth.

Figure 23. A) Severely damaged *Acropora monticulosa* colony showing different stages of damage repair. B) Coral fragments alive and dead wedged in a reef top crevice.

A) **B)**

4.1.7 Site 7

This area is located on the reef top of the To'atuga Reef (Lat. 13^0 45' 57"; Long. 171^0 44' 50"). The station is located at 17.5-21m depth.

Table 13. Benthic composition at site 7

Grand total	N	Mean	SD
Hard coral	18	6.0	1.7
Soft coral	0	0.0	0.0
Coral Fragments	1	0.3	0.6
Recently dead coral	0	0.0	0.0
Dead standing coral	0	3.7	0.6
Turf algae	0	0.0	0.0
Coralline algae	27	9.0	2.0
Encrusting soft algae	0	3.7	0.0
Sponge	2	0.7	0.6
Rock	0	0.0	0.0
Rubble	1	0.3	0.6
Sand	0	0.0	0.0

Figure 24. Percentage of benthic cover at site 7

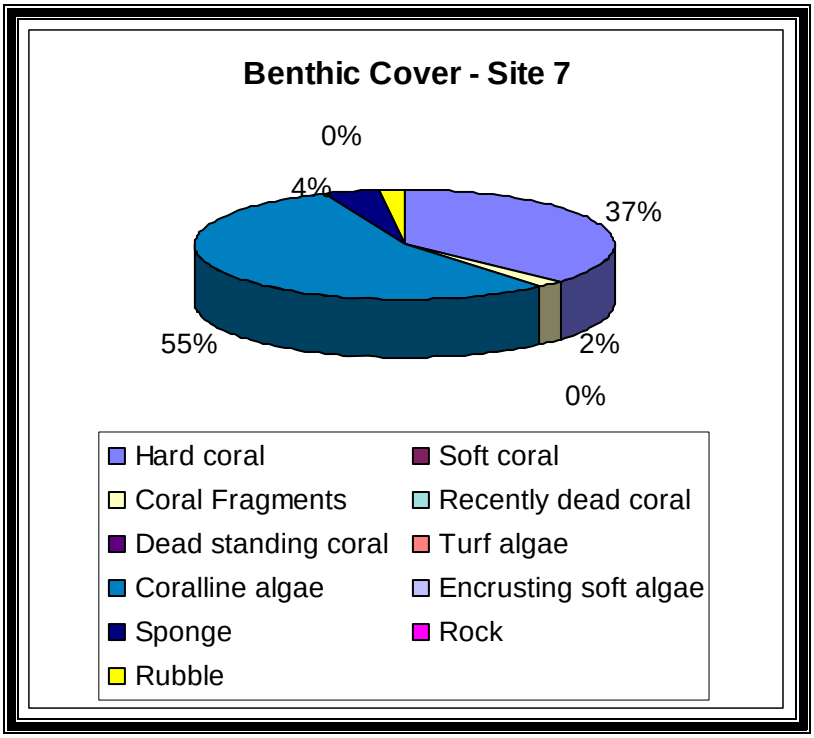


Table 14. Coral composition in a 30m transect

Hard coral	**Occurrence in 30m**
Acropora sp.	5
Montipora	9
Pavona sp.	3
Montastrea curta	1

Figure 25. A) Coral cornice with *Pocillopora eydouxi* and *P. meandrina* colonies with coralline algae covering the reef surface. B) Four corymbose *Acropora divaricata* colonies.

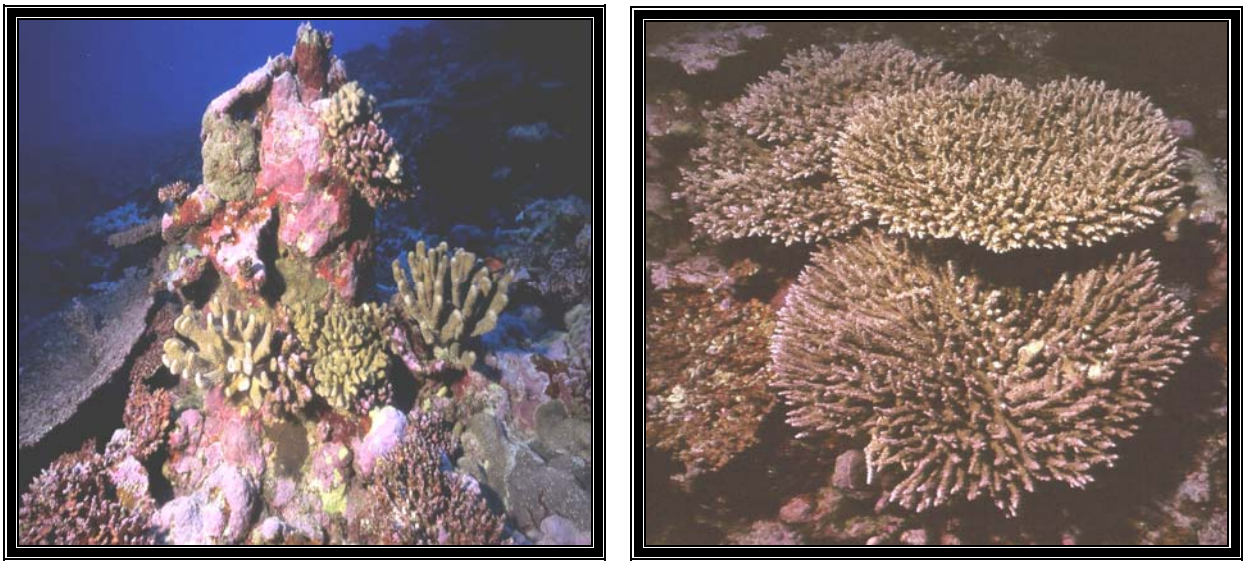


Figure 26. Progressive death of an *Acropora clathrata* colony with several stages of demise from white-band disease. The far left of the colony is alive with the white area recent death.

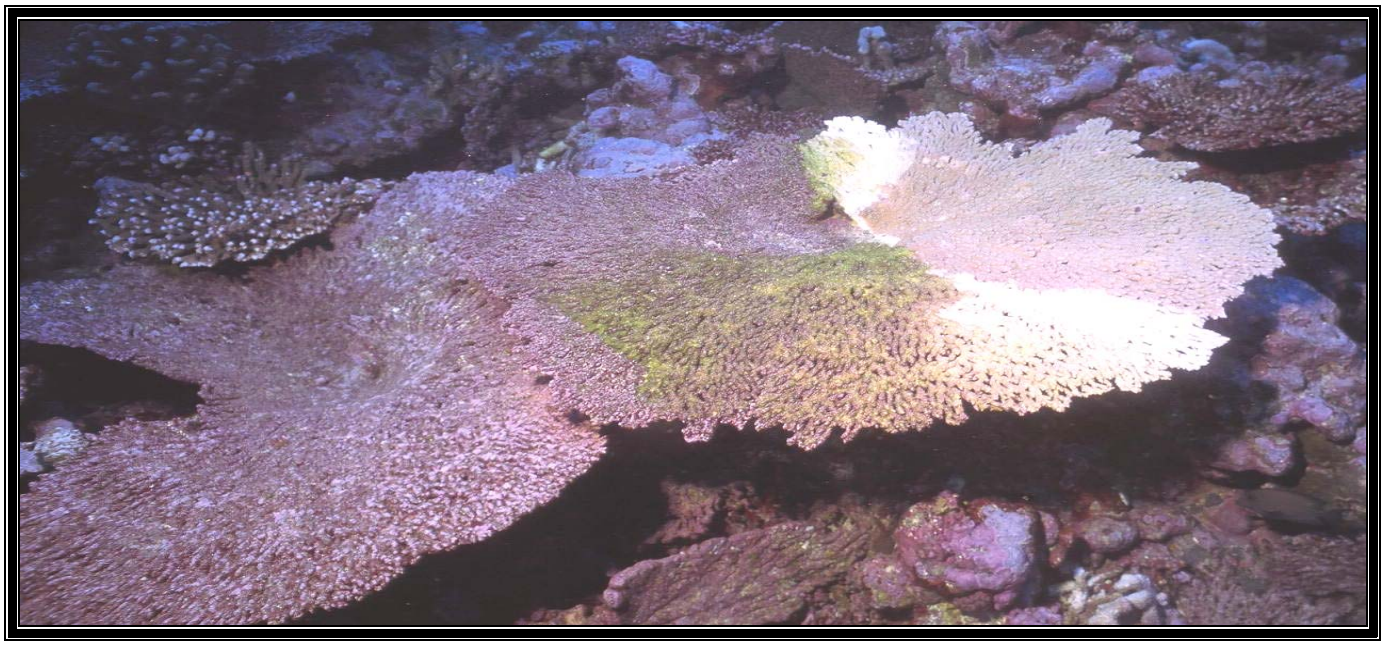
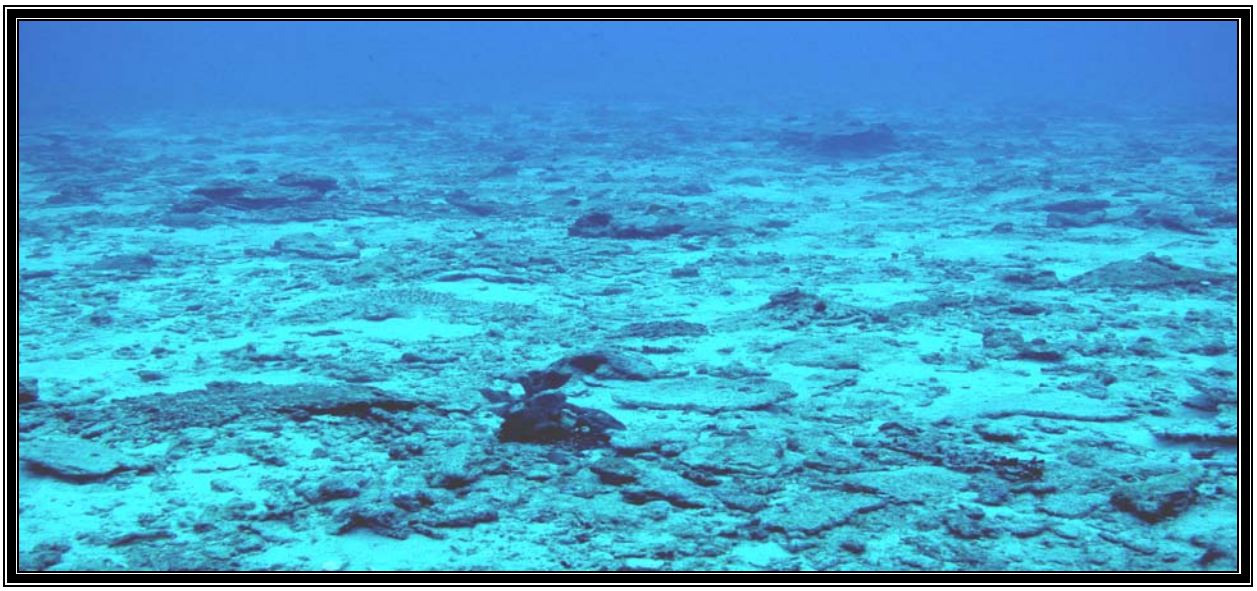


Figure 27. A, B) Views of the slope on the east side of To'atuga Reef at 40m as it descends to the horizontal sandy base. This is a lee side of the reef protected from the open-ocean northerly storms and swells. It is covered by coral fragments many of which are cemented to the reef by coralline algae.

A) **B)**

Figure 28. Rubble covered bottom at 40m depth.



4.1.8 Site 8

This area is located on the reef top of the To'atuga Reef (Lat. 13^0 46' 14"; Long. 171^0 44' 34"). The station is located at 40m and 25m.

