Marine Environment Monitoring Program for Fagaloa and Uafato Bays, Samoa: Final Report

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Acronymns

GBRMPA	Great Barrier Reef Marine Park Authority
MAFF	Ministry of Fisheries, Agriculture and Forestry
MNRE	Ministry of Natural Resources and Environment
SMEC	Snowy Mountain Engineering Corporation
SPREP	Secretariat of the Pacific Regional Environment Program
SROS	Scientific Research Organisation of Samoa

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Executive Summary

The Asian Development Bank through its contractor, the Snowy Mountain Engineering Corporation were tasked with exploring the potential of augmenting the capacity of the Afulilo Reservoir to power a third turbine at the Ta'elafaga Hydro-power Station. To assist in this augmentation assessment, SMEC arranged with the Secretariat of the Pacific Regional Environment Program to oversight a consortium of partners to conduct a 11 month monitoring program with the purpose of assessing the status of the marine environment, particularly the coral reefs, as well as water quality in the Fagaloa and Uafato Bays.

The data from the 2009-1010 marine monitoring program implies that several sites in Fagaloa Bay are exhibiting signs of various impacts from various inputs into the marine environment, which are most notable at sites 1, 2, and 14. These sites are closest to the apex of Fagaloa Bay where the Ta'elefaga Creek discharges into. Impacts for these sites include low or no coral cover and recruitment, growth in algal cover, lower salinity levels, higher rates of sedimentation and turbidity, as well as high nutrient inputs. Fish biomass at site 14 was also the lowest (sites 1 and 2 were not surveyed due to poor visibility).

Other specific results across all sites include a reduction in live coral cover, a general shift to more hardier coral species, and low fish bio-mass when compared with other sites in Samoa.

Recommendations

The possibility of using a submarine outfall and diffuser system for disposing the freshwater passing through the Ta'elefaga Hydro-power Station to the marine environment should be investigated. The most important factor in considering the environmental impacts of this type of disposal system is the very location of the outfall, this is important for stratification, but also understanding currents, coastal circulation and hydro-dynamics. Unfortunately, SPREP does not have the technical expertise to assess this, it is recommended that an appropriate technical engineer be hired to investigate this further.

Further education and outreach would also be pertinent. This would need to cover a range of activities, including:

- the results of the studies conducted by SMEC and SPREP;
- better land use practices, including alternative agricultural practices involving contour plantings, terracing and other erosion control measures;
- improving sewage disposal, as well as pig waste management;
- fisheries and marine resource management (and possible rehabilitation); and
- watershed management.

Some form of management committee could also be devised, that would focus on a holistic 'whole of Fagaloa Bay' approach to management, because at present, it would appear that more could be done to address environmental issues by local villagers.

Further work will also be required to fully understand the dynamics of the marine environment in Fagaloa Bay, and the possible links with environmental issues posed by the Ta'elefaga Hydro-power Scheme, particularly as the current marine monitoring program only provides an environmental 'snapshot' in time for Fagaloa and Uafato Bays, though one that can be used as a baseline for future studies.

Subsequently, a continuation of the marine monitoring program is also recommended.

1. Introduction

Following previous Environmental Impact Assessments of the Afulilo-Ta'elafaga Hydro-power Scheme prior, during and after its construction (see Cheng *et al*, 2001; Onorio and Tamata, 1997; Waugh *et al*, 1991; Winders *et al*, 1987), the Asian Development Bank through its contractor, the Snowy Mountain Engineering Corporation (SMEC) were tasked with exploring the potential of augmenting the capacity of the Afulilo Reservoir to power a third turbine at the Ta'elafaga Hydro-power Station.

The water that currently passes through the Ta'elafaga Hydro-power Station is drawn from the Afulilo Reservoir and after passing through the Ta'elafaga Hydro-power Station's two turbines, is discharged through tailraces directly into the Ta'elafaga Creek which then flows into Fagaloa Bay at its apex.

The current discharge of the Ta'elafaga Hydro-power Station into the Ta'elafaga Creek is thought to be around 1.7 m^3/sec, similar to a continual small 'freshet' for this size stream (Waugh *et al*, 1991).

To assist in this augmentation assessment, and particularly the continued and potential impacts of discharging larger volumes of freshwater into the Fagaloa Bay; SMEC arranged with the Secretariat of the Pacific Regional Environment Program (SPREP) to oversight a consortium of partners consisting of Samoa's Ministry of Fisheries, Agriculture and Forestry (MAFF); and the Scientific Research Organisation of Samoa (SROS); to conduct a 12 month monitoring program (see Appendix A for contractual letter from SMEC to SPREP) with the purpose of assessing the status of the marine environment, particularly the coral reefs, as well as water quality in the Fagaloa and Uafato Bays. Further assistance in the monitoring program was provided by the Ministry of Natural Resources and Environment (MNRE).

2. Background

2.1 Demography

Fagaloa and Uafato Bays are located in the Vaa O Fonoti District, which covers an area of 34.6 km² on the north-east coast of Upolo Island, Samoa (Figure 1). In 2006, the population of this district stood at 1,624 people (Bureau of Statistics, 2008).

The 2006 population figures for Fagaloa Bay detail a population of 767 people, residing in 102 households (Table 1) (Bureau of Statistics, 2008). Figures from the yet to be released 2009 Agricultural Census lists the current number of households at 111 (SMEC, 2009), which if household size remains, would give a current population in Fagaloa Bay of around 810 people. Lona and Ta'elafaga villages have the highest populations in Fagaloa Bay (Table 1).

Table 1: Population details for villages in Fagaloa Bay

Location	Population	No. of households	Average household size
Musumusu	81	11	7.4
Salimu	63	10	6.3
Ta'elefaga	184	25	7.4
Maasina	131	15	8.7
Lona	241	29	8.3
Samamea	67	12	5.6
Total	**767**	**102**	**7.3**

Source: Bureau of Statistics, 2008.

There is only one village in Uafato Bay, which is also called Uafato. Unfortunately, no details on current population levels are available.

A coastal road services the villages of both Fagaloa and Uafato Bays, which connects to a main road that winds itself up the mountains behind Ta'elefaga Village.

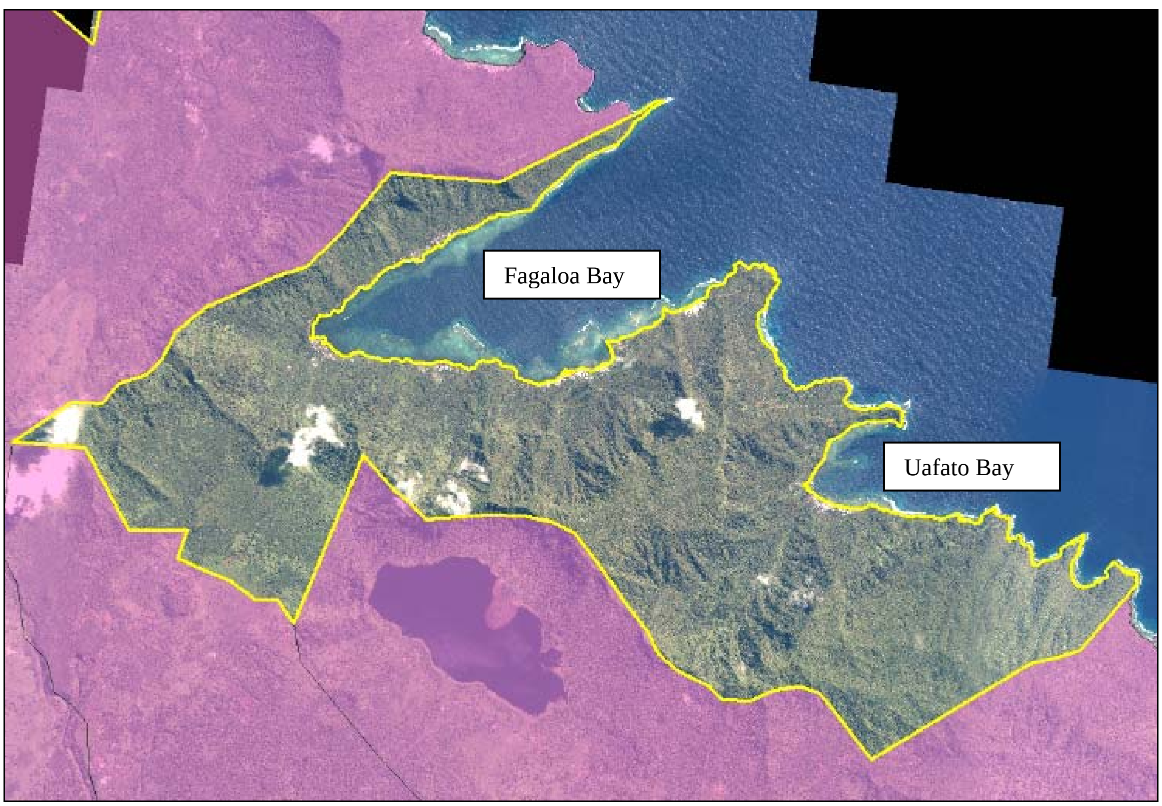


Figure 1: Vaa O Fonoti District encompassing Fagaloa and Uafato Bays

2.2 Geography

The surrounding mountain ranges that encircle Fagaloa and Uafato Bays descend abruptly to narrow flat low-lying coastal plains, which due to the steep slope, is also the main area of human habitation. Both Fagaloa and Uafato Bays are semi-enclosed, funnel-shaped bays, with the eastern sides having wider fringing coral reef structures, which end in prominent points at their mouths.

Total coral reef area has been estimated by Zann (1991) to be around 210 ha for Fagaloa Bay, and about 130 ha for Uafato Bay (Table 2). Both Fagaloa and Uafato Bays are characterised by irregular coral reef margins, which are broken by the entrances of numerous creeks and streams (Figures 2 and 3).

The coral reefs found bordering the inner coast line of both the Fagaloa and Uafato Bays are also influenced by prevailing conditions of wind, tides and oceanic swell.

Table 2: Marine characteristics for Fagaloa and Uafato Bays

Location	Bay area (km^2)	Shore length (km)	Reef area (ha)	Reef edge area (km)
Fagaloa Bay	~ 8.2	~ 10.5	~ 210	~ 11
Uafato Bay	~ 1.8	~ 6	~ 130	-

Source: Zann, 1991.

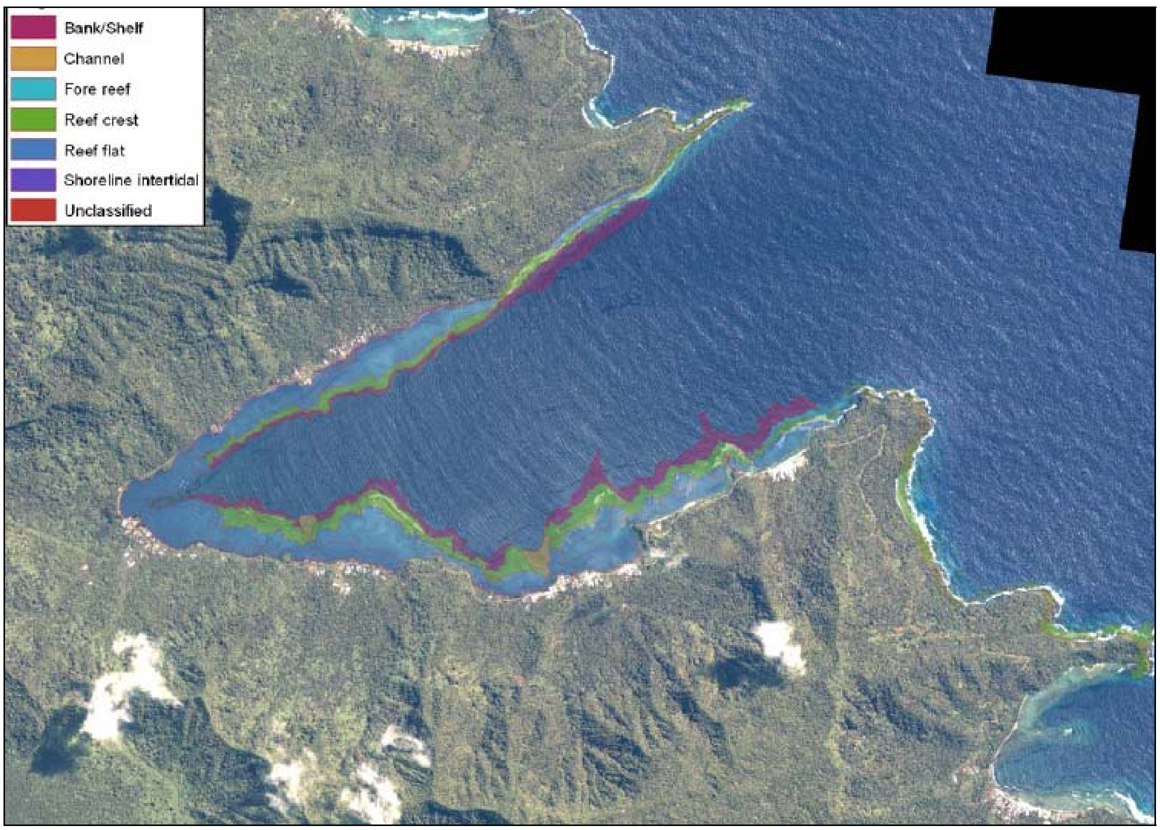


Figure 2: Reef structure in Fagaloa Bay
Source: SPREP.

Figure 3: Reef structure in Fagaloa Bay
Source: © Stuart Chape.

Both Fagaloa and Uafato Bays lie within the geological field that has been named Fagaloa Volcanics, which were developed during the late-Pliocene to mid-Pleistocene era (Zann, 1991; Suluvale, 1997). The steep weathered slopes of both Fagaloa and Uafato Bays consist of inter-calated *a'a* and *pahoehoe* flow rocks, rubbly scona, ash beds, vitric tuffs, and contemporaneous basaltic dykes (Richmond, 1991). Soils are thick, plastic sticky clays, with strongly eroded olivine basalt and basaltic endesites (Kear and Wood, 1959, 1962; Kear *et al*, 1979; Wright, 1962), which due to their consistency impede rainwater absorption and increases freshwater run-off. The shores are rocky boulders in exposed areas and coral sand beaches in protected areas.

Suluvale (1997) notes that perennial streams exist only in the north-east and central parts of Upolu, which are restricted to the older Fagaloa and Salani Volcanics which as noted above covers the areas of both Fagaloa and Uafato Bays. During his assessments, Suluvale (1997) identified 38 perennial streams in the Fagaloa and Uafato Bay areas. In contrast, Zann (1991) stated that Ta'elefaga Creek was the only perennial stream in Fagaloa Bay. SMEC (2009) states that only Ta'elefaga Creek and the Pago Creek at Lona are the only perennial streams in Fagaloa Bay; though their consultant did note that all villages reported excessive surface water run-off during prolonged rainy periods which form rapidly flowing streams of brown muddy water from the exposed farming lands behind the villages.