Table 15. Benthic composition at site 8

Grand total	N	Mean	SD
Hard coral	15	5.0	2.0
Soft coral	0	0.0	0.0
Coral Fragments	6	2.0	1.7
Recently dead coral	0	0.0	0.0
Dead standing coral	0	4.0	1.7
Turf algae	0	0.0	0.0
Coralline algae	17	5.7	1.2
Encrusting soft algae	2	4.0	0.6
Sponge	0	0.0	0.0
Rock	0	0.0	0.0
Rubble	8	2.7	1.2
Sand	0	0.0	0.0

Figure 29. Percentage of benthic cover at site 8

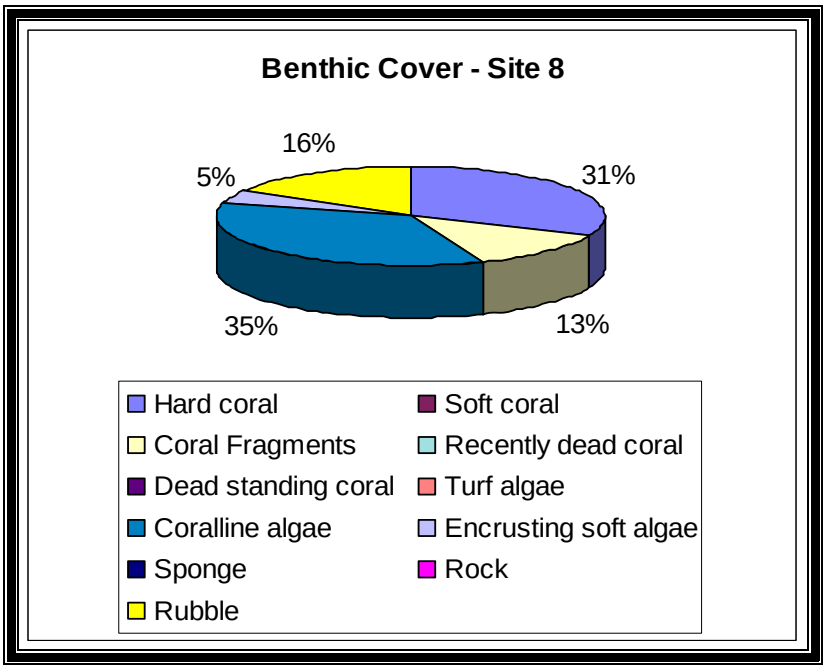


Table 16. Coral composition in a 30m transect

Hard coral	**Occurrence in 30m**
Acropora sp.	1
Montipora sp.	9
Pavona maldivensis.	2
Pocillopora eydouxi	2
Leptastrea purpurea	1

Figure 30. Spillway of coral fragments as it descends from the reef top down the east side of the reef. This talus slope extends from the reef top at 20m to the sandy floor at 40m.

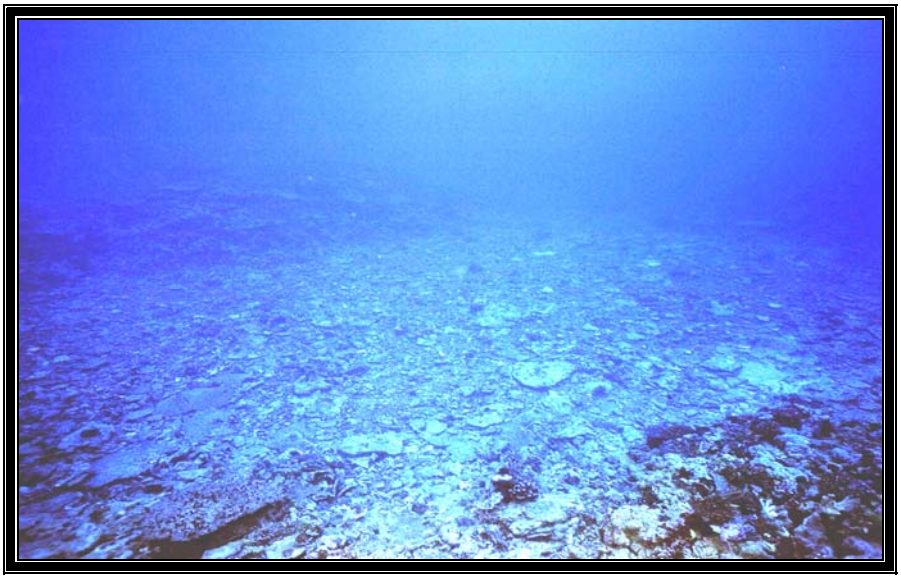


Figure 31. ***Acropora divaricata*** **colony on the steep eastern lee slope being protected from the fragment damage characteristic of the reef top.**

4.1.9 Site 9

This area is located on the reef top of the To'atuga Reef (Lat. 13^0 45' 58"; Long. 171^0 45' 04"). The station is located at 22m depth.

Table 17. Benthic composition at site 9.

Grand total	N	Mean	SD
Hard coral	10	3.3	2.3
Soft coral	0	0.0	0.0
Coral Fragments	5	1.7	1.2
Recently dead coral	0	0.0	0.0
Dead standing coral	0	4.0	2.0
Turf algae	0	0.0	0.0
Coralline algae	26	8.7	2.1
Encrusting soft algae	0	4.0	0.0
Sponge	0	0.0	0.0
Rock	1	0.3	0.6
Rubble	6	2.0	2.0
Sand	0	0.0	0.0

Figure 32. Percentage of benthic cover at site 9

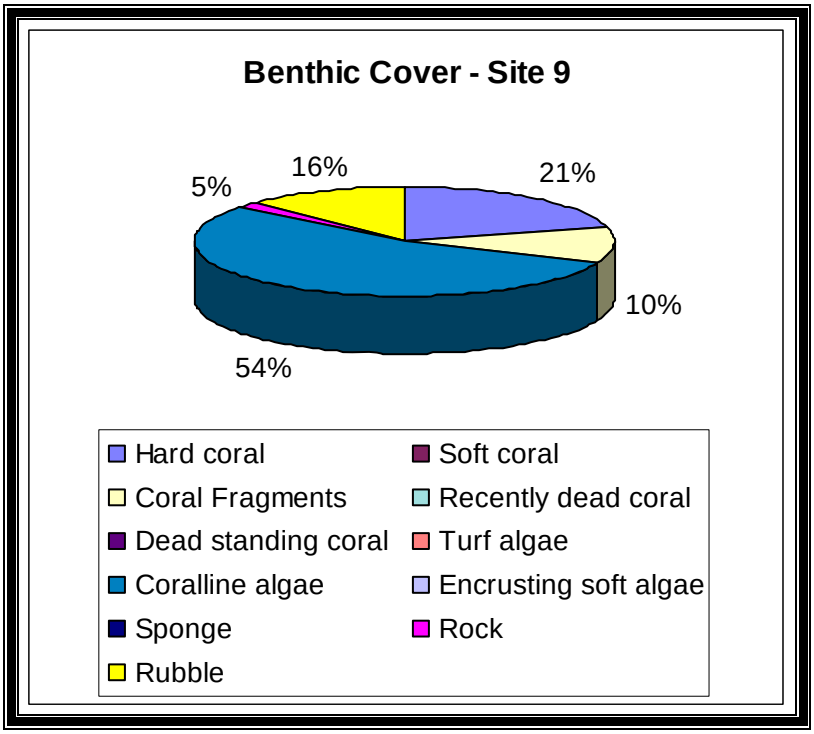


Table 18. Coral composition in a 30m transect.

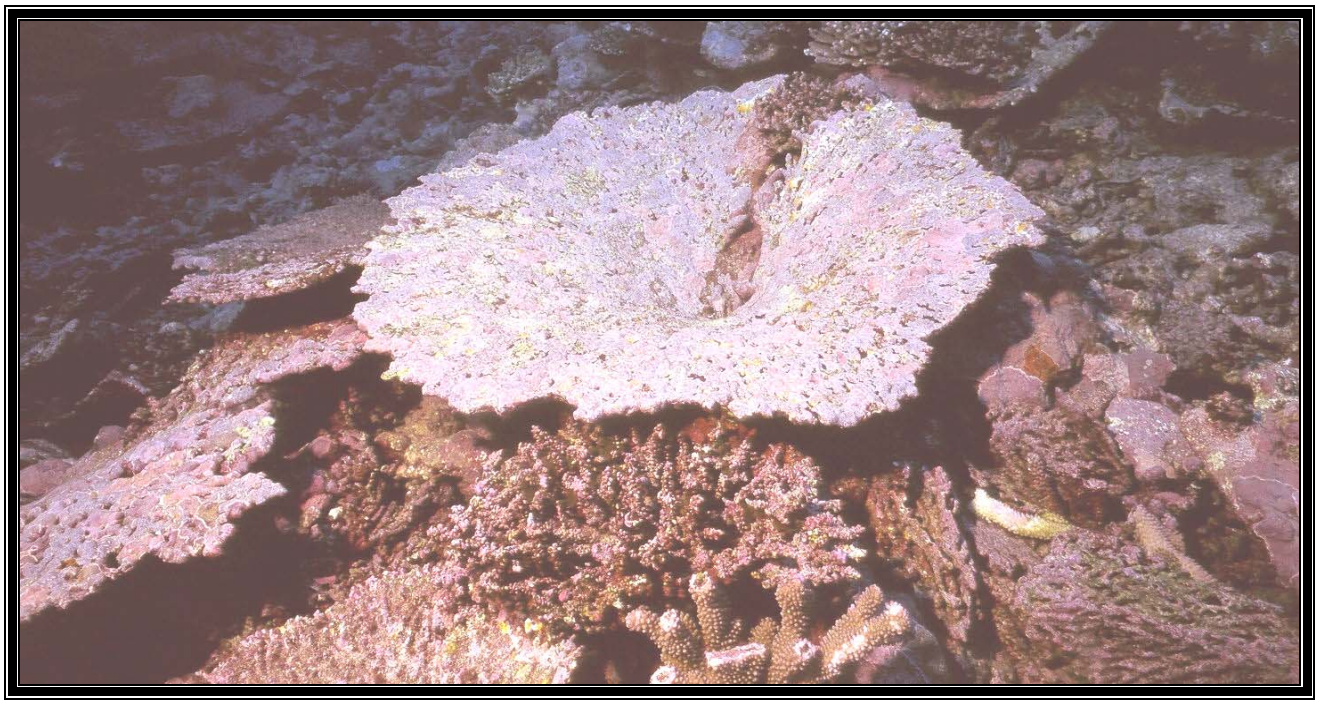
Hard coral	**Occurrence in 30m**
Acropora clathrata	2
A. cytherea	1
Montipora sp.	2
Pavona sp.	2
Pocillopora eydouxi	3

4.1.10 Site 10

This area is located on the reef top of the To'atuga Reef (Lat. 13^0 45' 55"; Long. 171^0 44' 59"). The site is located at 22m depth.

Figure 33. Live *Pocillopora meandrina* and *Acropora secale* and dead colonies on a reef outcrop.

Figure 34. Long dead coral coralla encrusted with coralline algae (top), dead standing coral (below), fragments of broken coral (rights). Damaged *Pocillopora eydouxi* with broken branches (center foreground).



4.1.11 Site 11

This area is located on the reef top of the To'atuga Reef (Lat. 13^0 46' 02"; Long. 171^0 44' 47"). The station is located at 22m depth.

Table 19. Benthic composition at site 11.

Grand total	N	Mean	SD
Hard coral	12	4.0	2.6
Soft coral	0	0.0	0.0
Coral Fragments	0	0.0	0.0
Recently dead coral	0	0.0	0.0
Dead standing coral	6	2.0	2.0
Turf algae	0	0.0	0.0
Coralline algae	20	6.7	1.2
Encrusting soft algae	**5**	2.0	1.5
Sponge	0	0.0	0.0
Rock	15	5.0	1.7
Rubble	2	0.7	0.6
Sand	0	0.0	0.0

Figure 35. Percentage of benthic cover at site 11.