What ever the case is, many streams, creeks and obvious drainage channels are seen on the steep slopes on both sides of the Fagaloa and Uafato Bays, (Figures 4 and 5), with the east sides of both Fagaloa and Uafato Bays, having watersheds that are more extensive and in greater number then the west sides.

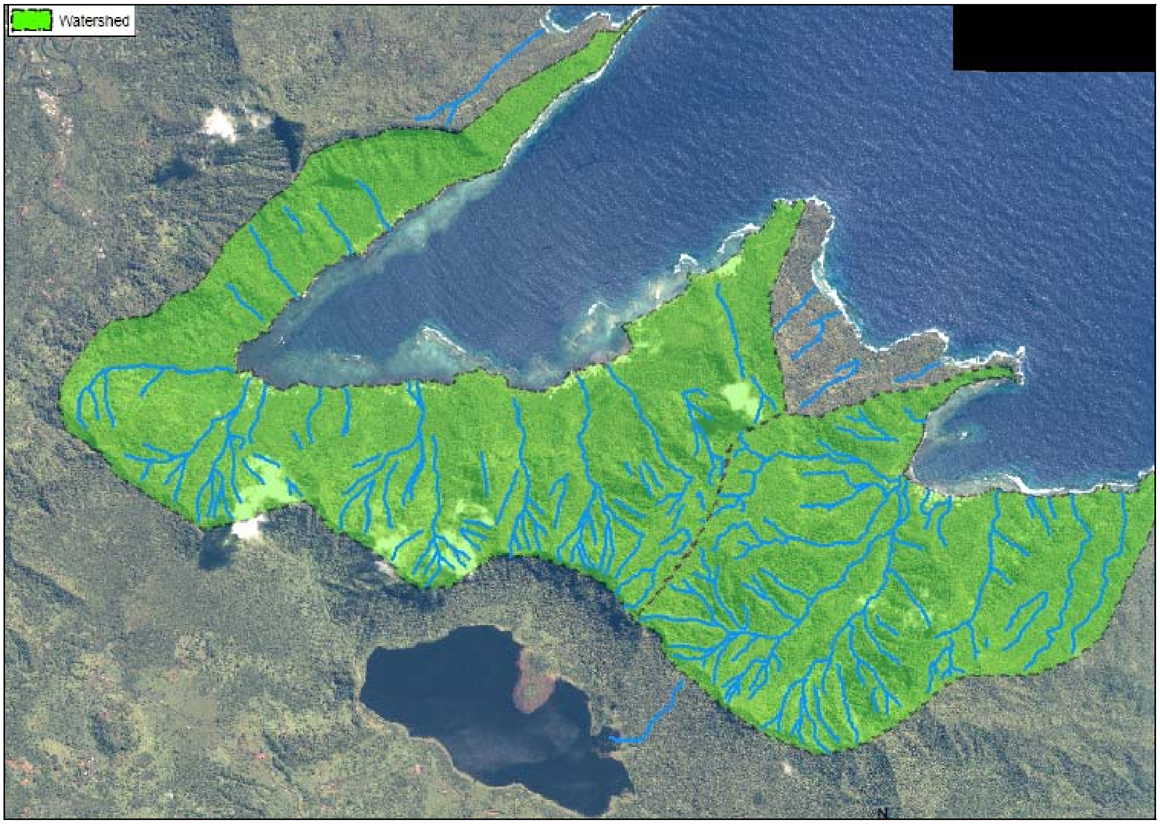


Figure 4: Watersheds and streams in the Fagaloa and Uafato Bays
Source: SPREP.

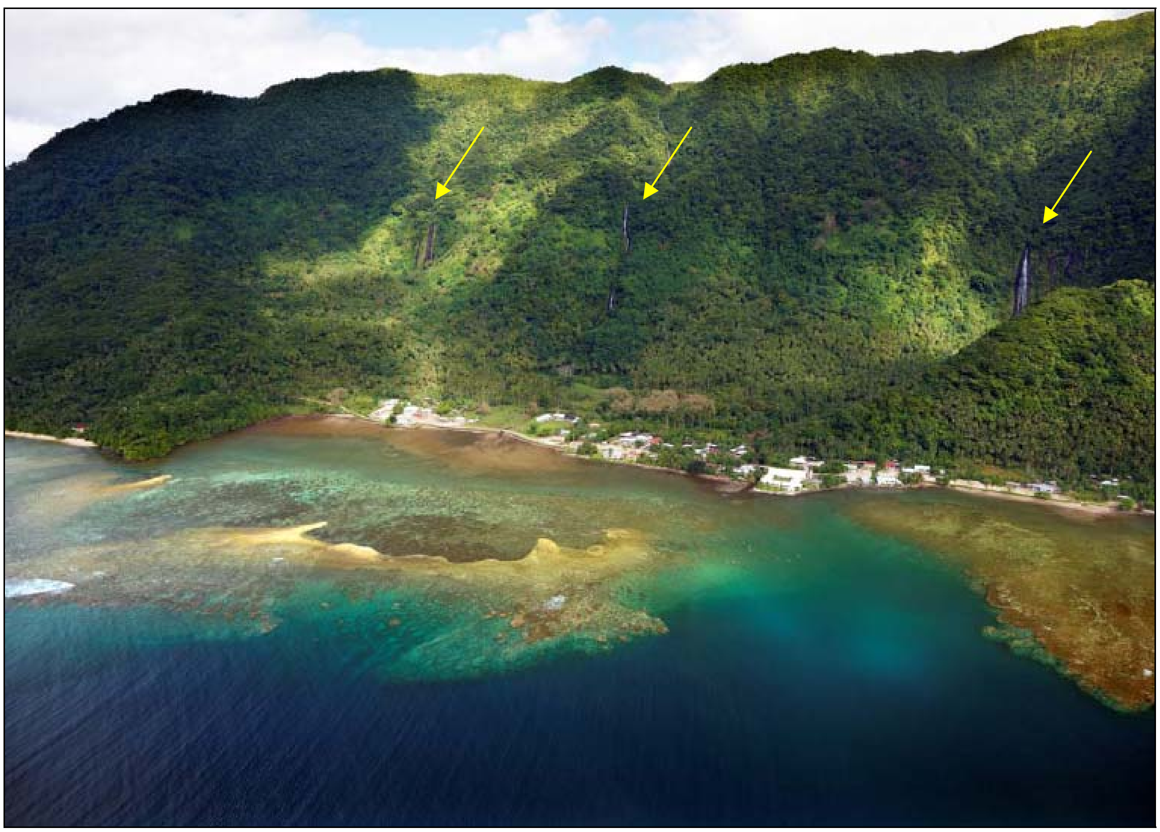


Figure 5: Watersheds and streams in the eastern side of Fagaloa Bay
Source: © Stuart Chape.

2.3 Rainfall

The climate in Fagaloa and Uafato Bays is tropical due to Samoa's equatorial location, which is typified by high humidity and heavy precipitation, occasionally accentuated by severe cyclonic storms during the wet season from November to April each year.

The average annual rainfall for Samoa is about 3,000mm with about 75 % of precipitation occurring during the wet season (Suluvale, 1997). In general though, annual rainfall is variable according to location and altitude, and wide variance can occur even over short distances. For example, rainfall recorded at Afulilo (which is 3.4 km from Ta'elafaga, and sits above Ta'elefaga) and Saletele (which is 4.1 km west of Ta'elafaga along the coast) over the marine monitoring program period, showed wide variance for some months, and a total difference of 755 mm over the course of the marine monitoring program (Table 3).

Table 3: Rainfall records (mm) for Afulilo and Saletele: July 2009-May 2010

Month	**Afulilo**	**Saletele**
Jul 09	354	251
Aug 09	251	354
Sep 09	305	172
Oct 09	365	229
Nov 09	465	381
Dec 09	522	359
Jan 10	559	260
Feb 10	530	384
Mar 10	126	384
Apr 10	175	181
May 10	243	185
Total	**3,895**	**3,140**

Source: Afulilo (SMEC), Saletele (MNRE-Meteorology)

The quantity of freshwater run-off is dependent on several parameters, such as soil type, vegetation, orientation, geology, elevation and slope. Drainage patterns in the Fagaloa and Uafato Bays closely follow their geological formations, with the steep, variable topography affecting localized rainfall amounts, and thus causing highly variable flows. Of all the rain that falls in Samoa, Stednick (1990) estimated that nearly half (48 %) enters into stream systems and thus discharged into the marine environment.

2.4 Livelihoods

Unfortunately, at the time of producing this report, the results of the more recent 2009 Agricultural Census was not available, despite several attempts to obtain specific information for the Vaa O Fonoti District. Subsequently, information from the 1999 Agricultural Census is presented here to provide some background information and context of land use and fishing activities in the Vaa O Fonoti District.

2.4.1 Agriculture

In the 1999 Agricultural Census, approximately 655 ha were under cultivation in the Vaa O Fonoti District, with 207 households involved in some form of agricultural production (Table 4).

Table 4: Percentage of households involved in agriculture in the Vaa O Fonoti District: 1999

No. of households	**Percentage (n = 211)**
Non-agriculture	0.4
Home consumption only	33.2
Mainly for home consumption	60.2
Commercial	6.2
Total	**100**

Source: Department of Statistics and Ministry of Agriculture, 1999.

Approximately 44 % of all agricultural parcels are between 4-8 ha (Table 5), with approximately 42 % being under some form of tree or other crop production (Table 6).

Table 5: Percentage of agricultural parcels by size in the Vaa O Fonoti District: 1999

Number of parcels (ha)	**Percentage (n = 676)**
> 0.4	1.0
0.5-0.8	9.3
0.9-2.0	17.2
2.1-4.0	17.9
4.1-8.0	43.8
8.1-20.0	9.2
21.0-40.0	1.0
< 40.1	0.6
Total	**100**

Source: Department of Statistics and Ministry of Agriculture, 1999.

Table 6: Percentage of agriculture type by parcel in the Vaa O Fonoti District: 1999

Production	**Percentage (n = 653)**
Under tree crops	40.9
Under other crops	9.0
Under tree and other crops	41.7
Under fallow	2.8
Under virgin bush	0.0
Under non-agriculture use	2.5
Under livestock and poultry	1.5
Unknown	1.7
Total	**100**

Source: Department of Statistics and Ministry of Agriculture, 1999.

In 1999, most households in the Faa O Vonoti Districts grow coconuts, cocoa, *taamu*, breadfruit and bananas (Table 7). Crops are grown for a variety of purposes, some for sale, but most for home consumption, with a likely exception being *kava*..

Table 7: Percentage of holdings growing crops by type in the Vaa O Fonoti District: 1999

Produce	**Percentage (n = 213)**
Coconuts	98.6
Cocoa	72.8
Taro	68.5
Taro Palagi	36.6
Taamu	89.7
Coffee	3.3
Cassava	18.8
Kava	60.6
Yam	76.1
Maize	1.4
Peanuts	36.2
Beans	24.4
Cucumber	8.0
Head Cabbage	1.9
Chinese Cabbage	0.5
Lettuce	0.5
Pumpkin	19.2
Tomato	12.2
Banana	100.0
Oranges	22.5
Pineapple	31.5
Watermelon	2.8
Avacado	12.2
Breadfruit	82.2
Grapefruit	4.2
Lemon	43.2
Lime	35.7
Mango	67.6
Papaya	73.7
Vi	19.2
Tauta	25.8
Other crops	18.3

Source: Department of Statistics and Ministry of Agriculture, 1999.

In 1999, approximately 61 % of households were growing *kava* (Department of Statistics and Ministry of Agriculture, 1999). SMEC (2010) states that due to increasing prices and the destruction of coconut plantations in previous tropical cyclones, that there has also been an associated increase in the cultivation of *kava*, with approximately 89 % of all households in Fagaloa Bay now growing *kava* in either in mixed-garden or small mono-crop plots. SMEC (2010) has also suggested that this increase in *kava* production by villagers in Fagaloa Bay is also contributing ro an increase in sediment loads entering into the bay.

The clearing of forest for gardens (Figure 6), and the increasing trend towards mono-cropping with little use of shade trees exposes already steep hillsides to erosion (Stednick, 1990; Taulealo, 1993; SMEC, 2010). Tuivavalagi *et al* (2001) has also highlighted that mono-cropping rather than the more traditional systems such as mixed cropping and integrated farming is more likely to result in land degradation via soil erosion due to rain, and associated freshwater run-off.

Figure 6: Garden and modified forest on the south-east slope of Fagaloa Bay
Source: © Jeff Kinch.

In 1999, approximately 25 % of all holdings in the Vaa O Fonoti District were reported as using fertilisers, of which around 10 % were inorganic (Table 8). General farming practices by Samoan families also means that they actively maintain a weed-free environment. Some of this weeding is done manually, but can and does entail the use of herbicides. In 1999, approximately one-fifth of all holdings in the Vaa O Fonoti District were using herbicides (Table 8).

Table 8: Percentage of holdings using fertilizers in the Vaa O Fonoti District: 1999

Type	**Percentage (n = 213)**
Inorganic	10.3
Organic	14.1
Herbicide	20.6
Total	**100**

Source: Department of Statistics and Ministry of Agriculture, 1999.

Some herbicides cause rapid (but reversible) photo-physiological stress in corals after short-term exposure at environmentally relevant concentrations (Jones and Kerswell, 2003; Jones *et a*l, 2003; Owen *et al*, 2003); though their effects at chronic low-level exposures are still largely unknown (Fabricus, 2005).

2.4.2 Livestock

Most households in the Vaa O Fonoti District keep livestock. SMEC (2009) estimated that on average, each household in Fagaloa Bay owned 30 chickens, 30 pigs, and about 12 cattle (Table 9). Ta'elefaga village reported the highest number of pigs/household at 65 pigs (Table 9).

Estimates for total pig populations in the Fagaloa Bay in 2009 by SMEC (2009) is approximately 2,640, with the chicken population estimated to be in the order of 3,500, and a total cattle population of about 140.

Table 9: Average number of livestock by household/village in Fagaloa Bay: 2009

Village	No. of chickens/household	No. of pigs/household	No. of cattle/village
Salimu/Musumusu	25	35	7
Ta'elefaga	27	65	12
Maasina	35	22	20
Lona	35	18	8
Samamea	30	12	15
Average Fagaloa Bay	**30**	**30**	**12**

Source: SMEC, 2009.

Given current human population estimates and SMEC's (2009) estimates for pig populations, this would mean approximately 3 pigs/person. This appears to be extremely high, given figures for the rest of the Pacific. For example, in Melanesia, it is reported for Papua New Guinea, that there are 0.4 pigs/person; 0.1 pigs/person for the Solomon Islands; and 0.7 pigs/person for Vanuatu (Hide, 2003). Saville and Manueli (2002) record an average of 0.7 pigs/person for Niue, Tonga, the Cook Islands, Samoa, Tuvalu, Tokelau, and Wallis and Futuna. Estimates for American Samoa are 0.3 pigs/person (which are mostly kept in commercial piggeries) (Fenner *et al*, 2008).