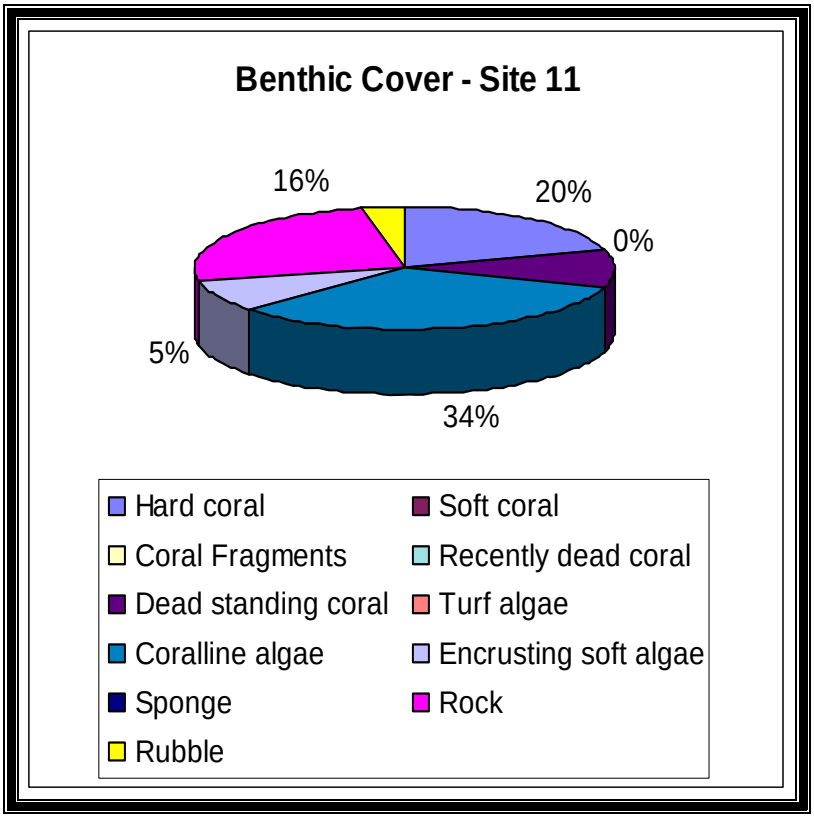


Table 20. Coral composition in a 30m transect

Hard coral	Occurrence in 30m
Acropora clathrata	2
A. cytherea	1
Montipora	2
Pavona	2
Pocillopora eydouxi	3

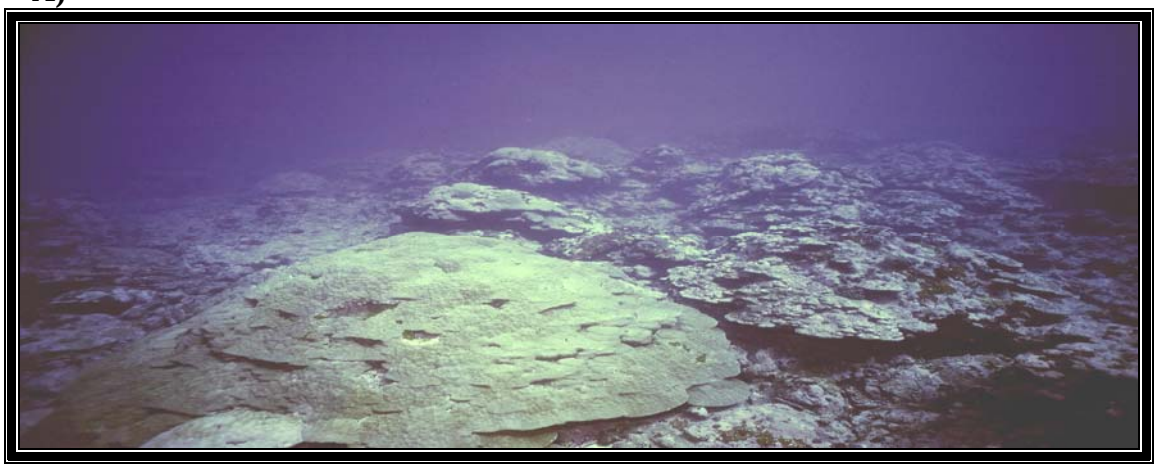
Figure 36. One of several fragment spillways cascading down the eastern side of the reef.

4.1.12 Site 12

This area is located on the reef top of the To'atuga Reef (Lat. 13^0 46' 13"; Long. 171^0 44' 54"). The station is located at 27-30m depth.

Figure 37 A,B. Large Porites colonies are typical of the southwest margin of the reef. A) The colony in the foreground is healthy with many of the surrounding colonies dead. B) Live and dead dome-like Porites colonies on the edge of the reef at 35m.

A)



B)

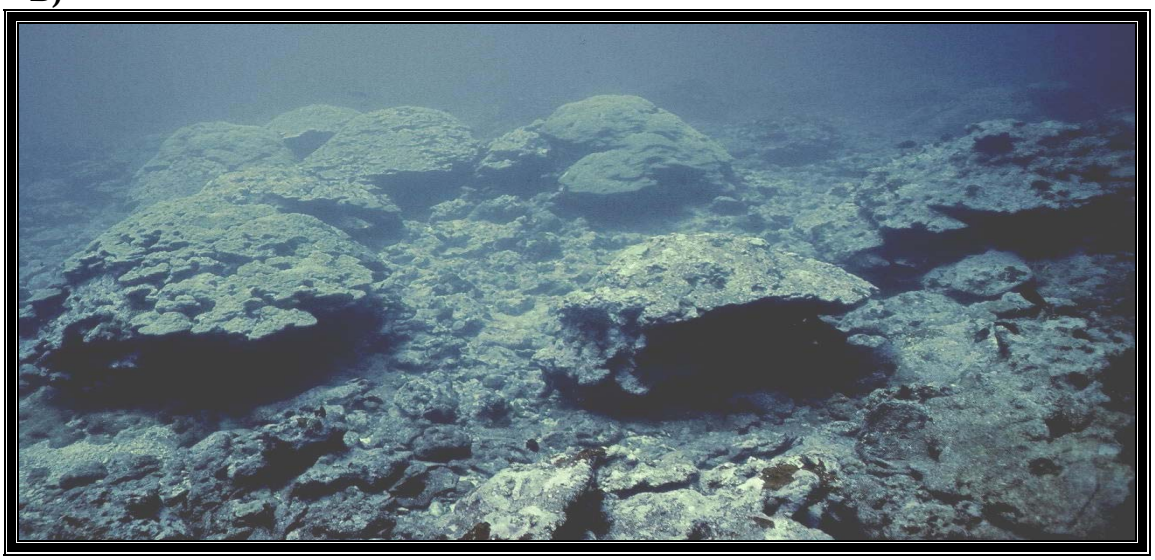


Figure 38. Close-up of the cemented reef surface showing coralline algae, brown algal patches, and Montipora colony (center right).

4.1.13 Site 13

This area is located on the southwest reef deeper margin of the To'atuga Reef (Lat. 13^0 46' 04"; Long. 171^0 44' 50"). The station is located at 20-30m depth.

Table 21. Benthic composition at site 13

Grand total	N	Mean	SD
Hard coral	2	0.7	0.6
Soft coral	0	0.0	0.0
Coral Fragments	0	0.0	0.0
Recently dead coral	0	0.0	0.0
Dead standing coral	3	1.0	1.0
Turf algae	0	0.0	0.0
Coralline algae	0	0.0	0.0
Encrusting soft algae	**0**	1.0	0.0
Sponge	0	0.0	0.0
Rock	13	4.3	3.8
Rubble	21	7.0	6.1
Sand	1	0.3	0.6

Figure 39. Percentage of benthic cover at site 13

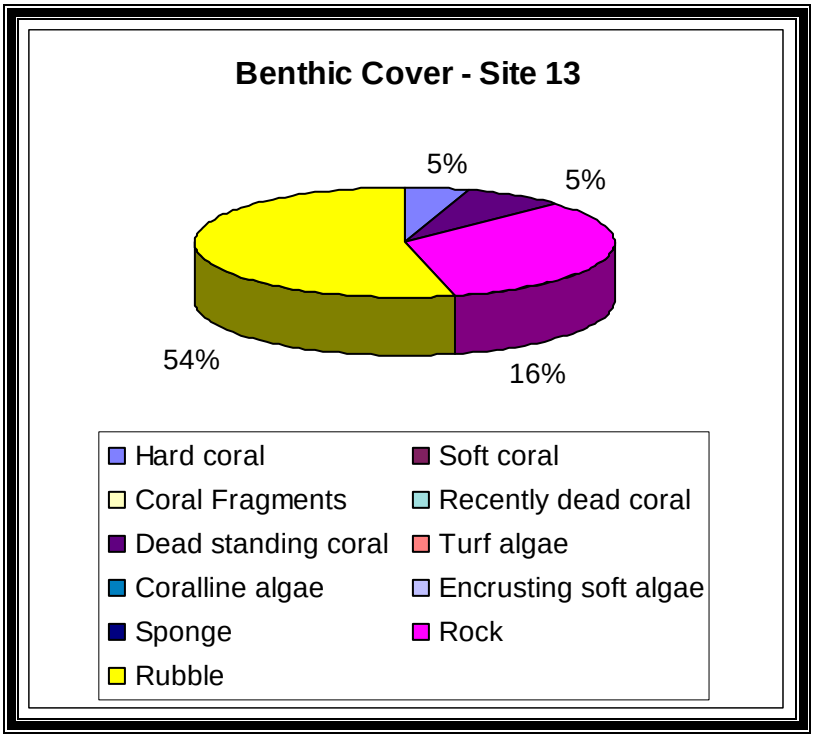


Table 22. Coral composition in a 30m transect.

Hard coral	**Occurrence in 30m**
Montipora	1
Porites lobata	1

Figure 40. Porites colonies thriving at 25m.

Figure 41. Horizontal reef margin (35m depth) of the southwest site composed of sand, stones and boulders which extends to greater depth.

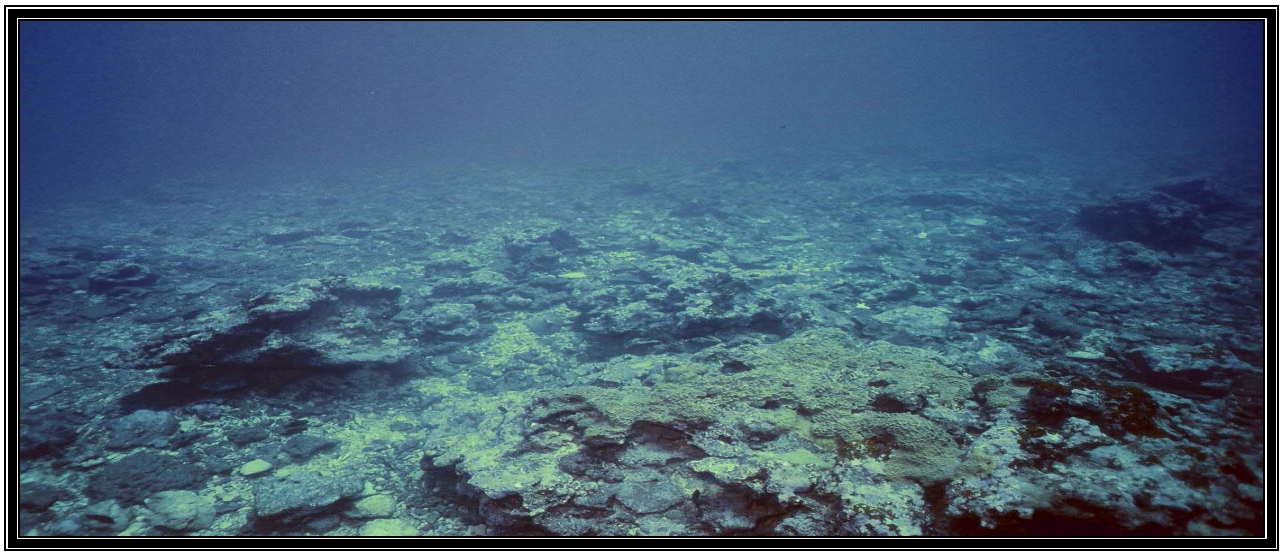


Figure 42. Unidentified *Acropora sp.* colonising on the edge of the dead Porites corallum.

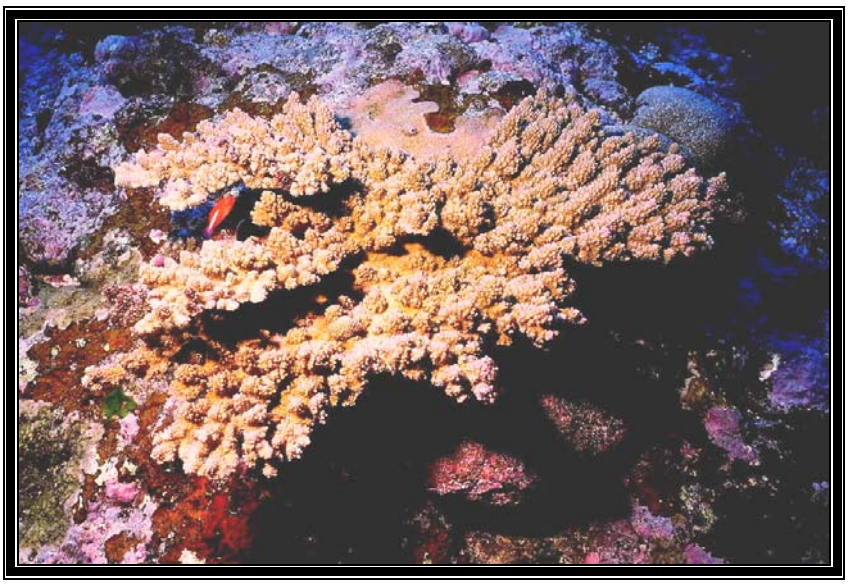


Table 23. Summary of transect information from the survey sites.