The number of pigs reported by SMEC (2009) would give a density of 23 pigs/ha, which again seems high given the limited area within Fagaloa Bay. In addition, given the dietary requirements needed to feed all these pigs, it would mean that possibly eight tonnes of fodder/day (include supplementary foraging) would be required.

2.4.3 Fishing

In the 1999 Agricultural Census, approximately 75 % of all households in the Vaa O Fonoti District participated in some form of fishing (Department of Statistics and Ministry of Agriculture, 1999), with most fishing occurring in the inshore areas (i.e. areas close to shore) (Table 10). The average number of fishing trips in 1999 was reported to be three trips/week (Department of Statistics and Ministry of Agriculture, 1999), with spearing reported as the most common method used (Table 11).

Table 10: Percentage of households fishing by location: 1999

Location	Percentage (n = 158)
Inshore	91.1
Offshore	7.6

Source: Department of Statistics and Ministry of Agriculture, 1999.

Table 11: Percentage of fishing method used: 1999

Method	Percentage (n = 158)
Fish net	13.9
Fish fence	3.2
Hook and line	18.9
Spears	78.5
None	1.9

Source: Department of Statistics and Ministry of Agriculture, 1999.

The most extensive study conducted on fishing in the Fagaloa Bay was conducted by Tuaopepe (2005) as part of her Masters thesis at the University of the South Pacific. Tuaopepe (2005) notes that unicornfish (*Naso* spp.) and the dot-tailed goatfish (*Parupeneus indicus*) were caught at Ta'elafaga from spearing, and that filefish (*Aluterus scriptus*) were captured at Ta'elafaga and longtom (*Platybelone argalus platyura*) was caught at Maasina by fishers using gillnets.

3. Methods

3.1 Survey sites

Specific locations for surveying were the same as the areas surveyed by Lovell and Toloa (2002) (Figure 7and Table 12), with the exception that sites 6, 7, and 8 were not surveyed during the coral reef assessments because Lovell and Toloa (2002) had not taken photographs of the corals and reef structure in these sites. Sites 6, 7, and 8 also posed a safety risk to SPREP and SROS staff due to difficulties in accessibility and due to their location were often exposed to adverse weather and sea conditions. Site 10 was also dropped during the course of the water quality monitoring due to cost-cutting measures.

Figure 7: Location of sites surveyed in Fagaloa Bay by Lovell and Toloa (2002) and current program
Source: Lovell and Toloa (2002).

Table 12: Survey site characteristics

Site	Name	Location	Distance from Ta'elefaga Creek (m)	Average survey depth (m)	Distance from shore (m)
1	Channel	130 56.45' S 1710 34.13' W	~ 50	5	~ 50
2	Reef at entrance to the channel	130 56.42' S 1710 34.07' W	~ 165	5	~ 80
3	Headland at Salimu village	130 56.21' S 1710 33.87' W	~ 465	5	~ 180
4	Musumusu village	130 55.88' S 1710 33.29' W	~ 850	5	~ 220
5	Headland north of Musumusu	130 55.18' S 1710 32.75' W	~ 1,200	5	~ 165
9	Embayed reef north of Sameamea village	130 55.93' S 1710 31.97' W	~ 1,600	5	~ 165
11	South of point opposite Lonu village	130 56.37' S 1710 32.71' W	~ 930	5	~ 220
12	West of point between Lonu and Maasina village	130 56.32' S 1710 33.39' W	~ 630	5	~ 200
13	In the bay opposite Maasina	130 56.58' S 1710 34.08' W	~ 410	5	~ 150
14	Outside of reef between Maasina and Ta'elefaga villages	130 56.42' S 1710 33.87' W	~ 230	5	~ 65

Source: Lovell and Toloa (2002).

3.3 Activities

Survey activities commenced with community consultations in June 2009. Substrate surveys and fish biomass assessments were conducted once during the marine monitoring program, coral recruitment was conducted over three periods (due to adverse weather conditions and SPREP staff commitments, sites 1 and 2 could not be surveyed until March 2010, see Appendix B and C for further details); and water quality and marine organisms were conducted monthly (Table 13).

Table 13: Activities conducted for the marine monitoring program

Activity	Jul 09	Aug 09	Sep 09	Oct 09	Nov 09	Dec 09	Jan 10	Feb 10	Mar 10	Apr 10	May 10
Community consultation	✓										
Substrate	✓										
Fish	✓										
Coral recruits	✓				✓				✓		
Water quality (marine)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Water quality (freshwater)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Meteorology	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Marine organisms	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

3.2.1 Community consultation

A series of workshops were carried out with all villages in the Fagaloa and Uafato Bays over the period from the 7^{th}-15^{th} July, 2009. The purpose of these consultations was to introduce the villages to the purpose of the marine monitoring program (see Appendix D for consultation report). This work was coordinated by the MAFF.

Consultations were arranged to meet at the village mayor's house or a village meeting house where all the *matai*'s (village chiefs) came together to hear the purpose of the visit. As part of the consultation protocol, kava ceremonies were performed.

3.2.2 Substrate surveys

During the current marine monitoring program, the photo-quadrant method was used instead of the line intercept transect method that was used by Lovell and Toloa (2002) as the photo-quadrant method was considered more time efficient, easier to perform (even without the use of SCUBA), and would also provide a record of pictures for each site that can be used over time.

The photo-quadrant method thus involved taking photographs of a 75 cm^2 quadrant positioned along a 25 m transect laid at a depth of 5 m. Along each transect, 25 photographs were taken. Photographs were then analyzed using the *Coral Point Count* with Excel extension software.

Substrate composition was divided into four main categories, coral, algae, other live organisms and substrate (Table 14).

Table 14: Substrate categories

Category	Definition
Coral	all living hard corals
Algae	all macro-algae
Other live organisms	other live organisms, such as sponges and soft corals
Substrate	sand, mud, rock, dead coral and rubble

For the purpose of the substrate surveys, coral cover was further broken down into *Acropora, Pocillopora*, *Montipora*, and *Porites* spp.; and soft corals (Figure 8). These species were chosen as they are the most common species (Zann, 1991), and prefer specific habitat qualities, which makes them useful as indicators to coral reef health. *Acropora*, *Montipora* and *Pocillopora* spp. in particular are considered to be sensitive genera (Fabricius, 2005) whereas *Porites* spp. are known to be among the most persistent and sediment and nutrient-tolerant coral genus (Done, 1982; Stafford-Smithy and Ormond, 1992; Birkeland, 2000; Philipp and Fabricius, 2003).

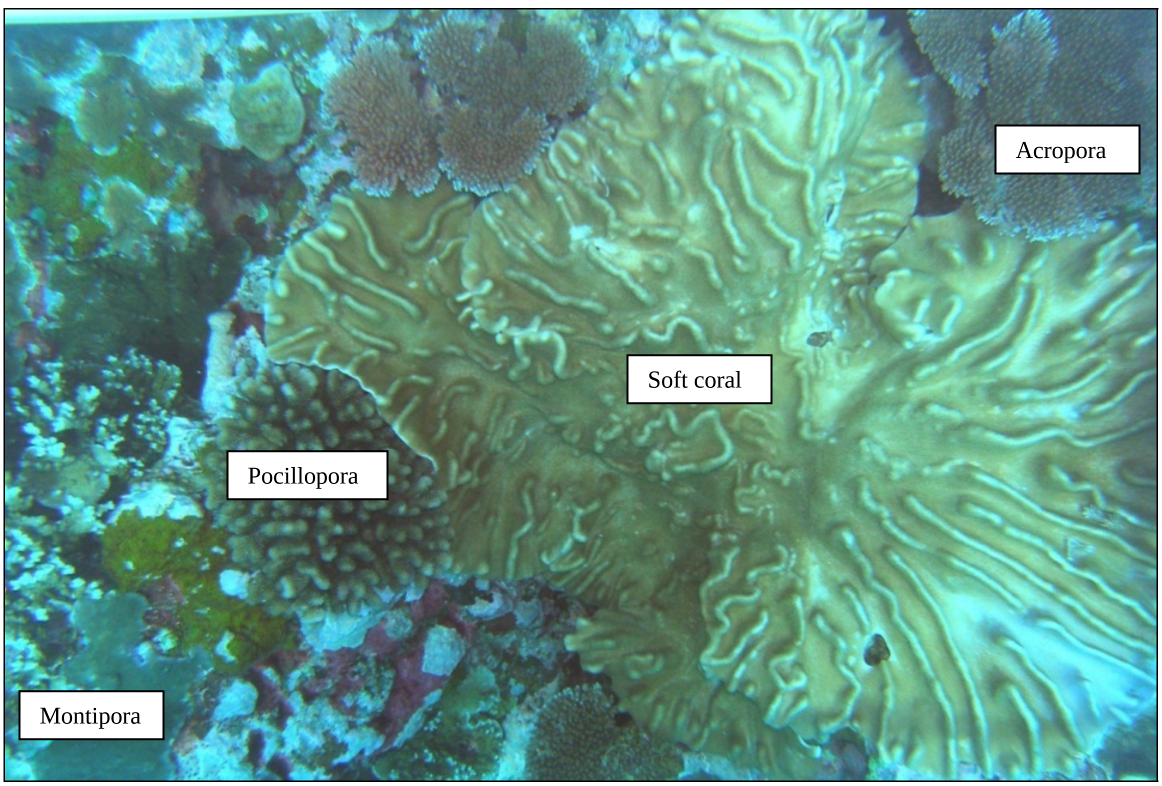


Figure 8: Four of the five corals species used for the coral composition study

3.2.3 Fish surveys

The status of finfish resources in selected sites was assessed by MAFF staff using the distance-sampling underwater visual census following Labrosse *et al* (2002). Main commercial fish families were recorded for all sites in Fagaloa (except sites 1 and 2 which had extremely poor visibility at the time of surveying) and Uafato Bays. These fish surveys are the first of this kind conducted in Fagaloa Bay, thus quantitative pre-Afulilo Dam comparisons are not be possible.

3.2.4 Coral recruitment surveys

The coral recruitment survey involved recording recruits (< 5 cm in diametre) from the four main coral genera (listed above) were recorded along the same 25 m transect used for the substrate surveys, whereby, a similar 75 cm^2 quadrant was moved along the transect, and juvenile corals were recorded inside the quadrant every 2.5 m, making a total of 12 quadrants surveyed/site.

3.2.5 Water quality sampling and assessments

SPREP oversaw the marine water quality testing that was conducted by SROS. Initially SROS collected the water samples, but as the sampling regime changed during the course of the marine monitoring program (details and contract variations are provided in Appendix E), SMEC took over responsibility for the provision of marine water samples to SROS. Rainfall and tide times indicating date and time of sampling are provided in Appendix F and G.

Several parameters were tested by SROS during the water quality program (testing methods are listed in Appendix H), with key parameters: salinity, Totally Suspended Sediments, turbidity, nitrogen, phosphorus, iron and ammonia; used in this analysis.

Hydrogen sulphide, lead, and mercury were initially sampled, but were dropped through the course of the survey as unnecessary. Hydrogen sulphide in particular, was removed from sampling, as it was not detected in water samples. Both lead and mercury levels were below detectable levels or just at detection limits, which were below levels for health concerns for both marine organisms and/or people.

3.2.6 Marine organism sampling and assessments

SROS was also responsible for sampling and analysis of marine organisms, with the Venus shell (*Garifarium* spp.) being the main species targeted for testing. Specimens were tested for iron, magnesium and lead.

4. Results

4.1 Community consultation

During the consultations, villages were pleased to hear that there would be an assessment of the Fagaloa Bay marine environment. During consultations, *matai*s raised concerns over the proposed augmentation of the Afulilo Reservoir, and detailed both 'real' and perceived impacts of the current Ta'elafaga Hydro-power Scheme.

Concerns expressed by community members included:

- decreased number of fish;
- decreased number of shellfish;
- loss of marine habitats (corals);
- murky color of the sea water from time to time, especially when it rains heavily; and
- an increase in the number of hours required to obtain similar catches of fish to those caught in the past (Tiitii, 2009).

Similar issues were raised with SMEC during their community consultations (SMEC, 2009).

All villages appreciated the effort of making them aware of the marine monitoring program and all the activities to be undertaken during the 2009-2010 survey period.

4.2 Substrate surveys

Results from the marine monitoring program show that live coral cover across all sites in 2002 ranged from 26 % to nearly 75 % compared to current ranges of 12 to 45 % (Figures 9 and 10; full site descriptions can be found in Appendix I). In 2002, all sites, except site 1, were above 50 % coral cover with Lovell and Taloa (2002) also reporting good recruitment occurring prior to their survey. A survey conducted in 2005-2006 in neighbouring American Samoa reported that mean benthic cover was essentially unchanged during this survey period (Fenner *et al*, 2008).

In contrast, in the 2009 survey, none of the survey sites recorded coral cover above 50 %, with a steep decrease in tabular *Acropora* spp. and to a lesser extent, *Porites* spp (Figure 10).

A possible explanation for the decrease in coral cover in Fagaloa Bay observed in the 2009-2010 marine monitoring program, could be the result of damage caused by tropical cyclones *Heta* in 2004 and *Olaf* in 2005. According to Craig *et al* (2008), tropical cyclone *Heta* caused considerable damage to coral reefs in American Samoa. As explained by Birkeland *et al* (2003), one of the most conspicuous effects of tropical cyclones is the stripping away of any dead and living corals that offered a high coefficient of drag to the storm waves. *Acropora spp*. and especially tabular *Acropora* spp. fall into this category.

In Fagaloa Bay, the impacts of tropical cyclones *Ofa* and *Val* resulted in living coral cover in Fagaloa Bay either being damaged or destroyed, and in some cases washed away (Zann, 1991; Zann and Sua, 1991; Suluvale, 1997; Lovell and Toloa, 2002). For example, high coral cover off Utuloa Point and East Point were also almost completely obliterated (Zann, 1991; Lovell and Toloa, 2002). Overall, Zann (1991) estimated that approximately 95 % of all corals were destroyed in cyclone impacted areas of Fagaloa Bay during 1990-1991. Similar impacts have also been described for American Samoa (Birkeland *et al,* 2003; Garrison *et al,* 2007 a,b; Fenner *et al,* 2008).