	Sample Sites														
Benthic Attributes	**1**	**2**	**3**	**4a**	**4b**	**5**	**7**	**8**	**9**	**11**	**13**	**Mean**	**Max.**	**Min.**	**St. Dev.**
Hard coral	15%	32%	10%	24%	22%	27%	37%	31%	21%	20%	5%	22%	37%	5%	0.11
Coral Fragments	23%	7%	8%	8%	8%	10%	2%	13%	10%	0%	0%	8%	23%	0%	0.07
Dead standing coral	0%	0%	32%	19%	12%	0%	0%	0%	0%	10%	8%	7%	32%	0%	0.12
Turf algae	0%	0%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%	0.01
Coralline algae	51%	46%	32%	31%	43%	47%	55%	35%	54%	33%	0%	39%	55%	0%	0.18
Encrusting soft algae	0%	0%	0%	0%	0%	3%	0%	4%	0%	8%	0%	1%	8%	0%	0.03
Sponge	0%	0%	0%	0%	0%	1%	4%	0%	0%	0%	0%	0%	4%	0%	0.01
Rock	6%	2%	3%	15%	3%	4%	0%	0%	2%	25%	33%	8%	33%	0%	0.12
Rubble	4%	14%	12%	3%	12%	10%	2%	17%	13%	3%	53%	13%	53%	2%	0.17
Sand	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	0%	3%	0%	0.01

Table 24. Benthic organisms and substrate types ranked as to decreasing occurrence in the sample transects.

Attribute	Mean (%)	Range
Coralline algae	39	0-55
Hard coral	22	5-37
Rubble	13	2-53
Rock	8	0-33
Coral Fragments	8	0-23
Dead standing coral	7	0-32
Soft encrusting algae	1	0-8
Sponge	0	0-4
Sand	0	0-3
Turf	0	0-2
Recent dead coral	0	0
Soft coral	0	0

4.2.1 Summary observations characteristic of sample sites

Due to constraints of the project, both in terms of the number of dives and bottom time, sampling was not extensive but conducted so as to provide a general description of the benthic reef composition. Representative areas were chosen to best reflect the nature of the reef .

4.2.1.1 Coralline algae

The coralline algae-covered substrate ranging from 31-51% (averaged 39%) with the exception of site 13 where the uncolonised rubble dominated. The widespread presence of the coralline algae reflects the surge environment which promotes the algal growth. Site 13 is on the lee side of the reef where the rubble relief and wave action is low.

4.2.1.2 Hard coral

For eight of the 11 sites, the occurrence of hard coral averaged 22% with a range of 20-37%, indicating its common occurrence. The lowest occurrence was 5% at site 13, which is an unusual area being dominated by large Porites colonies on a rubble bottom.

The assemblage is a mixture of the genera Pocillopora, Acropora, and Montipora on the reef top. The Pocillopora are the most evident living coral colonies with their vertical growth off the reef surface. The dead standing Acropora tables reflect a time of previous luxuriance. Much of the living coral are massive or encrusting colonies remain alive. Encrusting colonies of the genus Montipora are common on the reef surfaces competing with other encrusting corals such as Leptastrea and Pavona as well as coralline algae and turf algae. Large Porites colonies are an impressive feature of sites 12 and 13 on the southwest margin of the reef in 25m to 35m depth.

4.2.1.3 Rubble

Rubble occurrence is fairly uniform with an average occurrence of 13% and ranging from 2-17% for most of the sites. For site 13, 53% rubble occurrence reflects the larger areas of rubble between the large massive colonies.

4.2.1.4 Rock

The extent of uncolonised rock averaged 8% with a range of 0-33%. Rock forms the principle habitat for coralline algae, encrusting coral and turf algae. Rock surfaces were completely colonised on the reef top and sides. Bare rock was highest at sites 12 and 13 where the percentages of rock surfaces were 25% and 33% respectively.

4.2.1.5 Coral fragments

This type of rubble represents a unique feature of To'atuga Reef. reflecting the periodic damage sustained by the coral community due to the prominent wave environment. This material is represented by live pieces, recently fractured or growing now as unattached coral.

With regard to the current observations, the influence of the recent cyclone Heta has been prominent in terms of the recently generated rubble banks. Damage has been augmented by the fragile nature of the dead standing coral which is more liable to fragment and be swept across the reef, damaging living coral and creating more fragments.

4.2.1.6 Dead standing coral

This reef feature is the result of death due to coral bleaching and the subsequent effects of coral disease with regard to the tabulated coral and is represented by progressive death of the colony. The dead standing coral through bio- and physical erosion breaks up as rubble, entering the sand cycle.

4.2.1.7 Soft encrusting algae

These close cropped (encrusting) algae are brown and most probably a species within the Cyanophyceae or blue-green algae. It is common, though the transect data does not reflect this.

4.2.1.8 Soft coral

Though soft corals exist on To'atuga Reef, they were not present in the transects. They are represented by aggregations in reef areas.

4.2.1.9 Sponges and Turf algae

These categories are uncommon, though sighted during the survey.

4.2.1.10 Sand

Sand is uncommon on the reef top or slopes due to the chronic wave surge. Though extensive sand areas exist at the base of the reef and extend peripherally, sand does not accumulate within the shallow reef crevices and hollows.

4.2.1.11 Recent dead coral

This category is represented by tabulate corals which are dying due to white band disease. The difference between the recent and dead standing coral is that the recent dead coral is characterised by a white band of apparent bare coral skeleton. Older areas are colonised by light green algae. The transect sample does not reflect the occurrence due to its occurrence being confined to table corals.

4.3 Community type

Coastal fringing reefs which are characterised by a zonation caused by a varied wave and tidal environment and coastal features such as sedimentation and freshwater run-off. To'atuga Reef habitats and resulting community types are much more homogeneous. This is due to the limited light resulting from the reef depth, the surge environment and history of large wave events, the mobility of the fragment substrates, the low substrate relief for most of the reef.

4.4 Dynamics

Despite its superficial uneven nature, the reef top structure is the most consolidated of all the reef zones, with its dense pavement-like nature resulting coralline algae cementation in a high-energy surge environment. Rubble is constantly being generated by this action. This process in an extreme event occurred at Palolo Deep Marine Reserve near Apia (Zann and Sua, 1991) creating banks of displaced reef material. In the To'atuga Reef situation, the filling of holes is evident as are the cascades of material off the reef top.

The zone is impoverished due to the effects of wave action, isolation and uniformity of habitat 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 organisms are presumably cryptic or nocturnal due to the grazing and predatory fish fauna. As well as the consequences of depth and nutrient limitation, grazing may be responsible for the close-cropped nature of the algae. The lattice-like nature of the cemented boulders and rubble provides the most prominent habitat.

4.4.1 Coral death and fragmentation

At present, the progressive nature of Acropora plate death is very evident, highlighting the influences of coral disease (white band) on the table-type coral.. Although always a feature of the wave environment, fragmentation of coral skeleton has recently been aggravated by the extensive stands of dead coral resulting from the coral bleaching and disease. This material is progressively weakened by bio-erosion and subject to breakage with subsequent damage to living coral through wave-borne transport and impact.. Damage of living corals are evident, both recent and which have healed and regrown. Loose fragments are common in the crevices and hollows of the reef. Most notable are the spillways of the coral fragment talus that extends down the eastern edge of the steep reef slope. It is evident that the migration and consolidation of such material is to the northeast indicating a prevailing wave environment from the northwest due to the steepness of the slope and recent addition to this material by cyclone Heta.

5.0 Species Inventory

5.1 Scleractinia (Hard Coral)

The Scleractinian or hard coral fauna of To'atuga Reef is unique by virtue of the environment isolated from the mainland (Upolo I.), its history of chronic and intermittent disturbance involving two major cyclones, coral bleaching, disease, recreational and commercial use. The area is relatively depauperate as compared to the coastal embayed or lagoon habitats which offer protection both in habitat relief and wave protection.

The initial listing for To'atuga Reef notes 12 families, 24 genera and 64 species. A maximum generic number for the Samoa's, based on worldwide distributional data, is between 50 and 60 (Veron, 1993). 49 genera have been recorded from American Samoa (Birkeland et. al. 1992). 37 genera and 124 species have been recorded from the north coast of Samoa. This compares with 58 genera and 210 species from Fiji.

5.1.1 Taxonomy of coral and other species

Table 25. Comparative coral occurrence from To'atuga Reef, Palolo Deep, Fagaloa Bay with total records from Samoa.

Taxonomy	To'atuga Reef (Collection or photo specimens)	Palolo Deep	Fagaloa Bay	Samoan Records*
Class ANTHOZOA Subclass ZOOANTHERIA Order SCLERACTINIA				
Family POCILLOPORIDAE				
Pocillopora damicornis (Linnaeus, 1758)		X	X	X
Pocillopora eydouxi (Edwards & Haime, 1860)	X (3)	X	X	X
Pocillopora verrucosa (Ellis & Solander, 1786)	X	X	X	X
Pocillopora meandrina Dana, 1846	X (3)	X	X	X
Seriatopora hystrix Dana, 1846		X	X	X
Family ACROPORIDAE				
Acropora (I.) crateriformis (Gardiner, 1898)	X		X	X
Acropora (A.) sp. 1	X			X
Acropora (A.) sp. 2	X (2)			X
Acropora (A.) sp. 1		X		X
Acropora (A.) sp. 2		X		X

Taxonomy	To'atuga Reef (Collection or photo specimens)	Palolo Deep	Fagaloa Bay	Samoan Records*
Acropora (A.) abrotanoides (Lamarck, 1816)	X (2)	X	X	X
Acropora (A.) aculeus (Dana, 1846)		X		X
Acropora (A.) aspera (Dana, 1846)		X	X	X
Acropora (A.) austera (Dana, 1846)			X	X
Acropora (A.) carduus (Dana, 1846)		X		X
Acropora (A.) cerealis (Dana, 1846)			X	X
Acropora (A.) chesterfieldensis Veron & Wallace, 1984	X			X
Acropora (A.) clathrata (Brook, 1891)	X (4)	X	X	X
Acropora (A.) cuneata (Dana, 1846)		X		X
Acropora (A.) cytherea (Dana, 1846)	X (2)	X	X	X
Acropora (A.) dendrum (Bassett-Smith, 1890)	X			X
Acropora (A.) digitifera (Dana, 1846)			X	X
Acropora (A.) divaricata (Dana, 1846)	X (3)	X	X	X
Acropora (A.) florida (Dana, 1846)	X			X
Acropora (A.) gemmifera (Brook, 1892)		X	X	X
Acropora (A.) glauca	X			X
Acropora (A.) globiceps (Dana, 1846)	X			X
Acropora (A.) grandis (Brook, 1892)		cf. X	X	X
Acropora (A.) humilis (Dana, 1846)	X	X	X	X
Acropora (A.) hyacinthus (Dana, 1846)			X	X
Acropora (A.) intermedia (Dana, 1846)			X	X
Acropora (A.) latistella (Brook, 1892)			X	X
Acropora (A.) lutkeni	X			X

Crossland, 1952 **Taxonomy**	**To'atuga Reef (Collection or photo specimens)**	**Palolo Deep**	**Fagaloa Bay**	**Samoan Records***
Acropora (A.) microclados (Verrill, 1869)	X			X
Acropora (A.) microphthalma (Verrill, 1869)			X	X
Acropora (A.) monticulosa (Bruggemann, 1879)	X (2)			X
Acropora (A.) muricata (Dana, 1846)		X	X	X
Acropora (A.) nana (Studer, 1878)			X	X
Acropora (A.) nasuta (Dana, 1846)	X	X	X	X
Acropora (A.) paniculata Verrill, 1902		X	X	X
Acropora (A.) pulchra (Brook, 1891)			X	X
Acropora (A.) robusta (Dana, 1846)	X	X	X	X
Acropora (A.) samoensis (Brook, 1891)		cf. X	X	X
Acropora (A.) secale (Studer, 1878)	X	X	X	X
Acropora (A.) selago (Studer, 1878)			X	X
Acropora (A.) subulata (Brook, 1893)			X	X
Acropora (A.) tenuis (Dana, 1846)			X	X
Acropora (A.) valida (Dana, 1846)		X		X
Astreopora sp.			X	X
Astreopora listeri (Bernard, 1896)	X	X		X
Astreopora myriophthalma (Lamarck, 1816)		X		X
Montipora sp. 2	X	X	X	X
Montipora cf. australiensis Bernard, 1897	X			X
Montipora danae (Edwards & Haime, 1851)	X			X

Taxonomy	To'atuga Reef (Collection or photo specimens)	Palolo Deep	Fagaloa Bay	Samoan Records*
Montipora corbettensis Veron & Wallace 1984	X			X
Montipora efflorescens Bernard, 1897	X (5)			X
Montipora grisea Bernard, 1897	X (4)			X
Montipora nodosa (Dana, 1846)	X (4)			X
Montipora turgescens Bernard, 1897	X			X
Montipora venosa (Ehrenberg, 1834)	X (3)			X
Montipora verrucosa (Lamarck, 1816)	X (2)			X
Family AGARICIIDAE				
Pachyseris speciosa (Dana, 1846)		X	X	X
Pavona decussata (Dana, 1846)		X	X	X
Pavona duerdeni Vaughan, 1907	X			X
Pavona maldivensis (Gardiner, 1905)	X (2)	X	X	X
Pavona varians Verrill, 1864	X (2)	X	X	X
Leptoseris explanata Yabe & Sugiyama, 1941	X			X
Leptoseris mycetoseroides Wells, 1954		X		X
Family SIDERASTREIDAE				
Coscinaraea spp.			X	X
Coscinaraea columna (Dana, 1846)	X	X		X
Psammocora contigua Esper 1797		X		X
Psammocora nierstraszi Horst, 1921	X (3)			X
Psammocora profundacella Gardiner, 1898	X			X
Psammocora haimeana Milne Edwards & Haime, 1851	X	cf. X		X
Psammocora superficiales Gardiner, 1898			X	X

Taxonomy	To'atuga Reef (Collection or photo specimens)	Palolo Deep	Fagaloa Bay	Samoan Records*
Family FUNGIIDAE				
Cycloseris vaunghani (Boschma, 1923)	X			X
Fungia danai Milne Edwards & Haime, 1851	X			X
Fungia (D.) fungites (Linnaeus, 1758)	X (2)	X		X
Fungia horrida Dana, 1846	X			X
Fungia (D.) scruposa Kluzinger, 1879			X	X
Fungia (P.) scutaria Lamarck, 1801	X	X	X	X
Fungia (V.) repanda Dana, 1846	X (2)	X	X	X
Herpolitha limax (Houttuyn, 1772)		X	X	X
Halomitra pileus (Linnaeus, 1758)	X			X
Sandalolitha dentata Quelch, 1884	X			X
Family PORITIDAE				
Goniopora sp.			X	X
Goniopora lobata Milne Edwards & Haime, 1851		X		X
Alveopora allingi Hoffmeister, 1925		cf. X		X
Alveopora verrilliana Dana, 1872	X			X
Porites (P.) cylindrica Dana, 1846		X	X	X
Porites (P.) lobata Dana, 1846	X (2)	X	X	X
Porites (P.) lutea Edwards & Haime, 1860			X	X
Porites (P.) nigrescens Dana, 1846		X		X
Porites (S.) rus (Forskal, 1775)	X (3)	X	X	X
Family FAVIIDAE				
Diploastrea heliopora (Lamarck, 1816)		X	X	X
Cyphastrea chalcidicum (Forskal, 1775)	X			X

Taxonomy	To'atuga Reef (Collection or photo specimens)	Palolo Deep	Fagaloa Bay	Samoan Records*
Cyphastrea serailia (Forskal, 1775)	X			X
Echinopora lamellosa (Esper, 1795)			X	X
Echinopora gemmacea Lamarck, 1816	X (2)			X
Echinopora pacificus Veron, 1990	X			X
Favia spp.			X	X
Favia matthai Vaughan, 1918		X	X	X
Favia stelligera Dana, 1846	X			X
Favites spp.			X	X
Favites halicora (Ehrenberg, 1834)		X	X	X
Favites flexuosa (Dana, (1846)		cf. X		X
Favites russeli (Wells, 1954)			X	X
Goniastrea spp.			X	X
Goniastrea aspera (Verrill, 1905)	X			X
Leptastrea purpurea (Dana, 1846)	X	X		X
Leptoria phrygia (Ellis & Solander, 1786)	X	X	X	X
Montastrea curta (Dana, 1846)	X (3)	X	X	X
Oulophyllia crispa (Lamarck, 1816)			X	X
Family OCULINIDAE				
Galaxea fascicularis (Linnaeus, 1767)	X	X	X	X
Family MERULINIDAE				
Hydnophora exesa (Pallas, 1766)			X	X
Merulina ampliata (Ellis & Solander, 1786)		X	X	X
Merulina scabricula Dana, 1846	X (2)			X
Family MUSSIDAE				
Acanthastrea sp.			X	X
Symphyllia recta (Dana, 1846)			X	X
Lobophyllia sp.	X	X		X

Taxonomy	To'atuga Reef (Collection or photo specimens)	Palolo Deep	Fagaloa Bay	Samoan Records*
Family PECTINIIDAE				
Echinophyllia aspera		X		
Mycedium elephantotus (Pallas, 1766)			X	X
Oxypora spp.		X	X	X
Family DENDROPHYLLIIDAE				
Turbinaria reniformis Bernard, 1896			X	X
No. of Scleractinians:				
Genera	28	24	29	38
Species	64	58	68	123

Table 26. Non Scleractinian corals from To'atuga Reef

Taxonomy	To'atuga Reef (Collection or photo specimens)	Palolo Deep	Fagaloa Bay	Samoan Records*
Class HYDROZOA				
Order MILLEPORINA				
Family MILLEPORIDAE				
Millepora spp.			X	X
Millepora exaesa Forskal, 1775	X	X	X	X
Millepora platyphylla		X	X	X

Blue represent the coral found only at To'atuga Rf.
Red represents the species present at the other sites and To'atuga Rf.
Black represents the coral from Fagaloa Bay.
Green found only in Palolo Deep.
Purple represents Palolo Deep and Fagaloa Bay.
The number following the species presence (X) is the number of specimens in the collection.
* Samoan Records: Specimens have been collected to substantiate the identifications from Palolo Deep and To'atuga Reef. The Palolo Deep collection was identified by the taxonomic unit of the Tropical Museum of North Queensland.

Table 27. Other groups collected from To'atuga Reef

Phylum COELENTERATA
Class ANTHOZOA
Subclass OCTOCORALLIA
Order ALCYONACEA (soft coral)
Sarcophyton sp.
Cladiella sp.
Phylum ECHINODERMATA
Class Echinodea
Eucidaris metularia
Class Crinoidea
Cromanthus (?) sp.
Class Ophiuroidea
Ophiomastrix sp.
Phylum MOLLUSCA
Class Bivalvia
Tridacna squamosa
T. maxima
Phylum CRUSTACEA
Class Brachiura
Trapezia sp. 1
Trapezia sp. 1
Trapezia sp. 2
Trapezia sp. 3
Phylum ALGAE
Division Rhodophyta
Class Rhodophyceae
Lithophyllum sp.
Amphiroa dilatata
Class Cyanophyceae

6.0 Reef Origin

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 To'atuga Reef developed on the gentle sloping shelf, created during the mid to late Pleistocene by the Mulifanua volcanics. The most extensive 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.

To'atuga Reef would be endangered of drowning if it were subject to a depth increase of 10m. Relic or drowned barrier reefs (at 50-80m near shore and 80-100m depth, 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 overlain 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 Ages. 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 alternatively caused these reefs to emerge and drown. Sea-level fluctuated between present mean sea level and -150 m (Chappell, 1981). During the last glaciation (20,000 years ago), the sea dropped to over 100m 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 the sea flooded them, marine life would gradually re-establish and corals start to grow (Purdy, 1974). 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 (Moreton et al.,1989 MS).

During the period of submergence from the late Pleistocene to a Recent or Holocene high sea-level, there was drowning of reefs 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. Due to volcanism, reef development for 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 yrs. B.P. for the northern reefs. This presumption is based on known sea-level fluctuation without the complication of tectonic activity. The reef base for coastal reefs can be 30m deep (40m To'atuga Reef) would not have been subject to colonisation until that time. Through 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 yrs 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 (Moreton et. al., 1989 MS.).

7.0 Natural Impacts affecting To'atuga Reef

7.1 Chronic Sedimentation

Unlike the coastal counterparts, To'atuga Reef is largely immune to this, due to its distance from shore and the nature of the long shore currents which transport the sediments along the coast.

7.2 Wave environment

The island environments are subject to a wave environment generated by prevailing conditions or distant storms. Extreme manifestations are cyclones which are part of the climatic environment of Samoa. The wave environment conditions the habitats of To'atuga Reef through an ambient surge

environment which can be destructive, at times. The major cyclones Ofa and Valerie (1990, 1991) have had a pronounced effect on the reef with the living cover damaged and in some cases removed by these strong storms (Lovell and Toloa, 1993). While good recruitment has occurred the reef has been further subjected to the coral death caused by coral bleaching, disease and, more recently, cyclone Heta (150kph).

7.2.1 Storms

The most significant natural occurrence capable of causing immediate catastrophic coral mortality on reefs is tropical cyclones or hurricanes. 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. The effect of the cyclones depends on their intensity and direction, and the nature of the reef community. 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 the reefs growth and development.

Between February 1st and 5th 1990, tropical cyclone Ofa, the strongest cyclone in 150 years, devastated Samoa. A year later in January, another strong cyclone, Valerie occurred. The effect of these two cyclones has greatly affected the coral reefs of Samoa. Cyclone Valerie and Ofa stripped the seaward reef slopes of its coral. Details of the storms' path and general effect on Samoa are found in Zann and Sua, 1991.

Storms have different effects on different parts of the reef system. It is this feature that allows the coral reef to respond successfully to catastrophic events. To'atuga Reef is a good example of the ability of the system to respond in terms of recolonisation and regrowth. The diverse nature of the coastal reefs and isolated offshore reefs like To'atuga Reef provide the variety which aid reef survival. As well, environments within the reef system provide a protection in which the reef fauna and flora can survive the devastating nature of storm waves.

7.2.1.1 Devastation and Recovery

Observing the effect on Palolo Deep, the type of catastrophic coral mortality from cyclone Ofa was extreme 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. In the geologic time scale, this is not an uncommon event, and probably 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. In the case of Palolo Deep, coral coverage approaching 100% was achieved within 7 years though with very reduced species diversity as the reef front was monopolised by Acropora tabulate colonies (pers. observ.).

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 centre of the storm, the only coral to survive was the massive *Montastrea annularis*. Unlike the Honduras situation where corals survived with depth, there were almost no corals left alive, but rather the reef surface and slope were mantled with rubble (Ball, Shinn & Stockman, 1967).

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

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

Shinn (1972) found that coral recovery following hurricanes Donna and Betsy in Florida could be relatively short term. Despite apparent extensive damage, within one year the damage was barely noticeable. In 4 years, the 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 overlainby lava. The bare substrate has experienced remarkable recruitment and general recovery in 5 years (Tomascik, in press). As with the case in Palolo Deep near Apia, it is an Acropora-dominated assemblage which has settled prolifically on the reef after the inundation 10 years ago.

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 reef recovery following the Low Isles, Great Barrier Reef storm, was minimal

Endean (1971) discussed the theoretical considerations that 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 the coral reef's development. It may account for major regional differences between cyclonic and non-cyclonic areas (Stoddart 1968, 1969e).

7.3 Crown of Thorns Starfish (COT) or Alamea (*Acanthaster planci*)

The periodic increase in the populations of this coral-eating starfish has made it an influential feature of reef communities. 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 corals tissue, the skeleton is initially colonised by algae. The associated fauna changes, particularly with respect to the fish assemblage, which become 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 1972 a,b). The occurrence of terrestrial run-off has been linked to Acanthaster outbreaks (Birkeland, 1982). Normal population densities at six specimens per kilometre of reef have been estimated (Endean, 1982).

No crown-of-thorns starfish were observed during the survey. It is speculated that the presence of depth and the chronic surge environment prevent the occurrence of the COT. Though juveniles

have been collected at depths of > 10m, this is an algal-feeding stage, with the adults migrating to the shallower reefs once coral feeding begins.

Documented outbreaks have been recorded five times on Upolu (1932-33, 1950s, 1969-70, 1977-80, 1980s) (Zann and Bell, 1991). Infestations may not have occurred at To'atuga Reef during these periods due to wave, depth and isolation. This feature enhances the value of the isolated systems in providing a reservoir of recruitment for coastal reefs unaffected by such predation..