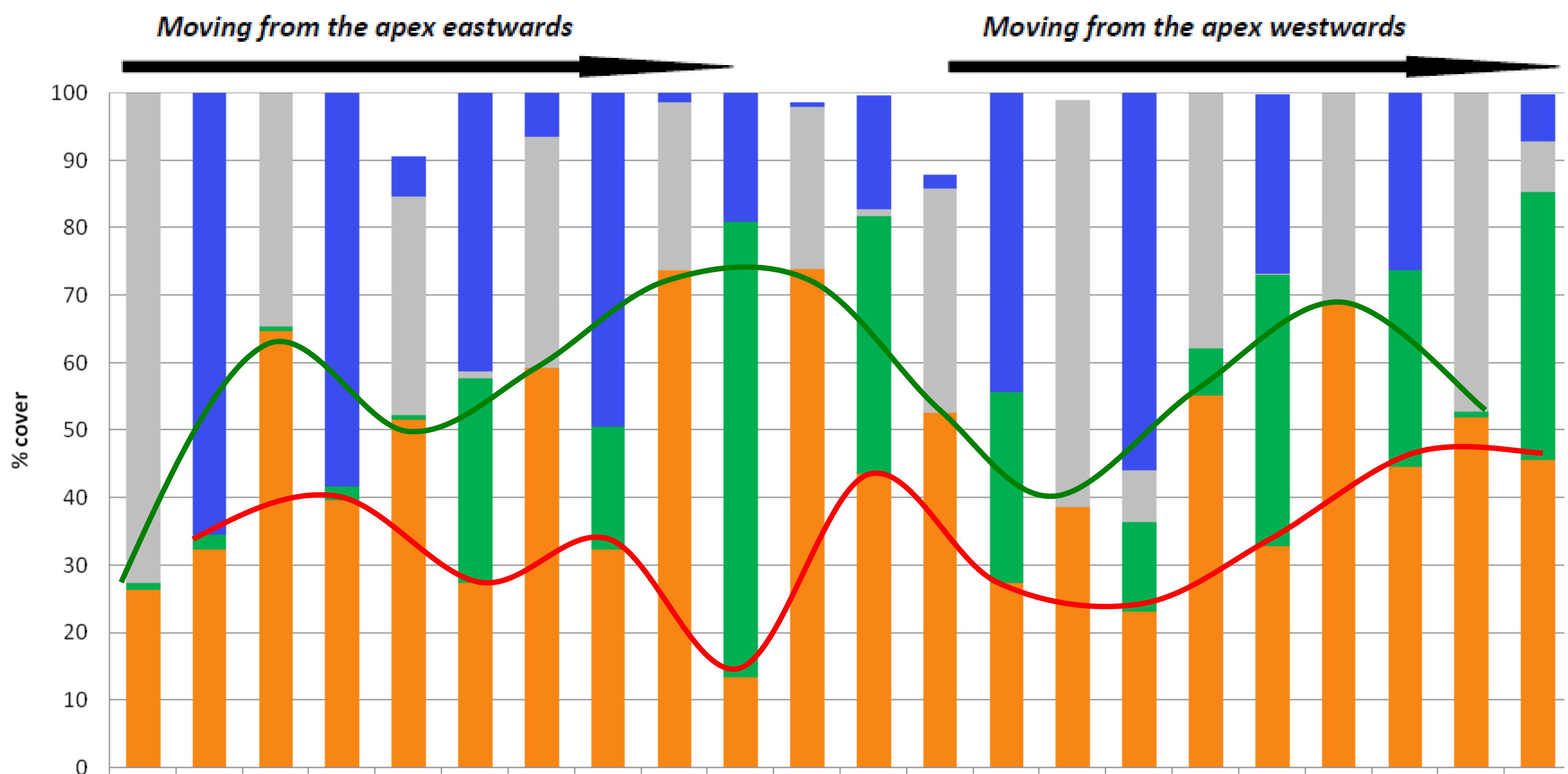
Damage from tropical cyclone *Ofa* in Fagaloa Bay was particularly extreme, especially along its eastern shore, whereby emergent and exposed (~ 1 km in length and consisting of 10 separate banks) and tidal (~ 2 km in length) banks along the reef crests from Lona to Samamea village can still be seen today. These banks had been formed by the cyclone uprooting live corals from the front reef slope and dumping them along the leeward side of the reef crest (Zann, 1991; Lovell and Toloa, 2002).

Paralleling the decrease of *Acropora* spp. and rise in coralline algae, there has also been a notable increase of *Montipora* spp. It is probable that the increase in *Montipora* spp. is linked to the removal of tabular *Acropora* spp. by tropical cyclones *Heta* and *Olaf*. Lovell and Taloa (2002) reported relatively dense populations of tabular *Acropora* spp. in 2002, which were considered to be preventing other species recruiting and developing, due to shading. Tabular *Acropora* spp. are known to out compete other corals (Fenner *et al*, 2008). With the removal of tabular *Acropora* spp. by tropical cyclones *Heta* and *Olaf*, space was freed up, and the *Monitpora* spp. colonised vacant places. *Montipora* spp are also known to have a higher tolerance to sedimentation and turbidity (Latypov, 2006).

Algae cover in Fagaloa Bay has also increased significantly between 2002 and 2009 ranging from 12 % at site 12 to nearly 70 % at site 5 (Figure 11). In contrast, Lovell and Toloa (2002) recorded very little algae cover in 2002.

During the 2009-2010 survey, two main types of algae were found in Fagaloa Bay, encrusting coralline algae and *Halimeda* spp. The presence and spread of *Halimeda* spp. could be linked to a decrease in coral cover and diversity through the deposition of sediments associated with terrestrial freshwater run-off (see Latypov, 2006). *Halimeda* spp. also inhibits coral recruitment due to its fleshy nature. *Halimeda* spp. has increased in sites 3, 12, 13 and 14 and has spread in sites 4 and 11 (Figure 11). Encrusting coralline algae has also spread across all sites, especially, site 5 (Figure 11). Sites 1 and 2 near the apex of Fagaloa Bay showed very low to no coralline algae and this obsence may have limited coral recruitment.

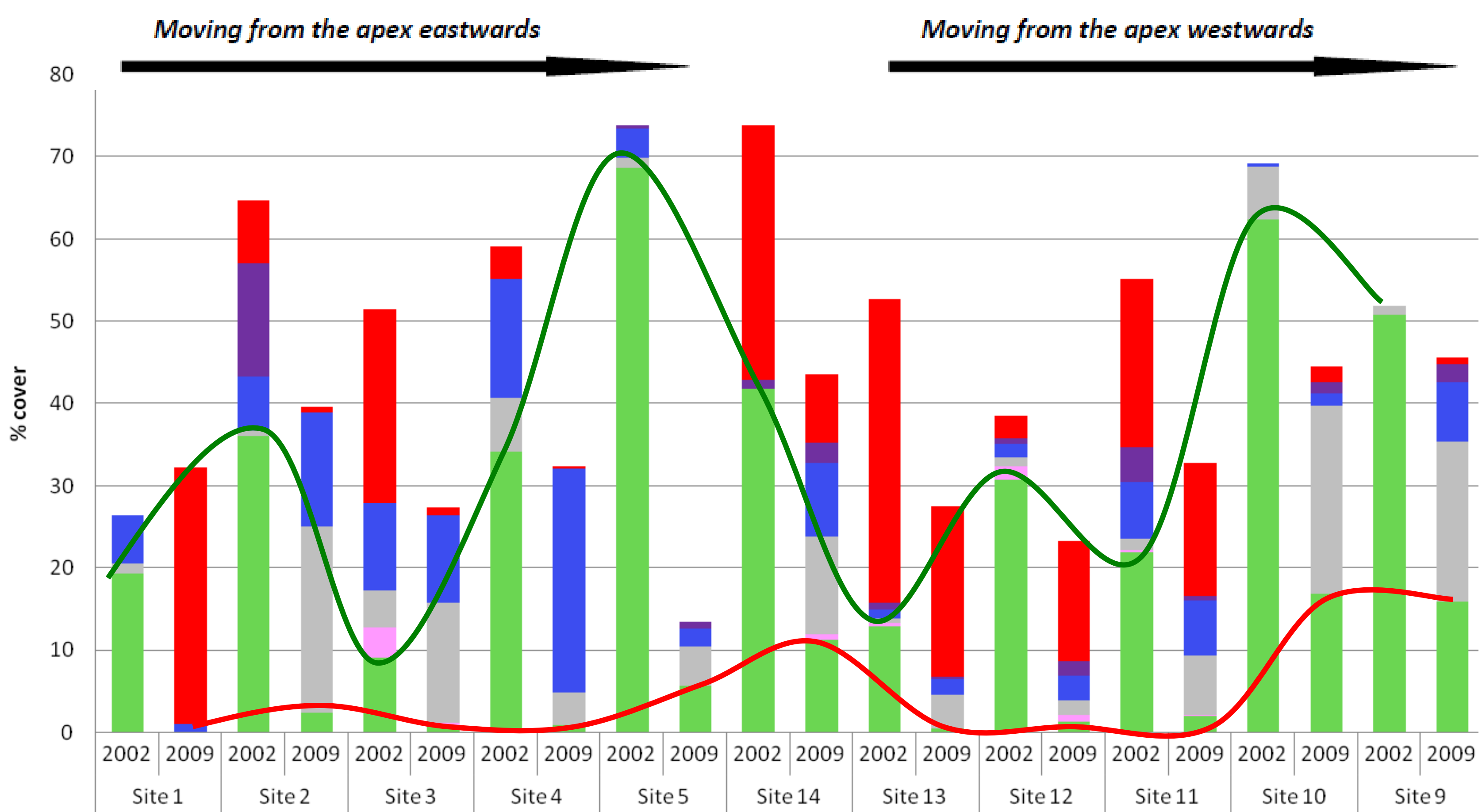
Information from the American Samoa's coral reef status reports describe how several bleaching events in 2002 and 2003 (Craig *et al*, 2006) and 2005 (Fenner *et al*, 2008), resulted in an increase in encrusting coralline and turf algae cover due to the loss of live coral cover (Fenner *et al*, 2008). Bleached corals were observed by Lovell and Toloa (2002) at several sites in Fagaloa Bay during their 2002 survey, though no bleached corals were observed in 2009.



	Site 1		Site 2		Site 3		Site 4		Site 5		Site 14		Site 13		Site 12		Site 11		Site 10		Site 9	
	2002	2009	2002	2009	2002	2009	2002	2009	2002	2009	2002	2009	2002	2009	2002	2009	2002	2009	2002	2009	2002	2009
Other Live	0	65.4	0	58.3	6	41.2	6.49	49.5	1.33	19.0	0.67	16.8	2	44.2	0	56.0	0	26.4	0	26.2	0	6.99
Substrate	72.6	0.00	34.6	0.00	32.3	1.10	34.3	0.00	24.8	0.00	24.1	1.04	33.2	0.00	60.4	7.60	37.8	0.21	30.8	0.00	47.1	7.50
Algae	1	2.27	0.67	1.96	0.83	30.3	0	18.1	0	67.5	0	38.1	0	28.3	0	13.2	7	40.3	0	29.1	0.93	39.6
Coral	26.3	32.2	64.6	39.6	51.5	27.3	59.1	32.3	73.7	13.4	73.8	43.5	52.6	27.3	38.5	23.2	55.1	32.7	69.1	44.5	51.9	45.6

Figure 9: Changes in substrate composition at Fagaloa Bay: 2002 and 2009

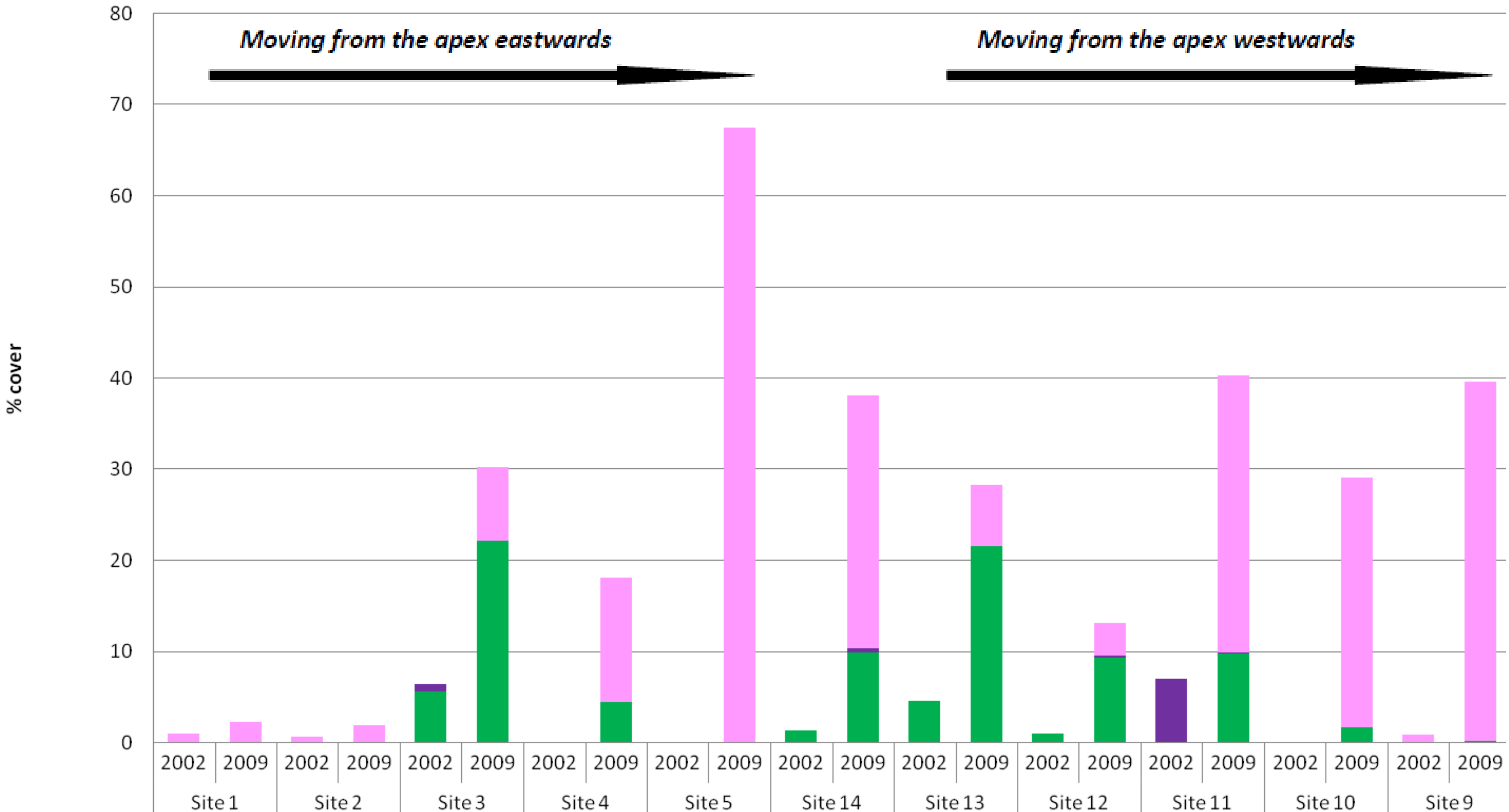
Note: Orange bar denotes coral, green = algae; grey = substrate, blue = other living things. Green line denotes trend changes across sites for coral cover in 2002, the red line is for 2009



	Site 1 2002	Site 1 2009	Site 2 2002	Site 2 2009	Site 3 2002	Site 3 2009	Site 4 2002	Site 4 2009	Site 5 2002	Site 5 2009	Site 14 2002	Site 14 2009	Site 13 2002	Site 13 2009	Site 12 2002	Site 12 2009	Site 11 2002	Site 11 2009	Site 10 2002	Site 10 2009	Site 9 2002	Site 9 2009
Porites	0	31.3	7.67	0.77	23.6	0.90	4	0.26	0	0.00	31	8.23	36.8	20.7	2.83	14.6	20.5	16.2	0	1.90	0	0.85
Pocillopora	0	0.00	13.6	0.00	0	0.00	0	0.00	0.33	0.94	1	2.50	0.88	0.24	0.67	1.80	4.16	0.63	0	1.48	0	2.22
Other Live Coral	5.83	0.91	6.67	13.8	10.6	10.7	14.5	27.3	3.5	2.19	0	8.98	1.13	1.90	1.67	3.00	7	6.67	0.33	1.43	0	7.24
Montipora	1.33	0.00	0.67	22.6	4.5	14.5	6.5	3.95	1.33	4.69	0	11.9	0.5	4.05	1	1.80	1.33	7.16	6.5	22.9	1.07	19.4
Fungia	0	0.00	0	0.00	3.67	0.43	0	0.00	0	0.00	0	0.63	0.38	0.00	1.67	0.80	0.33	0.21	0	0.00	0	0.00
Acropora	19.2	0.00	36	2.31	9	0.65	34.1	0.79	68.6	5.62	41.8	11.2	12.8	0.48	30.7	1.20	21.8	1.88	62.3	16.7	50.8	15.8

Figure 10: Changes in coral composition in Fagaloa Bay: 2002 and 2009.