7.4 Coral Bleaching

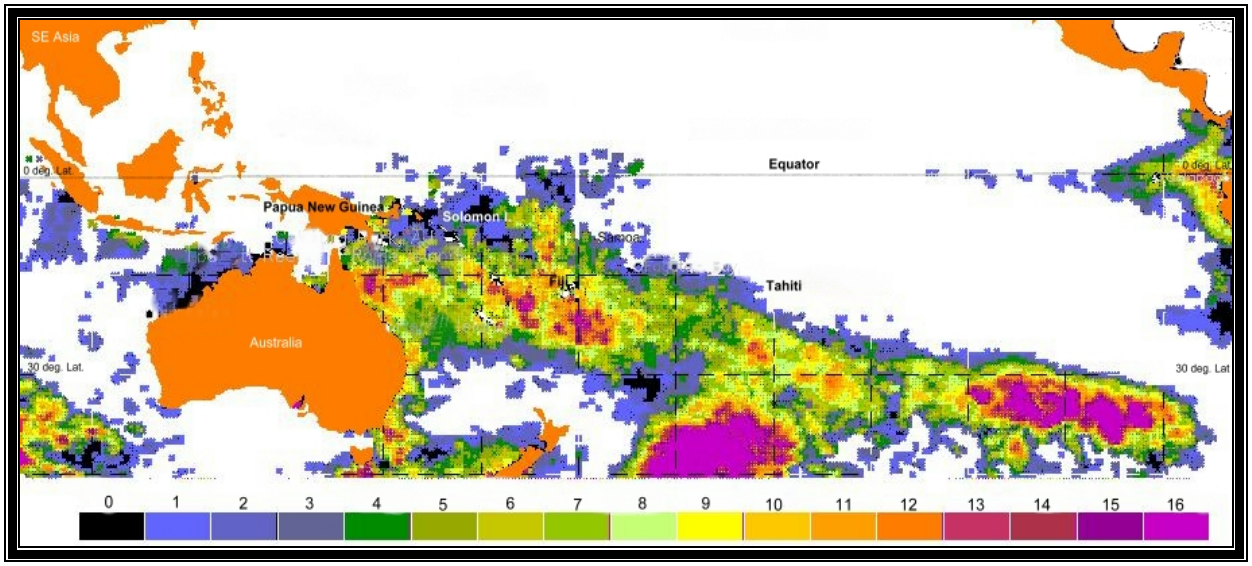
Coral bleaching is a global phenomenon (Williams and Bunkley-Williams, 1990). Its frequency, scale and severity seem to be increasing. There have been 60 bleaching events between 1979 and 1990 (Glynn, 1993). Few were reported before that period. The worst on record affected the Indian Ocean, Southeast Asia and Australia in 1998. The South Pacific has experienced major mass coral bleaching for several years.

7.4.1 What is Coral Bleaching?

Coral bleaching is a descriptive term applied to the influence of higher sea temperatures on a variety of coral reef organisms, which include sea anemones and giant clams as well as corals. What they all have in common is the internal presence of symbiotic algae, the zooxanthellae. Prolonged, unusually high sea temperatures cause physiological problems and the algae are expelled from the host organisms. The resulting appearance of coral or other organisms is a lightening or whiteness, though the inherent coloration of the animal host may dominate commonly as purple, blue or yellow.

The Great Barrier Reef in Australia has experienced coral bleaching in 1983, 1998 and 2002. Bleaching first occurred in the Central South Pacific in Tahiti in 1991 and again in 1994. Fiji experienced bleaching in 2000 after a prolonged period of temperatures in excess of 30^0C. This coincided with similar coral bleaching being reported across the South Pacific from Papua New Guinea (PNG) to Easter Island. Prior to and during this period, satellite surveillance of sea surface temperatures (SST) revealed a band of progressively elevating temperatures. They were above average in PNG as early September 1999. Waters around Fiji began to warm in the third week of December 1999. By mid-February it had reached its full extent. By the middle of March, the trans-Pacific zone of higher temperature began to break up but the effect on the corals was now widely reported. Areas to the north of Fiji remained cool.

Figure 43. A NOAA DHW chart graphically shows the state of the accumulation of warm water event in 2002.



The scale uses Degree Heating Weeks (DHW) and refers to the amount of time the temperature has remained 10^0C more than the maximum monthly mean. For the duration of the event, Tonga, Cook Is. and areas south of Fiji showed 10-15 DHW. Bleaching occurred after 5-6 DHW in Fiji. For the first time South Pacific countries such as Kiribati, Tuvalu and the Samoas (2nd year) experienced coral bleaching.

In both the Southwest Pacific and Australia, the unusual occurrence of warm water appears to be the result of a calm weather phenomenon moderated by oceanic and local current. When coinciding with the zenith of the sun on its seasonal transit, warming of the sea surface occurs often to depth.

As To'atuga Reef is a relatively deep reef, it would be expected that the bleaching might be moderated by depth. At a site in Fiji, bleaching occurred to at least 30m though the percentage of death was less (10% at 30m; 80% within 3-6m). The reduced bleaching most probably was largely due to a difference in the species assemblage which was dominated by tabulate Acroporas in the shallow areas and Montipora at depth (Lovell 2001c).

7.4.2 Samoa and the South Pacific

The first Southwest Pacific bleaching occurred in Samoa in the mid-nineties (1996-97?). In 2001, some bleaching was reported in Samoa. In 2002, bleaching was prominent throughout the Samoas. The actual coral bleaching event was observed in Palolo Deep and elsewhere in on coastal reefs in Samoa.

This survey recorded evidence of that event in the form of dead standing coral.

In the 2002 coral bleaching event, the ocean water around Samoa began to warm up in December with the National Oceanographic Atmospheric Administration (NOAA) sea surface temperatures (SST) degree heat week (DHW) charts showing 1-2 DHW accumulating (NOAA 2004). Heating was relatively rapid with 4 DHW by 1st January, 5 DHW by 15th January, 5-6 by 29th January, when bleaching began. By the 8 DHW stage (15th February DHW chart) bleaching became widespread. Cooling was fairly rapid with the DHW's decreasing in March and April. By contrast to the coral

bleaching event of 2000 in Fiji, the period of warming was short and the accumulation of DHW's moderate by comparison to the 2000 event which affected other South Pacific countries.

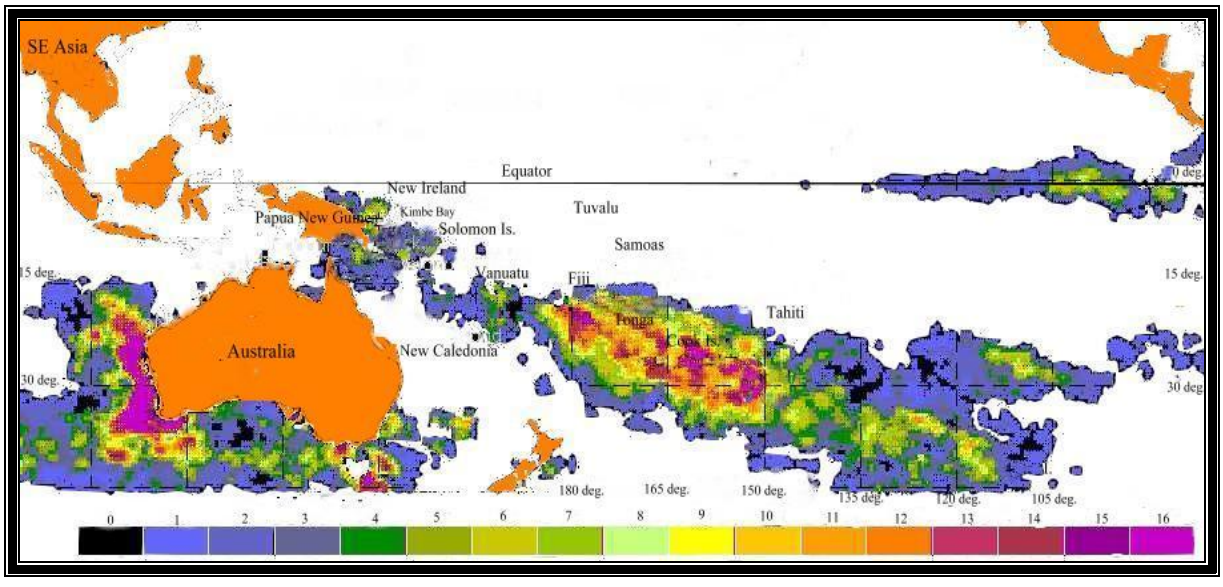
Table 28. Accumulation of Degree Heat Weeks (DHW) in Samoa during the bleaching event of 2002.

Date	Degree heat weeks (DHW)*
December 29, 2001	1-2
2002	
January 1	4
January 15	5
January 29	5-6
February 5	8
March 18	5-6
April 1	2-3
April 13	1-2

*http://www.osdpd.noaa.gov/PSB/EPS/SST/dhw_retro.html

In the Fijian situation in the 2000 bleaching event, the situation was much more severe. Figure 44 shows the state of the event in April as a summary of the elevated water temperatures. The color scale refers to the Degree Heating Weeks (DHW) which is the amount of time the temperature had remained 1^0C higher than the monthly mean (MM) are often expressed as a value within a 3 month period. 6-10 DHW's are sufficient to have wide-scale bleaching. The areas in Kimbe Bay and the southwest side of the Solomon Is. showed 3-6 DHW's as did Vanuatu. Those areas south of Viti Levu in Fiji, Tonga and the Cook Is. showed 13-15 DHW in some areas but generally less than 10. For the Fiji Islands, elevated water temperatures occurred for 19.5 weeks. Easter I., where 90% of the corals had bleached, showed 4-6 DHW. South Pacific countries such as Kiribati, Tuvalu and the Samoas experienced no coral bleaching.

Figure 44. Degree Heat Weeks accumulated in April, 2000.



7.4.3 How is the Coral Reef Affected?

Though generally correlated with high water temperatures, coral bleaching occurs differentially in the reef environment with corals in shallow reef areas being more affected in terms of the amount of bleaching and mortality. High current areas such as reef passes are less affected. More turbid inshore waters experience less bleaching. In this case, the key to this observation is the differential penetration of light and its effect on the algal photosynthetic processes within the host animal. In the presence of high temperatures and light, toxic photosynthetic products such as the build-up of oxygen radicals, poison the animal. Many corals survive the harmful effect of light, being moderated and protected by pigments within the animal. Some species of corals were tolerant to the high temperature with no bleaching occurring.

In the Fiji situation, observed trends included the survival of small colonies. Corals such as *Acropora crateriformis, Echinopora lamellosa, Turbinaria reniformis,* and *Pocillopora eydouxi* appeared to be resistant to bleaching. Those most liable to bleaching were *Platygyra sinensis, Pocillopora damicornis, P verrucosa, Acropora muricata, A. intermedia, A. hyacinthus, A. clathrata, A. cytherea, Diploastrea heliopora,* and *Porites spp.* The percentage of bleaching was less at greater depth and in inshore habitats, though these communities varied considerably in species dominance from the shallow water species assemblage (Lovell, 2001c). These observations are consistent with those of To'atuga Reef where the most obvious dead standing coral were tabulate forms of Acropora with other morphologies such as corymbose colonies being common. The current assemblage is dominated by *Pocillopora eydouxi* which was a good survivor during the Fiji 2000 event. Within the zone of large Porites colonies seen on the southwest side of To'atuga Reef, a large number of the colonies had suffered partial or complete death.

7.4.4 The Future of Coral Reefs?

Some say that, as global warming progresses, we may be witnessing the end of the coral reefs as we know them. From the observed bleaching, it is assumed that the photosynthetic processes within the corals are operating at the upper level of their temperature tolerance. Increases in temperature resulting from global warming may be progressively lethal to currently resistant corals. One scenario may include the dominant genus Acropora, the most affected, being replaced by the more resistant Porites genus. Another hypothesis is that there is a revitalizing of corals through survival or renewal of heat resistant zooxanthellae. With the inshore and reef flat species adapted to an environment of fluctuating water temperatures, future recruitment may rely on these habitats.

For many areas, coral bleaching may be a process such as a cyclone or outbreaks of the coral-eating crown-of-thorns starfish, which through disturbance, result in reef renewal by providing surfaces for new settlement and the removal of monopolising species. The areas diversity may increase through recruitment from peripheral environments. For some areas of the world, however, the mortality has been so complete and sources of recruitment so distant that a substantial amount of time will be required for the re-establishment of the "pre-bleaching" diversity of coral fauna.

7.5 Coral disease

Diseases of Scleractinian corals have increased over the last decade, and they may play a significant role in the widespread mortality of important reef-building species reported in the last few years (Antonius 1981, 1985, 1988; Williams and Bunkley-Williams 1990; Edmunds 1991; Bythell and Sheppard 1993; Bruckner and Bruckner 1997). Recent studies suggest that coral diseases are affecting a greater number of species, are increasing in frequency and distribution, and are spreading to new regions faster than ever recorded in the past. Although they are receiving greater

attention from the scientific community, most diseases have not been fully characterized, and their etiologies, including the causative agents, remain largely unknown. Identification of the causative agents, quantification of the distribution, abundance and impact of coral diseases, and the possible associations of coral disease with anthropogenic stressors are high priority research areas needed for effective coral reef management (Ginsburg R. N. 2000).

7.5.1 White-Band Disease (WBD)

From McCarty and Peters (2000):

About the same time that black-band disease (BBD) was discovered, Bill Gladfelter and colleagues noticed that tissue was slowly peeling off colonies of elkhorn and staghorn corals at Tague Bay, St. Croix, U.S. Virgin Islands. The loss of tissue resulted in a distinct band or line of bare white skeleton and, as a result, this disease was named white-band disease (WBD). Unlike the case of BBD, despite intensive study, no consistent assemblage of micro-organisms could be found at the junction of the sloughing tissue and the bare coral skeleton.

Tissue peels or sloughs off the skeleton at a fairly uniform rate around the branch of the coral and progresses from the base of the branch towards the tip. On the staghorn coral (*Acropora cervicornis*), tissue loss may also occur in the middle of a branch. No consistent population of micro-organisms has been found at the margin of the tissue loss.

All that can be seen with the naked eye is the tissue peeling off the bare white skeleton with occasional small bits of tissue remaining on the exposed skeleton. The rate of tissue loss is several millimetres (1/8 to 1/4 inch) per day. The bare skeleton is eventually colonized by filamentous algae, but the band of bare white skeleton that remains visible can be 5 to 10cm (2-3 inches) wide. The tissue remaining on the branch shows no signs of pronounced bleaching, although affected colonies might appear slightly lighter in color overall. However, a variant of WBD, termed WBD Type II, has been found on staghorn colonies in the Bahamas. Here, a margin of bleached tissue appears before the tissue is lost (Ritchie and Smith, 1995).

This loss of tissue from the base of the branch and progressing upward should not be confused with the natural lack of pigment in the growing tips of the *Acropora* species. The rapid growth of the skeleton in these corals exceeds the rate at which the zooxanthellae can reproduce, leaving the tips white in color.

The etiology of WBD remains unknown. Unusual aggregates of Gram-negative rod-shaped bacteria were found in the tissues of affected corals (WBD Type I). However, the role of this micro-organism in the development of disease has not yet been determined. Further complicating the situation, some acroporids containing these bacteria appear healthy, and other colonies with sloughing tissues have no bacterial aggregates. In WBD Type II, bacteria of the genus *Vibrio* have been found in the surface mucus of the bleached margin.

Tissue loss from acroporids can also be due to the grazing activities of predators, but their pattern of tissue removal differs (i.e., gastropods create scalloped incursions from the base of a branch or irregularly-shaped patches; polychaete worms such as *Hermodice* remove tissue from the branch tips of staghorn coral).

WBD Type I have been found on acroporid species around the Caribbean, the Philippines, the Great Barrier Reef, and the Red Sea. WBD Type II has only been found in the Bahamas to date. The effects at Tague Bay were devastating. Within five years, approximately 50% of the shallow reef crest elkhorn corals and many of the deeper staghorn corals were losing tissue (Gladfelter, 1982). In another five years, up to 95% of the elkhorn corals had died. Many colonies of acroporids have

succumbed to this disease in the Caribbean and the disease is still evident on many reefs (Bythell and Sheppard, 1993; Peters, 1993).

It is clear from the above text that there may be a major disease problem on To'atuga Reef. Progressive death of tabulate Acropora colonies is occurring. This observation is complemented by a similar situation in Palolo Deep. The outbreak is presumed to be related to the coral bleaching event of 2002. It was at this time that bleaching was widespread with some corals dying immediately from the event. Those corals, which bleached but survived, were weakened by the trauma and it is presumed that in such a condition, the corals would be most susceptible to disease.

Though unconfirmed, it is likely that much of the dead standing coral has resulted from death by disease rather than directly from the coral bleaching. This notion is substantiated by the wide-spread observations of the presence of the WBD and its progressive nature as it consumes the living coral leaving a dark algal-covered surface. This surface is distinct from the coralline algal covered surface typical of many of the colonies. These colonies most probably represent the coral which died from the 2002 bleaching, with the dark-green colonies reflecting the relatively recent and progressive death from the disease.

Figure 45. White band disease affecting *Acropora clathrata* and showing the progressive nature of the coral disease.

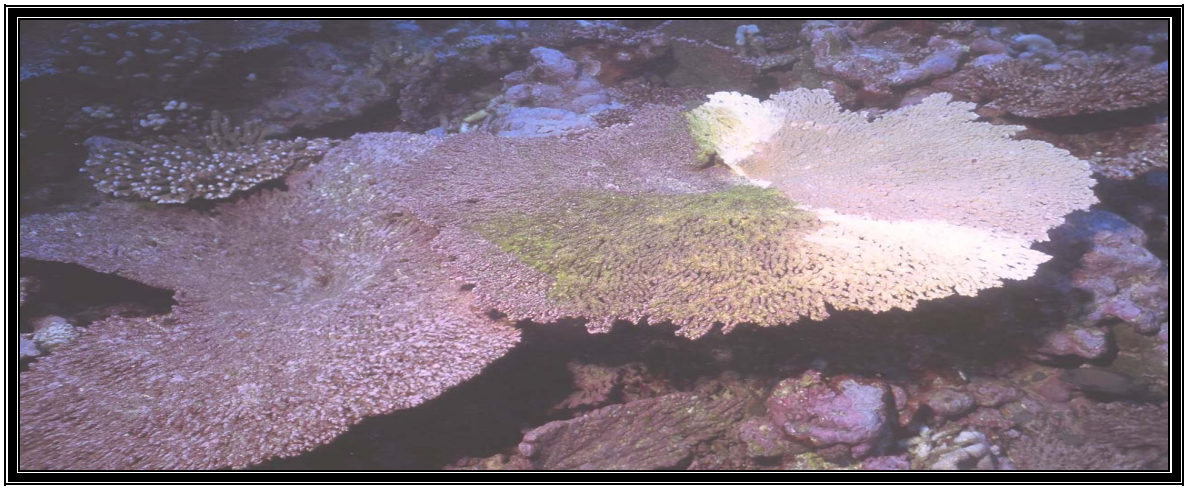


Figure 46. Recent and long standing dead coral.

7.5.2 Coralline Lethal Orange Disease (CLOD) McCarty and Peters (2000)

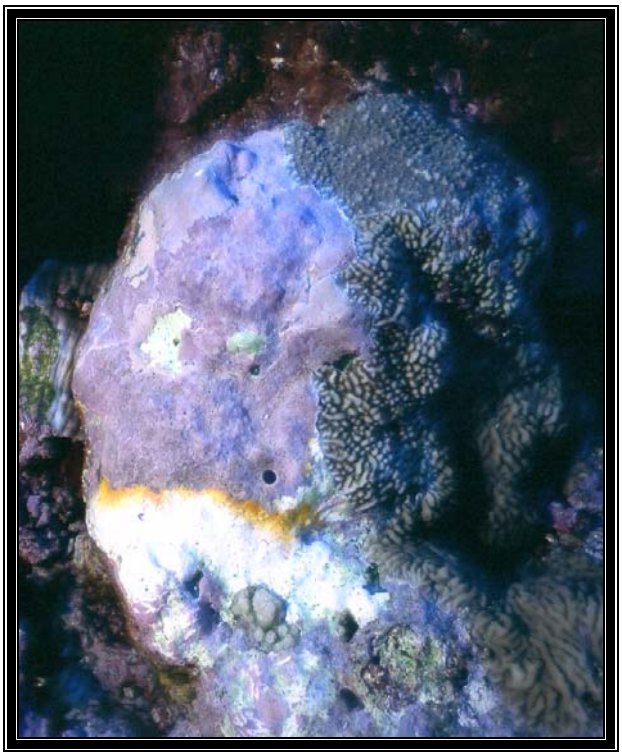
Given the importance of coralline algae in contributing material to the reef framework, it was particularly disturbing when a disease affecting the algae was discovered by Mark and Diane Littler in 1993 on reefs of the Cook Islands, Fiji, and the Solomon Islands. It was named coralline lethal orange disease (CLOD) because of its characteristic orange color.

A "band" of bright orange slimy material spreads across the algal surface, leaving behind the bare skeletal carbonate remains of the coralline algae. When this material reaches the margin of the algal thallus, it forms upright filaments and globules, similar to those formed by terrestrial slime moulds. The globules can be caught by waves and easily spread to nearby corallines.

Microscopic examination of the orange material revealed motile gliding rods of a colonial bacterium in a mucilaginous matrix. The orange globules can be experimentally transferred to other coralline algae and cause the same disease and loss of algal tissue. Additional studies of this bacterium associated with CLOD are underway.

The distribution of this disease is in the Western Indo-Pacific. Its recent appearance could potentially affect the structure and function of many reef sites since dead corallines, like dead corals, no longer contribute to productivity and carbonate accretion processes. Filamentous and fleshy algae overgrow the bare skeletons, inhibiting the settlement and growth of reef-building corals. These concerns are not relevant to To'atuga Reef due to the rareness of this conspicuous disease. The occurrences of fleshy algaes are minimal due to the depth and the prevalence of algal-grazing fishes.

Figure 47. A case of coralline lethal orange disease at To'atuga Reef.



8.0 Human Impacts

8.1 Diving and fishing

The principal influences from human activity are from diving and fishing. In both cases, anchoring is required which has the potential for limited damage to the tree top. Fishing has the added influence of removing food fish.

8.2 Anchor damage

Anchoring is a necessary feature of visiting To'atuga Reef by boat. The potential for accidents caused from drifting while attending SCUBA divers require the vessel to be anchored. Submerged moorings (>8m) may be a solution for dive operations. Fishing vessels will always anchor.

There is no doubt that coral and other benthos are damaged during anchoring. The consolidated nature of the reef does not allow setting the anchor through burial as with soft bottom sediment, but rather, anchoring results from fouling the reef surface. Setting the anchor initially drags along the bottom damaging substrate until it becomes lodged firmly by hooking on a ridge or crevice. Once set, the anchor chain drags over the surface as the boat moves back and forth with the wave and wind.

Despite this potential for damage, this influence is similar to the chronic damage caused by the strong surge environment. Fragments on the reef top and those in the talus spillways illustrate that this is an environment in which damaged coral and reef fragmentation are part of the natural environment. The reef surface is armoured by the cementation of the coralline algae.

Figure 48. An example of anchoring on the To'atuga Reef top. This surface is heavily cemented by coralline algae and resistant to breakage.

9.0 Management Recommendations

1) Assess the management issues after consultation with all stakeholders.

2) Integrate To'atuga Reef into the Samoan Global Coral Reef Monitoring Network due to the uniqueness of the reef.

3) Develop a monitoring program utilising the established site transect information to assess the general health of the coral reef.

4) Assess the nature and extent of the coral disease.

10.0 Monitoring

A monitoring program is essential to provide a more complete understanding of the dynamics of To'atuga Reef. Baseline information is fundamental to the assessment and dynamic of the reef system. The monitoring strategy is based on repeat inspections of transect and photo-quadrat assessment.

A long-term monitoring program will provide a fuller understanding of the natural background variation and enable to determine the extent of human-induced impacts. Given the dynamic change in the coral reef environment, monitoring will allow understanding, its cause and result. The assessment should describe the variation, its magnitude, its time-scale and processes causing the change.

10.1 Objectives

The monitoring program requires objectives which will answer the questions which lead to reef description and an understanding of its dynamics and variation. For To'atuga Reef, the objective must involve the augmentation of the base-line study and an a program for appreciation of changes such as damage and disease which are occurring on the reef.

The objectives may be limited by the funding and logistical constraints. This will affect the magnitude of the monitoring in intensity and extent. The logistical costs and difficulties of diving in a remote and relatively deep water location need to be considered. Discussion with stakeholders is required as to the value of the area and what levels of protection or conservation are appropriate.

10.2 Scale: spatial and temporal

The scales which are appropriate are the short-term recovery periods from cyclonic disturbance, the medium-term cyclonic recovery and disease prevalence. Longer-term issues involve general reef development and the influences of the short and medium term influences.

As To'atuga Reef is relatively small, a few sample sites (3-6) could be considered as representative of the reef. Sampling may be in a random manner, confined to particular reef areas (east slope, north reef top, etc.) or fixed locations such as determined by underwater moorings.

Information from To'atuga Reef should be incooperated into the larger Samoan program of coral reef monitoring such as the Global Coral Reef Monitoring Programme.

The frequency of sampling will rely on satisfying the objectives and the budget available. A contingency provision or fund should be available for the assessment of the reef if a cyclonic or bleaching event were to occur.

10.3 Design and Data

In the case of To'atuga Reef, the design should include all the areas of interest by establishing transects which are complemented by permanent photo-quadrats. Additional observations through swims and general photography will add to the information base.

- Determine what data is to be collected and how will it be analysed. Decide on how the data will be entered and stored? Develop collection sheets to facilitate data collection, entry and storage.

- Who will undertake the monitoring? If several people are involved, comparison of results will be required to assure uniformity. Examination of the data will be required to ensure quality and determine any anomalies.

- How will the information be communicated? Will periodic reporting be required?

10.4 Pilot study

Begin with a pilot study to assess the programs feasibility and applicability. The study can then be increased in extent as required. Creating the optimal design between the objectives and the logistical capabilities is essential. For To'atuga Reef, the distance offshore, the unprotected nature of the location and the reef depth all need to be considered. The state of the weather is important as are the diving capabilities of the people doing the monitoring. The overall survey plan should be subjected to periodic review.