Note: Greeen bar denotes acropora, pink = fungia, grey = monitpora, blue = other live corals, purple = pocillopora, red = porites. Green line denotes trend changes across sites for *Acropora* spp. in 2002, the red line is for 2009



	Site 1		Site 2		Site 3		Site 4		Site 5		Site 14		Site 13		Site 12		Site 11		Site 10		Site 9	
	2002	2009	2002	2009	2002	2009	2002	2009	2002	2009	2002	2009	2002	2009	2002	2009	2002	2009	2002	2009	2002	2009
Coralline	1	2.27	0.67	1.96	0	8.09	0	13.6	0	67.5	0	27.7	0	6.67	0	3.60	0	30.3	0	27.4	0.93	39.3
Macro Algae	0	0.00	0	0.00	0.83	0.00	0	0.00	0	0.00	0	0.42	0	0.00	0	0.20	7	0.21	0	0.00	0	0.00
Halimeda	0	0.00	0	0.00	5.67	22.2	0	4.47	0	0.00	1.33	10.0	4.63	21.6	1	9.40	0	9.79	0	1.68	0	0.28

Figure 11: Changes in algae composition in Fagaloa Bay: 2002 and 2009.

4.3 Fish surveys

A total of 16 different commercial fish families were recorded by MAFF in Fagaloa Bay in 2009 (Table 15). Dominant families both in terms of biomass and presence are Acanthuridae (surgeon fish) and Scaridae (parrot fish) with a biomass of 151.5 g/m², and 152.5 g/m² respectively (Table 15). Both these families were recorded in 8 of the 9 sites. The third most abundant family is the Lutjanidae (emperors) with a biomass of 62.1 g/m² and was observed at 5 of the 9 sites (Table 15). All other families show much lower biomasses ranging from 0.14 g/m²for the Priacanthidae (squirrel fish) to 19.8 g/m² for the Kyphosidae (Table 15).

In 2009, the average biomass for the eastern side of the Bay was around 35g/m², with the western side being slightly higher at 50g/m² (Figure 12). Total commercial fish biomass per site ranged from 2.3 g/m² at site 14 close to Ta'elefaga to 97g/m² at site 10 between Samamea and Lona villages (Figure 12), which also reported the highest coral cover.

Compared to other recent studies conducted in Samoa (Table 16) (Vunisea *et al*, 2008) and American Samoa (Sabater and Tofaeono, 2007; Fenner *et al*, 2008; Houk and Musburger, 2008), values for Fagaloa Bay are considered to be low, and this could be attributed to decline in coral cover, and fishing pressure, though no information on the latter is currently available.

Table 15: Fish families and biomasses recorded in Fagaloa Bay by MAFF: 2009

Family	**Site 3**	**Site 4**	**Site 5**	**Site 9**	**Site 11**	**Site 10**	**Site 12**	**Site 13**	**Site 14**	**Total Biomass (g/m²)**
Acanthuridae	✓	✓	✓	✓			✓	✓	✓	151.5
Caesionidae	✓								✓	6.5
Labridae	✓									10.1
Lutjanidae	✓			✓	✓			✓	✓	62.1
Mullidae	✓		✓	✓			✓	✓	✓	7.7
Pomacanthidae	✓	✓			✓		✓			5.7
Scaridae	✓	✓	✓		✓		✓	✓	✓	152.5
Serranidae	✓	✓			✓		✓		✓	4.3
Balistidae		✓	✓	✓	✓		✓	✓	✓	16.7
Chaetodontidae			✓					✓		0.8
Kyphosidae			✓	✓						19.8
Haemulidae				✓						0.9
Holocentridae				✓	✓		✓		✓	4.8
Siganidae							✓			1.0
Priacanthidae								✓		0.1
Total	**8**	**5**	**6**	**7**	**6**		**8**	**7**	**8**	

Table 16: Commercial fish biomass (g/m²) recorded in Samoa by the PROCFish-C project: 2005

Location	**Biomass**
Manono-Uta	201.2 (±30.9)
Salealavu	166.0 (±28.9)
Vailoa	179.0 (±32.0)
Vaisala	132.0 (±35.2)

Source: Vunisea *et al,* 2008.

Tuaopepe (2005) documents that Ta'elafaga and Maasina villagers do not fish as often as they used to, reportedly, because Fagaloa Bay now lacks many of the marine species that were present in the past. She also notes that many finfish, shellfish and invertebrates have now avoided or have disappeared from the discoloured and dirty inshore waters of Fagaloa Bay, with many large finfish (e.g. steephead parrotfish – *Chlorurous microrrhinus*, humphead maori wrasse – *Chelinus undulatus*, and trevally – *Caranx ignobilis*) no longer common inside the bay (Tuaopepe, 2005).

Tuaopepe (2005) also notes that the *igaga* fish (unidentified) which was reported to breed annually in the mouth of the Ta'elafaga Creek, has now disappeared, and that the purse-eye scad (*Selar crumenophthalmus*), which once mobilised villagers in the Fagaloa Bay in catching them as now rare, and their disappearance has been reported by villagers in Fagaloa Bay to be associated with the of establishment of the Ta'elafaga Hydro-power Station. Similarly, schools of rabbitfish (*Siganus* spp.) which also used to appear annually at Ta'elafaga have also declined. At neighbouring Maasina, other small finfish, such as the Eel catfish (*Plotsus lineatus*), Goatfish (*Mulloidichthys* spp. and *Parupeneus* spp.), and Ponyfish (*Leiognsthus equula*) have also declined (Tuaopepe, 2005).

Other invertebrates, such as the sea cucumber species, dragonfish (*Stichopus horrens*) and prickly redfish (*Thelenota ananas*) have been reported by Tuaopepe (2005) to have declined; along with a decline in the sea urchins (*Echinometra* sp. and *Diadema* sp. (see Birkeland *et al*, 2003 for similar experiences in Fagatele Bay, American Samoa).

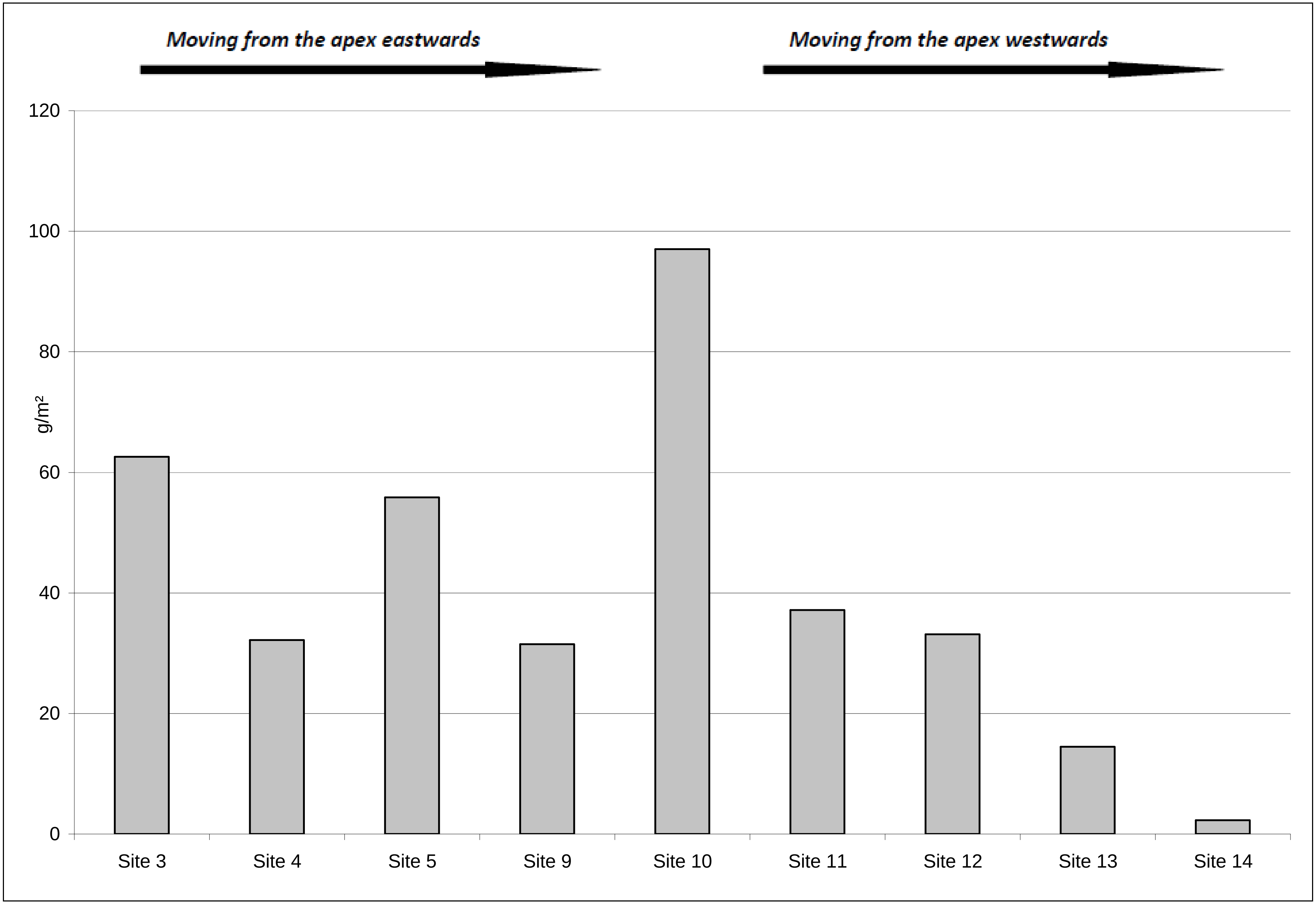


Figure 12: Commercial fish biomass recorded in Fagaloa Bay

4.4 Coral recruitment surveys

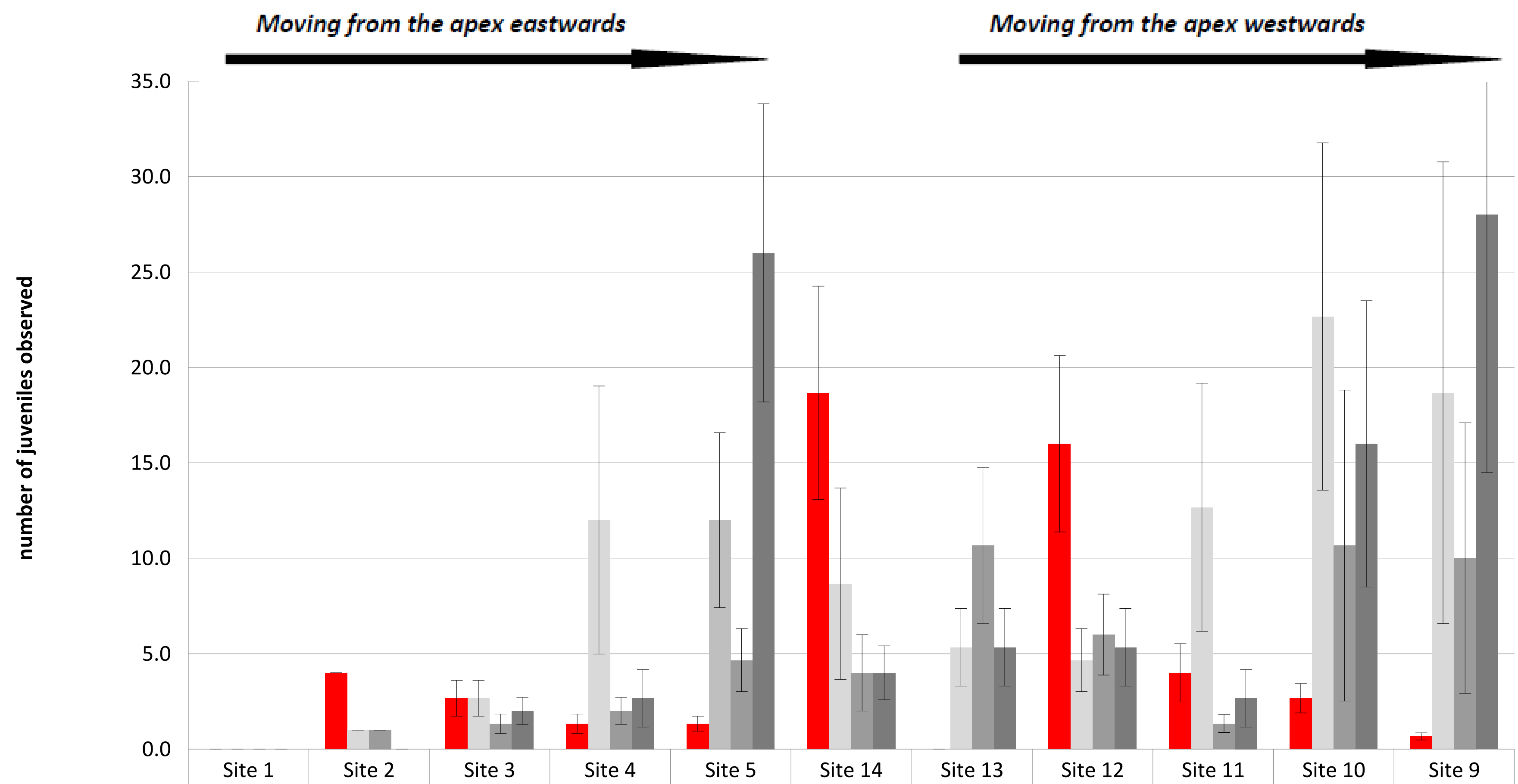
From the substrate surveys, areas that have high coral cover and encrusting coralline algae composition, will also be the most likely sites to show the highest recruitment rates, and this was confirmed with results from Sites 5, 9 and 10 (Figure 13).