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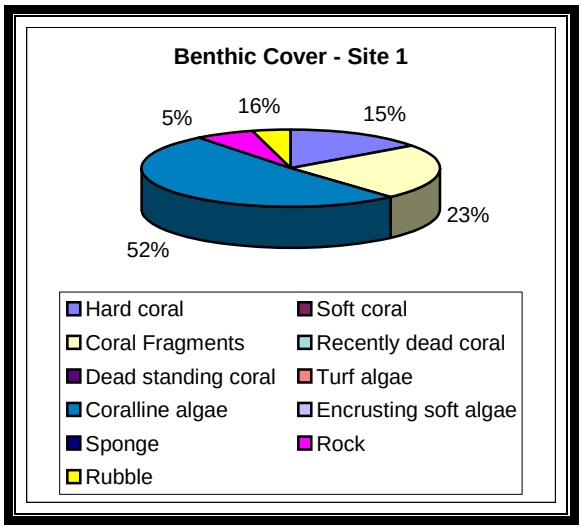
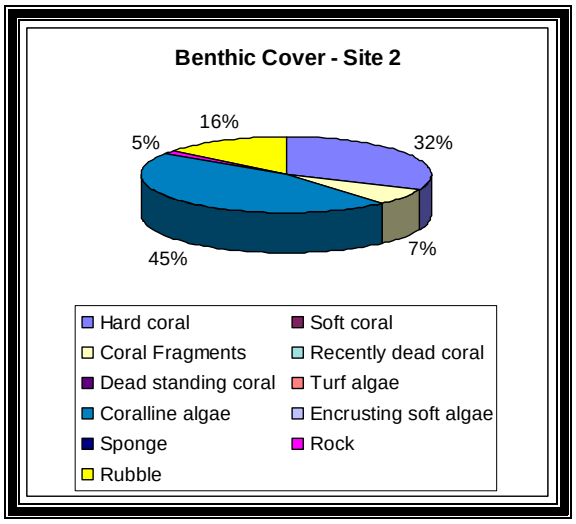
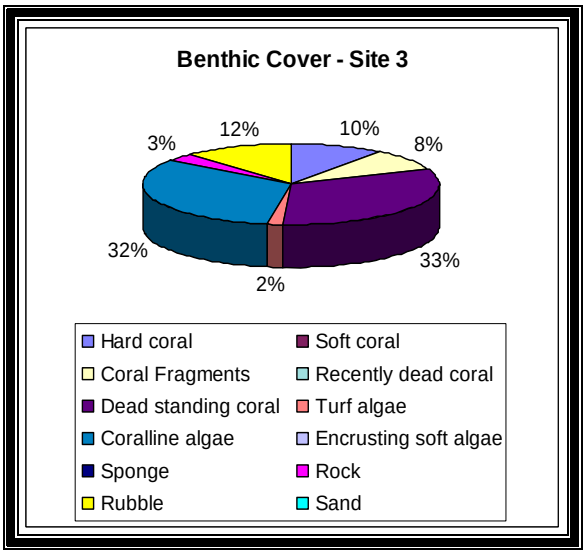
12.0 Appendix

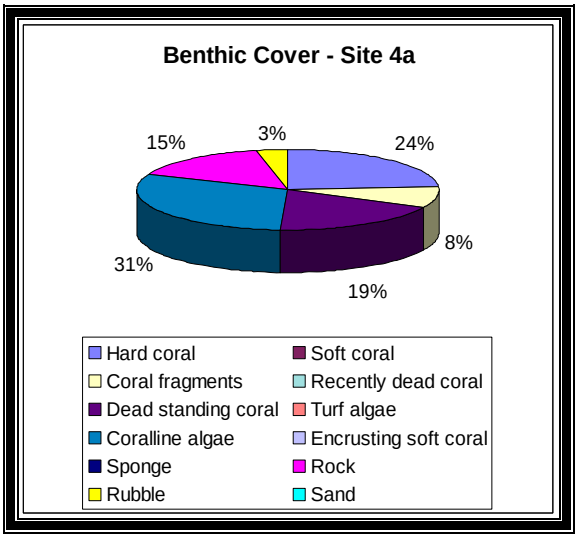
12.1 Comparative summary of benthic information.

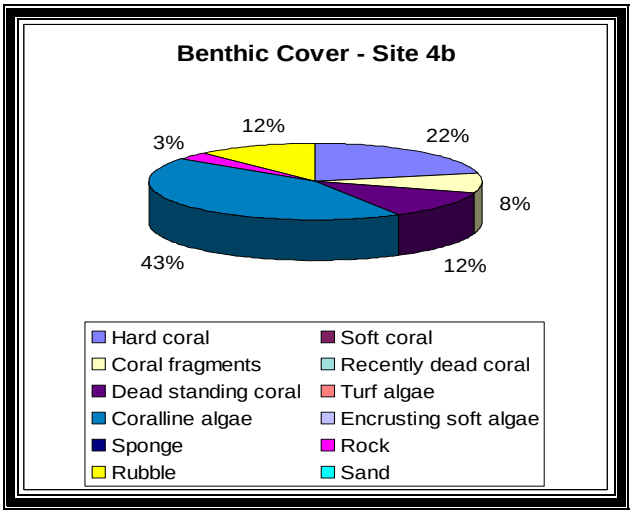
Figure 49. Summary pie diagrams for all sites surveyed.

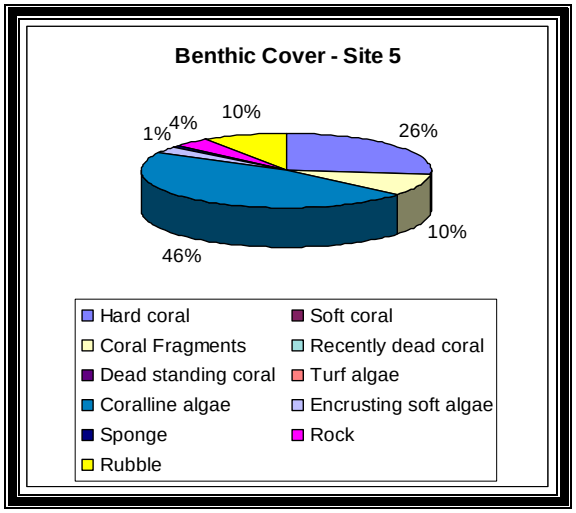


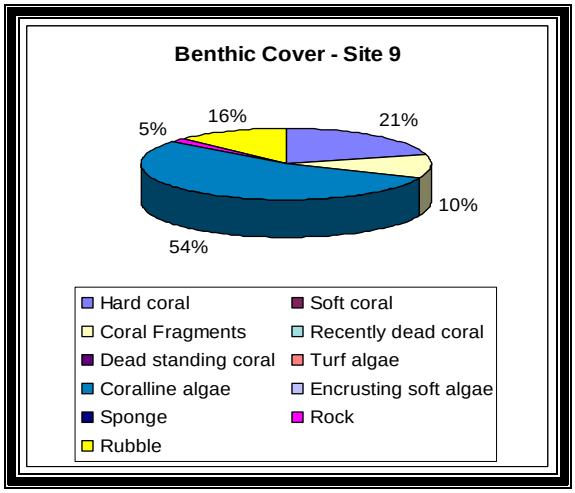


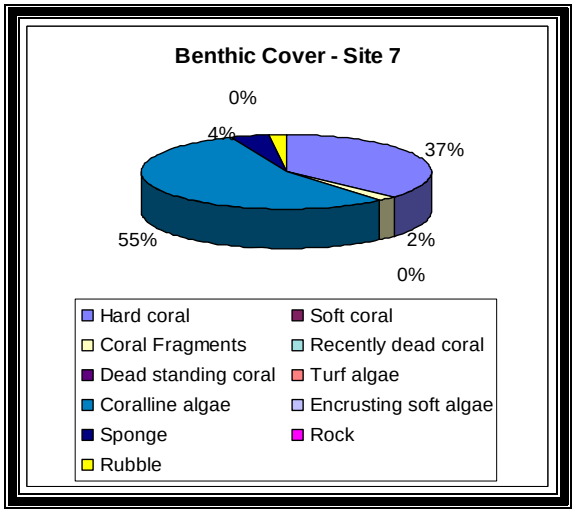


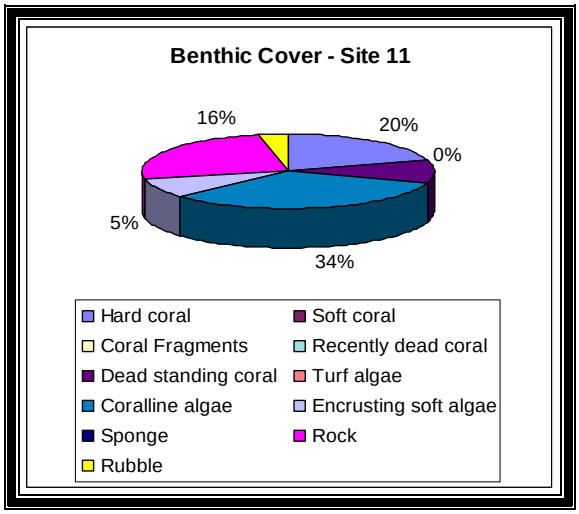


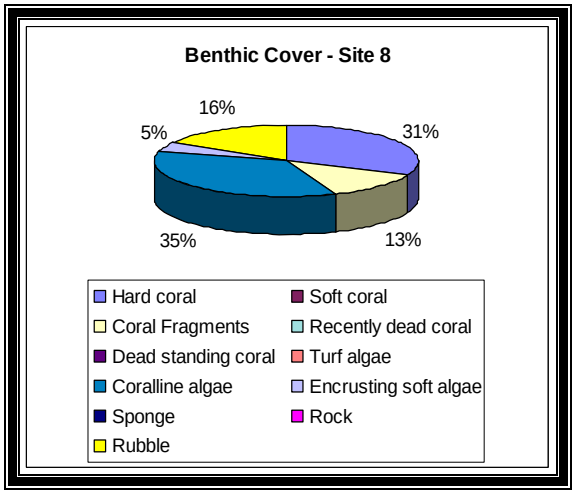


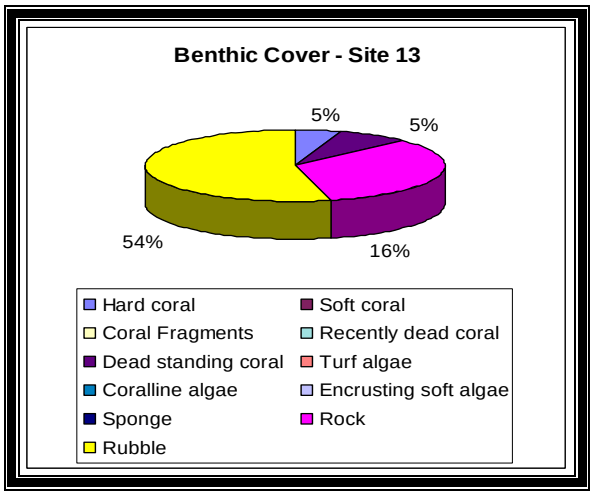

Benthic Cover - Site 5
1%
4%
10%
26%
10%
46%
Hard coral
Soft coral
Coral Fragments
Recently dead coral
Dead standing coral
Turf algae
Coralline algae
Encrusting soft algae
Sponge
Rock
Rubble


Benthic Cover - Site 9
5%
16%
21%
10%
54%
Hard coral
Soft coral
Coral Fragments
Recently dead coral
Dead standing coral
Turf algae
Coralline algae
Encrusting soft algae
Sponge
Rock
Rubble


Benthic Cover - Site 7
0%
4%
37%
55%
2%
0%
Hard coral
Soft coral
Coral Fragments
Recently dead coral
Dead standing coral
Turf algae
Coralline algae
Encrusting soft algae
Sponge
Rock
Rubble


Benthic Cover - Site 11
16%
20%
0%
5%
34%
Hard coral
Soft coral
Coral Fragments
Recently dead coral
Dead standing coral
Turf algae
Coralline algae
Encrusting soft algae
Sponge
Rock
Rubble


Benthic Cover - Site 8
16%
5%
31%
35%
13%
Hard coral
Soft coral
Coral Fragments
Recently dead coral
Dead standing coral
Turf algae
Coralline algae
Encrusting soft algae
Sponge
Rock
Rubble


Benthic Cover - Site 13
5%
5%
54%
16%
Hard coral
Soft coral
Coral Fragments
Recently dead coral
Dead standing coral
Turf algae
Coralline algae
Encrusting soft algae
Sponge
Rock
Rubble