Sites 5 and 9 in particular show a majority of *Acropora* spp. Fenner *et al* (2008) reports that in 2007, a recruitment pulse of the tabular *Acropora* coral (*A. hyacinthus*) was observed at several sites around American Samoa. It is probable, that the coral recruitment observed through the 2009-2010 marine monitoring program, are also from this period given the size of coral recruits observed.

There was no recruitment of corals at site 1, the closet site to the apex of Fagaloa Bay.

At sites 12 and 14, *Porites* spp. recruits were more dominant (Figure 13). At site 2, *Porites* spp. was also the main species showing recruitment, though numbers were very low. Both sites 14 and 2 are near the apex of Fagaloa Bay.

Porites spp. are known to be among the most persistent, and sediment and nutrient-tolerant coral genus (Done, 1982; Stafford-Smithy and Ormond, 1992; Birkeland, 2000; Philipp and Fabricius, 2003).



	Site 1	Site 2	Site 3	Site 4	Site 5	Site 14	Site 13	Site 12	Site 11	Site 10	Site 9
Porites	0.0	4.0	2.7	1.3	1.3	18.7	0.0	16.0	4.0	2.7	0.7
Montipora	0.0	1.0	2.7	12.0	12.0	8.7	5.3	4.7	12.7	22.7	18.7
Pocillopora	0	1.0	1.3	2.0	4.7	4.0	10.7	6.0	1.3	10.7	10.0
Acropora	0	0.0	2.0	2.7	26.0	4.0	5.3	5.3	2.7	16.0	28.0

Figure 13: Coral recruitment in Fagaloa Bay: August 2009-May 2010

4.5 Water quality sampling and assessments

4.5.1 Salinity, Sedimentation and Turbity

Salinity can be both a chronic and an acute stress factor for a majority of coral reef organisms (Smith and Buddemeier, 1992), with lethal and sub-lethal effects of lowered salinities usually occuring during and after freshwater run-off events, particularly for corals and organism living in water depths less than three metres (Birkeland, 1987; Coles and Jokiel, 1992; Ayling and Ayling, 1998; Brodie and Mitchell, 1992; O'Neill *et al*, 1992; McLaughlin *et al,* 2003; Yentsch *et al*, 2002; van Woesik and Done, 1997).

Tolerance of corals to freshwater influences varies between species (Dodge and Vaisnys, 1977; Stafford-Smith and Ormond, 1992), with soft corals usually more resistant to extended freshwater inundation then hard corals; of the latter, *Porites* spp. are more resistant, while *Acropra* spp. are generally more susceptible (Rogers, 1990; Cornish and DiDonato, 2004).

Sites 1, 2, and 14, the closest to the Ta'elefaga Stream showed lower salinity in all months compared with the other monitored sites (Figure 14), with all sites showing lower salinity values for the wet season months of November to February, which is consistent with the heavier rainfall experienced in these months (see Table 3).

Along with associated low levels of salinity, sites 1,2, and 14 also exhibited higher concentrations of total suspended sediments in October 2009, just before the start of the formal wet season; and sites 1 and 2 continuing this trend in November. This increase in sedimentation levels maybe due to loose materials being flushed out into Fagaloa Bay at the beginning of the wet season, or possibly due to land disturbances in the watersheds of Fagaloa Bay during these two month; with sedimentation rates then falling into a relatively stable level, except for some peaks for site 14 in February and May 2010.

Elevated sediment conditions and turbidity are known to impact on coral reefs by lowering larval production; increasing partial and/or full coral mortality; inhibiting settlement of recruits and smothering newly settled juveniles; reducing calcification; promoting physiological stresses; reducing coral diversity, size, cover, and depth ranges; and causing a transition from hard coral dominated communities to communities dominated by macro-algae (Anthony and Fabricius, 2000, Fabricius *et al*, 2003; Fabricus, 2005; Philipp and Fabricius, 2003; West and Van Woesik, 2001). As noted above, sites 1, 2, and 14 also exhibited low or no coral recruitment and/or coralline algae growth (see Figure 10).

Zann (1991) notes that since the mid-1950s (or possibly earlier), sediment deposition has resulted in a steady replacement of corals with algae on Samoa's coral reefs, which in turn has resulted in a collapse of some reef species. Concomitantly, erosion is now well recognized as a serious land management issue in Samoa (Johannes, 1982; Taylor, 1991; Bell, 1991; Zann, 1991; Suluvele, 1997).

Significant suspended sediment levels have also been observed to alter fish community composition, because high levels of sediment reduce light penetration, decreasing the volume of the photic zone and inhibiting primary production. Sediments also stress fish, inhibit visual detection of prey and causes fish to avoid the use of turbid reaches (*cf* Berg and Northcoat, 1985; Lloyd 1987). Site 14 reported the lowest fishing biomass (see Figure 12), sites 1 and 2 were not surveyed due to poor visibility.

The effects of tubidity on coral reef species richness are also strongly depth-dependent, as light requirements greatly varies between species, with corals inhibited by less than 70% of ambient light levels (Fabricus, 2005). Coral cover in clear waters usually average between 60-80 % (Roy and Smith, 1979). No sites in Fagaloa Bay have this level of coral cover (see Figure 9).

Turbidity values were highest in sites 1 and 2 during the months of October and November 2009, and are consistent with the high levels of sediments also reported for these months (Figure 16). The high turbidity level experienced in August 2009 at site 1, and site 2 in May 2010 could possibly be attributed to some land-use factor, or possibly re-suspension of existing sedimentations in the marine water column (which was reported by Lovell and Toloa, 2002 to be a regular phenomenon), though one would expect a corresponding increase in sedimentation for these two months.

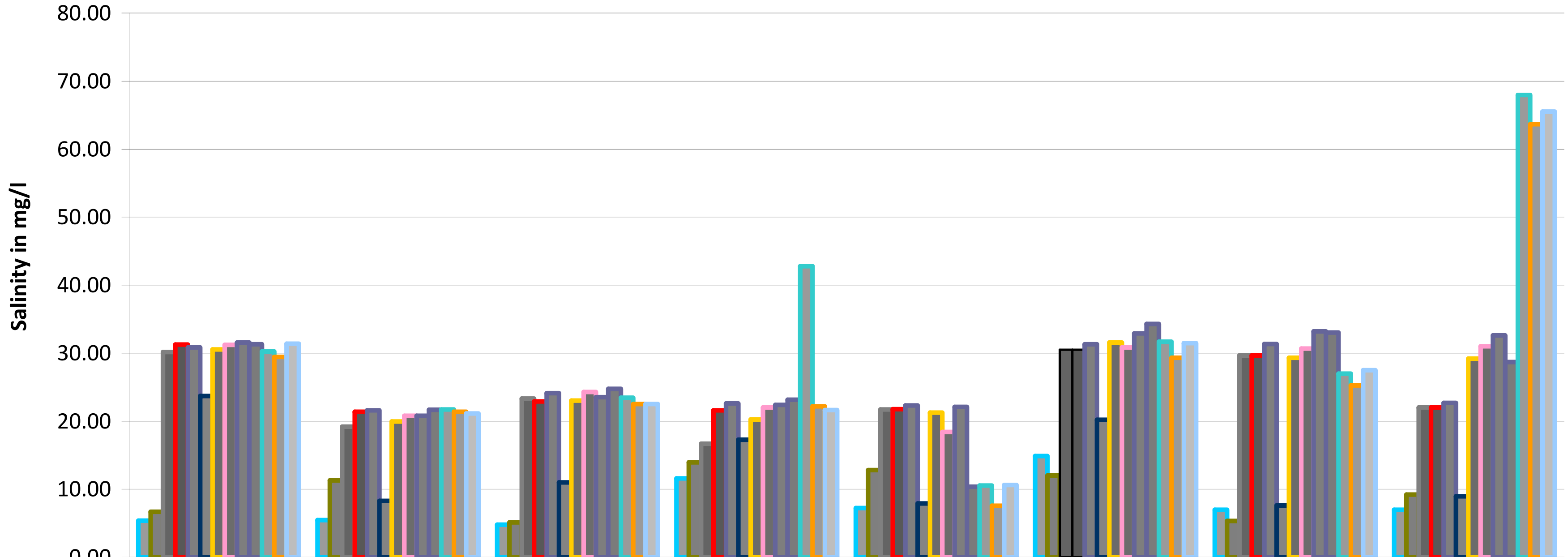
A key factor in the degree of erosion due to rainwater is the amount and nature of ground cover provided under each farming/cropping system. The greatest damage will be caused on sloping land where land is bared/uncovered during times of land preparation, planting or harvesting, and more so in the rainy season. The freshwater discharge of the Ta'elafaga Hydro-power Scheme that carries terrigenous material from the dam is another potential source (Waugh *et al,* 1991), particularly when water level in the Afulilo Reservoir is low. SMEC (2009) also state that the foraging by free ranging pigs is a major contributor to catchment soil erosion during rainy seasons.

In American Samoa, Birkeland *et al* (2003) found that chronic sedimentation had reduced coral diversity on the reef flats in Amanave Bay, although these reefs had greater diversity in the past. Whaylen and Fenner (2006) also found that coral cover in Fagasa Bay, also in American Samoa was very low due to excessive sedimentation.

Lovell and Toloa (2002) mentioned that the waters in Fagaloa Bay circulated clockwise which kept sediments suspended in the apex of the bay, and this may help to explain the higher levels of sedimentation and turbidity in sites 1, 2, and 14. Waugh *et al* (1991) noted sediments discharged from Ta'elafaga Creek during earthworks drifted to the true left of the stream mouth (which is in the location of sites 1 and 2). Lovell and Toloa (2002) also noted that in the shallow areas of the southwestern end of the Fagaloa Bay (where site 14 is located), sediments were continuously re-suspended.

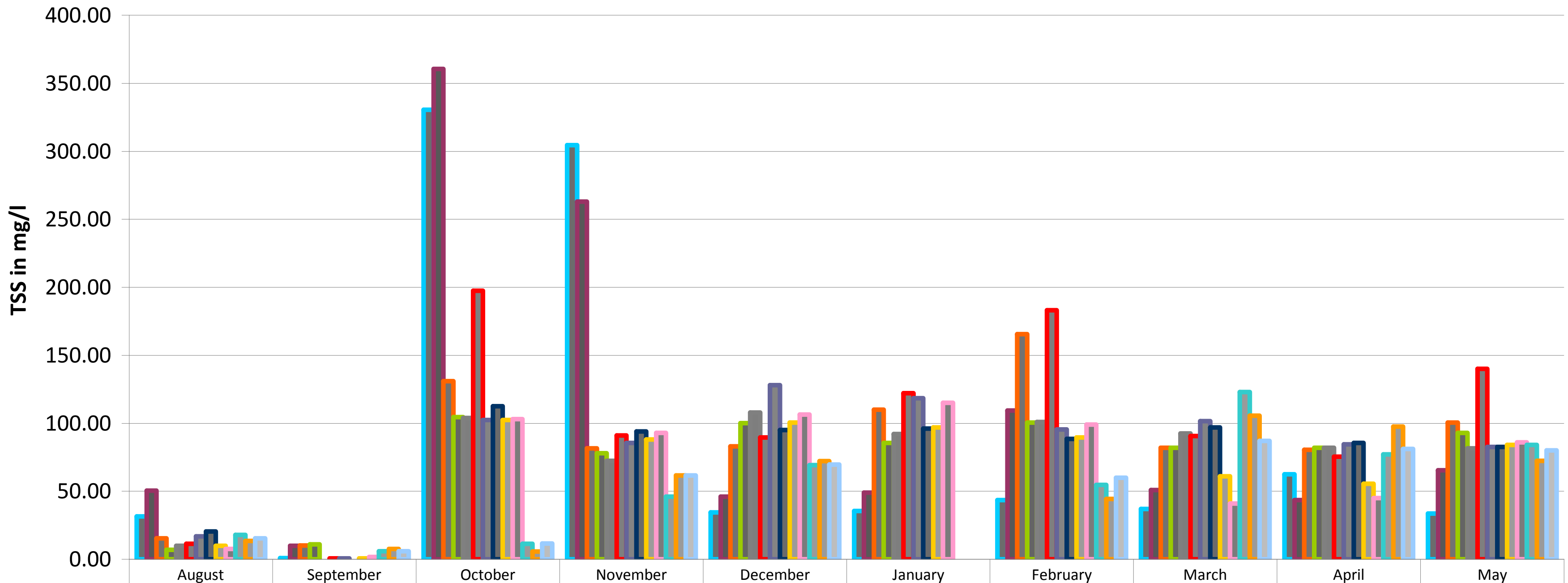
Discoloured water in the apex of Fagaloa Bay was regularly observed during the course of the marine monitoring program. The presence of tannins in the marine environment also discolours water, and thus increases turbidity.

Tannins washed from terrestrial run-off are generally associated with lowered salinity, entrained terrestrial sediments and tend to be suspended in surface waters until they are diluted out by seawater mixing. Unfortunately, the detection of impacts from tannins is difficult to discern in a natural situation due to the tannins being swamped by the larger effects of sedimentation (Lovell, E. *pers. comm.*). Also because there are natural levels of tannins (from mangroves, which are located in the apex of Fagaloa Bay; and other marine plants, such as macro-algae) in the marine environment, determining impacts from terrestrial run-off is also difficult due to these natural levels (Januchowski, S. *pers. comm.*).



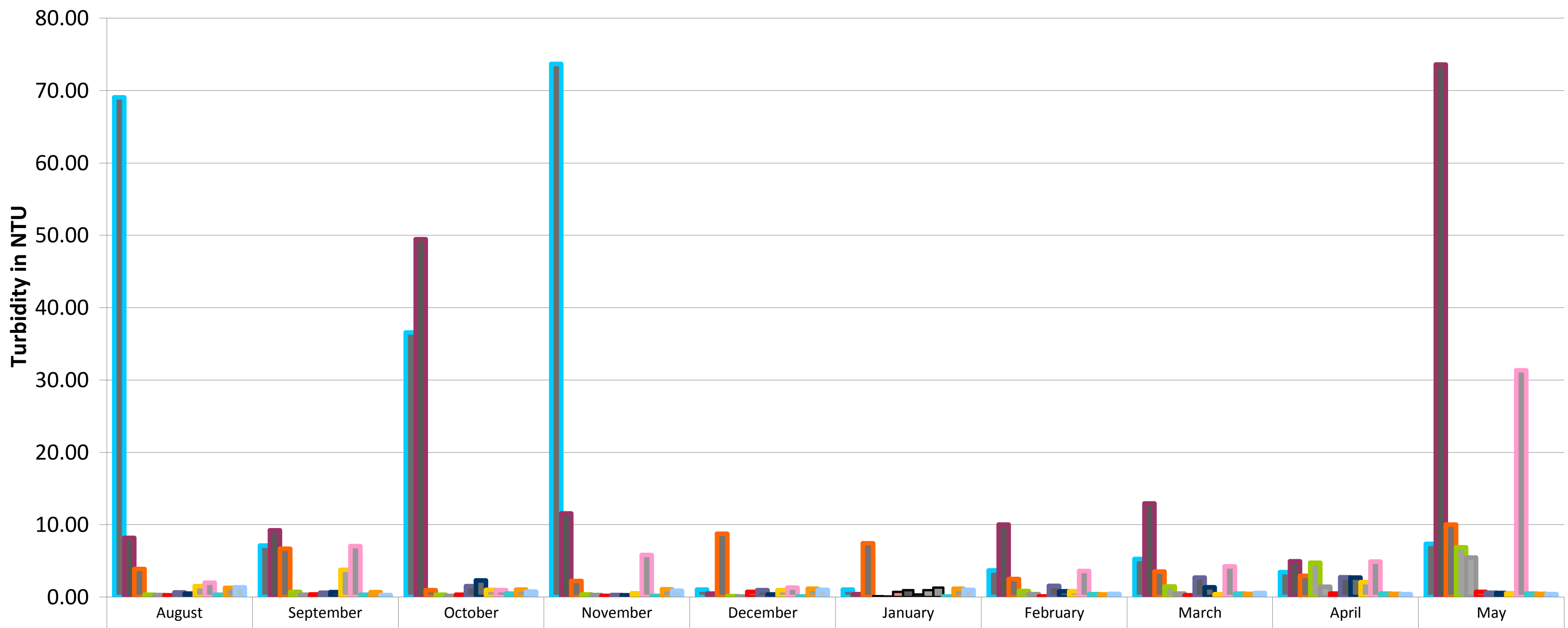
	August	November	December	January	February	March	April	May
Site 1	5.36	5.43	4.79	11.57	7.22	14.89	6.95	6.99
Site 2	6.67	11.26	5.13	13.93	12.82	11.98	5.34	9.21
Site 3	30.15	19.17	23.33	16.67	21.70	30.50	29.65	22.00
Site 4	31.25	21.37	22.90	21.60	21.77	30.50	29.65	22.00
Site 5	30.85	21.57	24.10	22.60	22.30	31.30	31.35	22.70
Site 14	23.70	8.30	11.00	17.27	7.89	20.17	7.60	8.95
Site 13	30.55	19.93	23.00	20.23	21.27	31.55	29.30	29.20
Site 12	31.20	20.80	24.30	22.00	18.43	30.85	30.65	31.00
Site 11	31.55	20.77	23.53	22.37	22.10	32.90	33.20	32.60
Site 9	31.30	21.67	24.73	23.17	10.37	34.30	33.05	28.70
Uafato 1	30.25	21.70	23.43	42.80	10.53	31.70	27.00	67.95
Uafato 2	29.45	21.37	22.53	22.17	7.57	29.30	25.25	63.65
Uafato 3	31.40	21.13	22.50	21.63	10.60	31.45	27.50	65.50

Figure 14: Changes in salinity values for Fagaloa and Uafato Bays: August 2009-May 2010



	August	September	October	November	December	January	February	March	April	May
Site 1	31.50	0.86	330.50	304.50	34.50	35.50	43.50	37.00	62.50	33.50
Site 2	50.50	9.94	360.50	263.00	46.00	49.00	109.50	51.00	43.50	65.50
Site 3	15.50	10.15	131.00	81.50	83.00	110.00	165.50	82.00	80.50	100.50
Site 4	7.00	10.96	104.50	78.00	100.05	85.50	100.50	82.00	82.00	93.00
Site 5	10.00	0.00	104.00	72.50	108.00	92.00	101.00	92.50	82.00	81.50
Site 14	11.50	0.54	197.50	91.00	89.50	122.00	183.00	90.50	75.50	140.00
Site 13	17.00	0.56	102.50	85.50	128.00	118.50	95.50	101.50	84.50	82.50
Site 12	20.50	0.00	112.50	94.00	95.00	96.00	88.50	97.00	85.50	82.50
Site 11	10.00	0.62	102.50	88.00	100.50	97.00	89.50	61.00	55.50	84.00
Site 9	7.50	1.79	103.00	93.00	106.50	115.00	99.00	41.00	45.00	86.00
Uafato 1	18.00	6.00	11.33	46.00	69.33	0.00	54.67	123.00	77.00	84.00
Uafato 2	13.50	7.67	5.60	61.67	72.33	0.00	44.33	105.50	97.50	72.50
Uafato 3	15.50	6.00	11.53	61.67	69.67	0.00	60.00	87.00	81.00	80.00

Figure 15::Changes in total suspended sediment levels in Fagaloa and Uafato Bays: August 2009-May 2010



	August	September	October	November	December	January	February	March	April	May
Site 1	69.05	7.13	36.57	73.67	1.01	1.01	3.68	5.24	3.44	7.37
Site 2	8.20	9.23	49.47	11.57	0.46	0.38	10.00	12.94	4.93	73.60
Site 3	3.89	6.69	0.94	2.23	8.73	7.43	2.51	3.51	2.94	10.00
Site 4	0.30	0.70	0.31	0.37	0.13	0.12	0.83	1.45	4.73	6.88
Site 5	0.30	0.32	0.16	0.30	0.09	0.09	0.39	0.48	1.43	5.47
Site 9	0.25	0.35	0.31	0.16	0.73	0.73	0.10	0.25	0.49	0.72
Site 11	0.62	0.59	1.52	0.30	0.97	0.97	1.56	2.70	2.73	0.59
Site 12	0.48	0.66	2.31	0.23	0.34	0.34	0.81	1.36	2.68	0.54
Site 13	1.52	3.74	1.00	0.52	0.94	0.94	0.79	0.41	2.04	0.52
Site 14	1.97	7.03	0.94	5.81	1.31	1.31	3.59	4.22	4.93	31.35
Uafato 1	0.31	0.32	0.47	0.15	0.09	0.09	0.39	0.46	0.49	0.49
Uafato 2	1.25	0.69	1.05	1.06	1.16	1.16	0.36	0.45	0.44	0.43
Uafato 3	1.35	0.29	0.76	0.88	0.97	0.97	0.44	0.56	0.39	0.39

Figure 16: Changes in the turbidity in Fagaloa and Uafato Bays: August 2009-May 2010

4.5.2 Nutrient loading

Nutrient increases impact on coral reefs by inhibiting fertilisation rates and embryo formation (particularly in *Acropora* spp.). This in turn reduces species size and diversity, which can result in a successional process from hard coral dominated coral reefs to a macro-algal or soft coral dominated state (Connell *et al*, 1997; Edinger *et al*, 1998; Szmant, 2002; van Woesik *et al*, 1999; Ward and Harrison, 1997Fabricius and De'ath, 1997; McCook and Price, 1997; Schaffelke and Klumpp, 1998 a,b; Lapointe *et al*, 2004).

Lapointe (1997) has proposed nutrient thresholds of 0.1 mg/l for nitrates and 0.01 mg/l for phospahtes for marine waters that, when exceeded, might indicate or portend nutrient-related reef degradation. Figure 17 shows that for nitrates these levels are exceeded at all sites. Figure 18 details that whilst levels were exceeded for Lapointe's (1997) threshold values, they were mostly complient with American Samoa's Environmental Protection Agency water quality standards's value (Table 17), except for the wet season months of November to February.

Table 17: Water quality standards adopted by the American Samoa Environmental Protection Agency

Parameter	Embayments	Open coastal waters
Total Nitrogen (mg/l)	not > 0.20	not > 0.13
Total Phosphorus (mg/l)	not > 0.030	not > 0.015

Source: DiDonato *et al,* 2009; Vaouli *et al,* 2010.

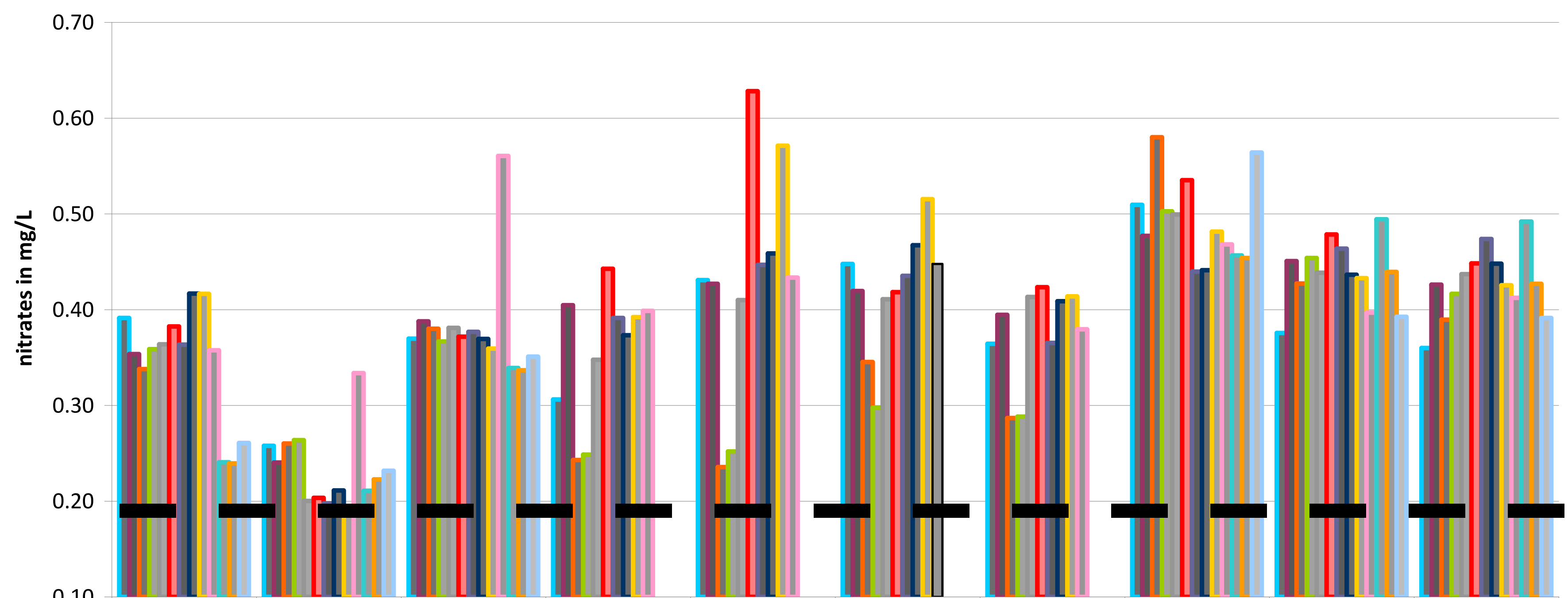
Bay water iron content was highest in December 2009 and January 2010, possibly due to high levels of rainfall. Iron is often limiting to marine organisms, with phytoplankton and cyano-bacteria able to take up soluble iron directly from the water column (Anderson and Morel, 1982). Iron is an important trace metal for algal and specifically cyanobacteria (Albert *et al,* 2005).

Tannins are also able to bind bio-available iron in a dissolved form, which can then be transported out into marine waters, however, the levels of bio-available iron in seawater fluctuates depending on the presence of organic carbon, which is often produced by anthropogenic manipulation of coastal forests which alters both organic carbon and iron balances, and thus in turn, impacting on the ecological integrity of marine systems (Albert *et al*, 2005). Preliminary evidence from American Samoa also demonstrate that nitrate concentrations in stream water goes up as intact forests are converted to agriculture or urban land use (DiDonate *et al,* 2009).

Lastly, there were some ammonia concentrations in sites 1, 2 and 14, in August 2009 with particularly high levels in September 2009 (Figure 20). These months are prior to the onset of the wet season, and thus the results for these sites, maybe be the result of lower dilution rates, particularly as pigs are regularly observed foraging in this areas.

Suluvale (1997) notes that the perennial streams of Fagaloa Bay have more phosphorous and nitrogen then the rest of Upolu's streams, and this could be due to natural weathering of the volcanic rocks in the area (see DiDonato *et al,* 2009 for studies in American Samoa).

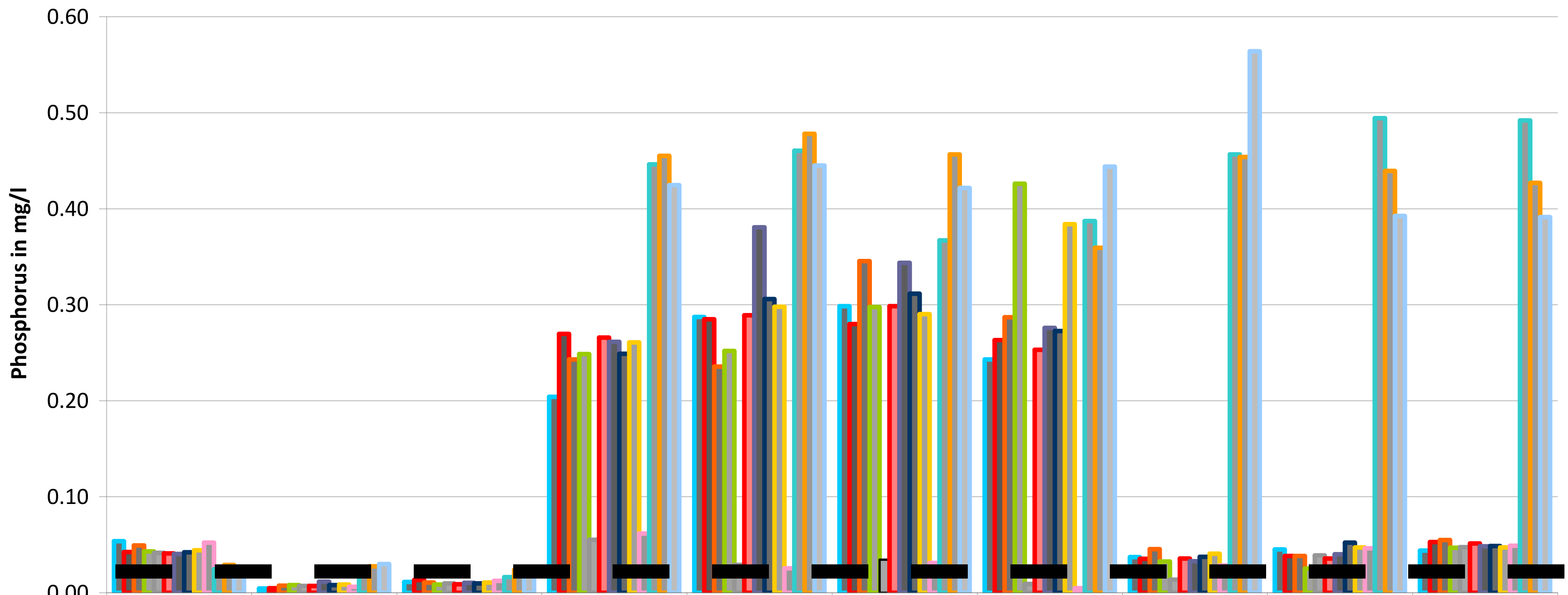
The most likely inputs of nutrients into Fagaloa Bay is through specific anthropogenic activities, such as the location of toilets near waterways; allowing pigs, cattle and chickens to roam the villages and watershed and have free access to waterways; and the application of phosphate-based fertilsers is contributing to nutrient loads that enter the marine waters of Fagaloa Bay. SMEC (2009) has also suggested similar issues.



	August	September	October	November	December	January	February	March	April	May
Site 1	0.39	0.26	0.37	0.31	0.43	0.45	0.36	0.51	0.38	0.36
Site 2	0.35	0.24	0.39	0.40	0.43	0.42	0.39	0.48	0.45	0.43
Site 3	0.34	0.26	0.38	0.24	0.24	0.35	0.29	0.58	0.43	0.39
Site 4	0.36	0.26	0.37	0.25	0.25	0.30	0.29	0.50	0.45	0.42
Site 5	0.36	0.20	0.38	0.35	0.41	0.41	0.41	0.50	0.44	0.44
Site 14	0.38	0.20	0.37	0.44	0.63	0.42	0.42	0.54	0.48	0.45
Site 13	0.36	0.20	0.38	0.39	0.45	0.44	0.37	0.44	0.46	0.47
Site 12	0.42	0.21	0.37	0.37	0.46	0.47	0.41	0.44	0.44	0.45
Site 11	0.42	0.19	0.36	0.39	0.57	0.52	0.41	0.48	0.43	0.43
Site 9	0.36	0.33	0.56	0.40	0.43	0.45	0.38	0.47	0.40	0.41
Uafato 1	0.24	0.21	0.34					0.46	0.49	0.49
Uafato 2	0.24	0.22	0.34					0.45	0.44	0.43
Uafato 3	0.26	0.23	0.35					0.56	0.39	0.39

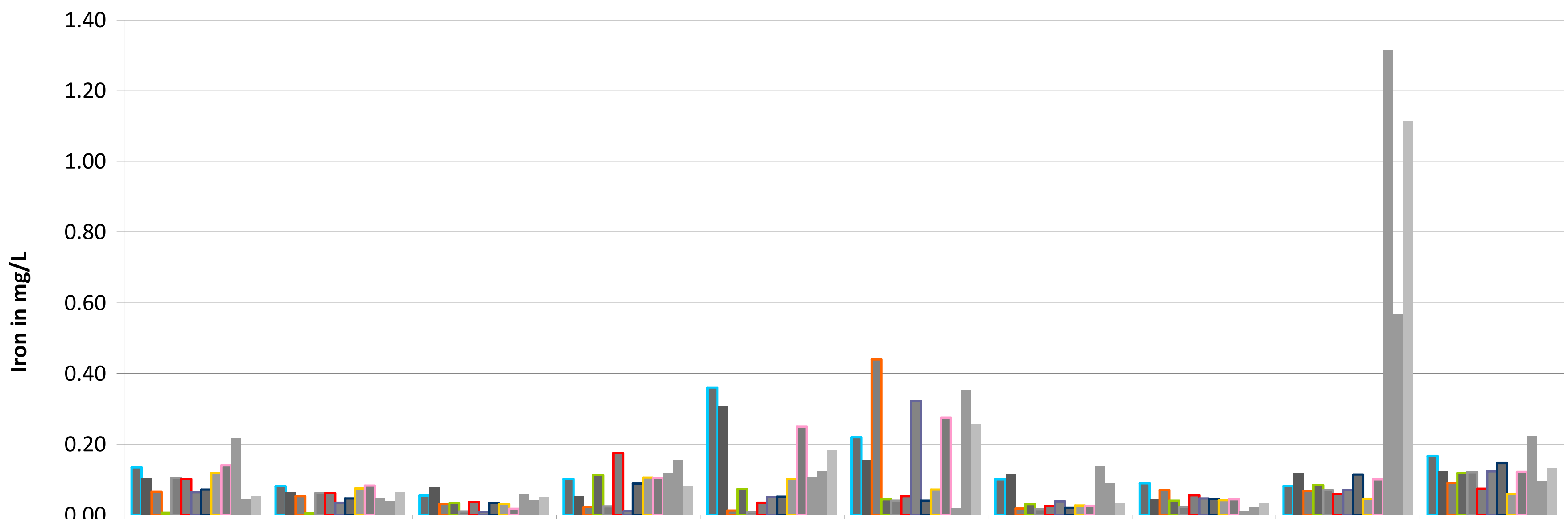
Figure 17: Changes in nitrate concentrations in Fagaloa and Uafato Bays: August 2009-May 2010

Note: Dashed-line represents the upper limit for nitrogen concentrations under American Samoa's Environmental Protection Agency's water quality regulations



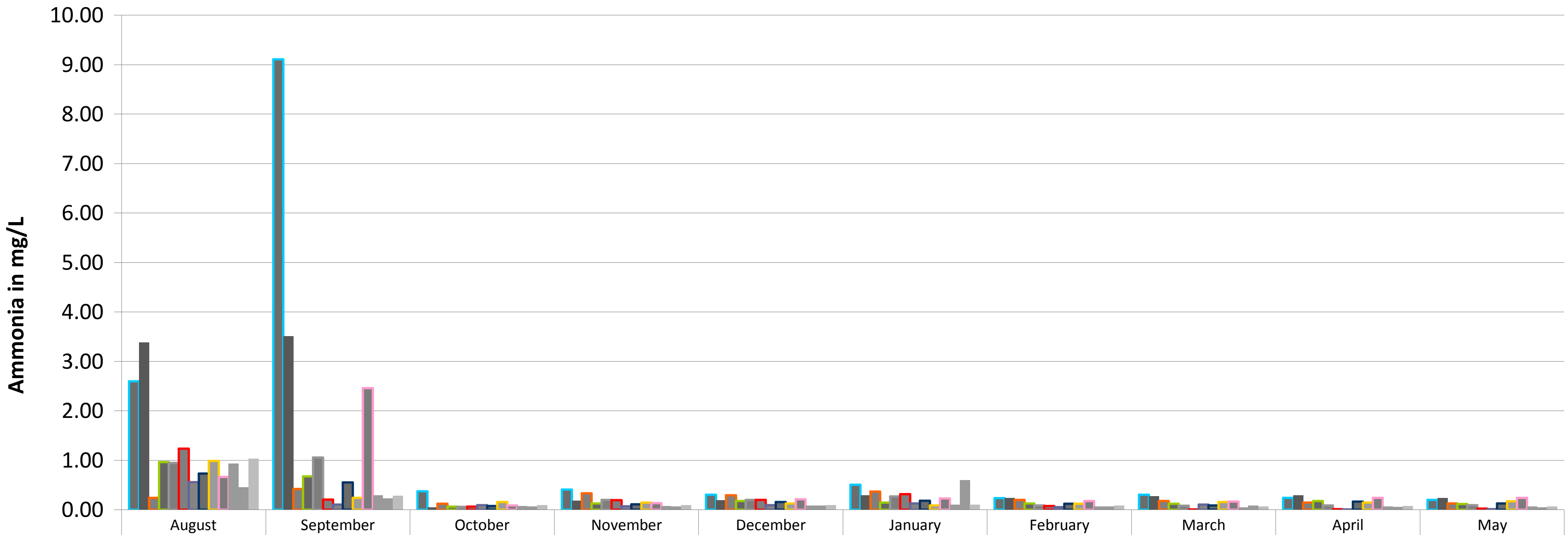
	August	September	October	November	December	January	February	March	April	May
Site 1	0.05	0.00	0.01	0.20	0.29	0.30	0.24	0.04	0.05	0.04
Site 2	0.04	0.00	0.01	0.27	0.28	0.28	0.26	0.04	0.04	0.05
Site 3	0.05	0.01	0.01	0.24	0.24	0.35	0.29	0.05	0.04	0.05
Site 4	0.04	0.01	0.01	0.25	0.25	0.30	0.43	0.03	0.03	0.05
Site 5	0.04	0.01	0.01	0.06	0.03	0.03	0.01	0.01	0.04	0.05
Site 9	0.04	0.01	0.01	0.27	0.29	0.30	0.25	0.04	0.04	0.05
Site 11	0.04	0.01	0.01	0.26	0.38	0.34	0.28	0.03	0.04	0.05
Site 12	0.04	0.01	0.01	0.25	0.31	0.31	0.27	0.04	0.05	0.05
Site 13	0.04	0.01	0.01	0.26	0.30	0.29	0.38	0.04	0.05	0.05
Site 14	0.05	0.01	0.01	0.06	0.03	0.03	0.00	0.03	0.05	0.05
Uafato 1	0.02	0.02	0.02	0.45	0.46	0.37	0.39	0.46	0.49	0.49
Uafato 2	0.03	0.03	0.02	0.46	0.48	0.46	0.36	0.45	0.44	0.43
Uafato 3	0.03	0.03	0.02	0.42	0.45	0.42	0.44	0.56	0.39	0.39

Figure 18: Changes in phosphorus concentrations in Fagaloa and Uafato Bays: August 2009-May 2010
Note: Dashed-line represents the upper limit for nitrogen concentrations under American Samoa's Environmental Protection Agency's water quality regulations



	August	September	October	November	December	January	February	March	April	May
Site 1	0.13	0.08	0.05	0.10	0.36	0.22	0.10	0.09	0.08	0.17
Site 2	0.11	0.06	0.08	0.05	0.31	0.16	0.11	0.04	0.12	0.12
Site 3	0.06	0.05	0.03	0.02	0.01	0.44	0.02	0.07	0.07	0.09
Site 4	0.01	0.00	0.03	0.11	0.07	0.04	0.03	0.04	0.08	0.12
Site 5	0.10	0.06	0.01	0.02	0.01	0.04	0.02	0.02	0.07	0.12
Site 9	0.10	0.06	0.04	0.17	0.03	0.05	0.02	0.05	0.06	0.07
Site 11	0.06	0.03	0.01	0.01	0.05	0.32	0.04	0.05	0.07	0.12
Site 12	0.07	0.05	0.03	0.09	0.05	0.04	0.02	0.04	0.11	0.15
Site 13	0.12	0.07	0.03	0.11	0.10	0.07	0.03	0.04	0.05	0.06
Site 14	0.14	0.08	0.02	0.10	0.25	0.27	0.02	0.04	0.10	0.12
Uafato 1	0.22	0.05	0.06	0.12	0.11	0.02	0.14	0.01	1.32	0.22
Uafato 2	0.04	0.04	0.04	0.16	0.13	0.35	0.09	0.02	0.57	0.10

Figure 19: Changes in iron concentrations in Fagaloa and Uafato Bays: August 2009-May 2010



	August	September	October	November	December	January	February	March	April	May
Site 1	2.60	9.11	0.37	0.41	0.30	0.51	0.23	0.30	0.24	0.20
Site 2	3.39	3.52	0.05	0.19	0.19	0.29	0.24	0.28	0.30	0.24
Site 3	0.24	0.42	0.12	0.33	0.29	0.37	0.20	0.18	0.15	0.13
Site 4	0.96	0.68	0.07	0.13	0.18	0.15	0.13	0.12	0.18	0.12
Site 5	0.95	1.06	0.06	0.20	0.20	0.27	0.09	0.08	0.09	0.10
Site 9	1.24	0.21	0.06	0.19	0.20	0.32	0.08	0.01	0.01	0.02
Site 11	0.56	0.10	0.09	0.07	0.10	0.13	0.05	0.10	0.01	0.01
Site 12	0.73	0.55	0.07	0.11	0.16	0.18	0.12	0.09	0.16	0.13
Site 13	0.99	0.24	0.16	0.15	0.13	0.09	0.12	0.16	0.15	0.17
Site 14	0.66	2.46	0.09	0.14	0.21	0.23	0.18	0.17	0.24	0.24
Uafato 1	0.94	0.30	0.07	0.07	0.09	0.11	0.07	0.05	0.07	0.06
Uafato 2	0.45	0.23	0.06	0.06	0.08	0.61	0.07	0.08	0.06	0.05

Figure 20: Changes in ammonia concentrations in Fagaloa: August 2009-May 2010

4.6 Marine organism sampling and assessment

The marine organism sampling program experienced significant difficulty in finding enough samples to test every month. Tuaopepe (2005) noted that venus shell (*Galfrarium* spp.) were now considered rare in Fagaloa Bay, including other species, such as giant clams (*Tridacna* spp.), turbo shells (*Turbo chrysostomus*), and false trochus (*Tectus pyramis*); as does Onorio and Tamata (1997) who also reported a noticable decline in several molluscs species (*Turbo chrysostomus, Garafuna* sp., *Pinna* sp., *Spondylus* sp., *Tectus pyramis, Galfrarium* sp.) in Fagaloa Bay.

However, despite these difficulties, venus shells were collected in July, September and November 2009. Results of their testing did not show any significant levels of iron, magnesium, or lead that were of concern, with results for lead and magnesium ranging from > 0.0004mg/l to 0.01mg/l which is far below the 0.7-0.9mg/L at which marine organisms are affected.

Suluvale's (1997) also reported similar results in 1995 for organisms tested in Fagaloa Bay. Similar studies in American Samoa, have also shown that the levels of contamination in herbivorous fish tissues collected indicated that bio-accumulation of toxins was minimal (Pushat and Brown, 2005; Fenner *et al*, 2008).

5. Discussion

The data from the 2009-1010 marine monitoring program implies that several sites in Fagaloa Bay are exhibiting signs of impacts from inputs into the marine environment, which are most notable at sites 1, 2, and 14. These sites are closest to the apex of Fagaloa Bay where the Ta'elefaga Creek discharges into. Impacts for these sites include low or no coral cover and recruitment, growth in algal cover, lower salinity levels, higher rates of sedimentation and turbidity, as well as high nutrient inputs. Fish biomass at site 14 was also the lowest (sites 1 and 2 were not surveyed due to poor visibility).

Impacts of tropical cyclones *Heta* in 2004 and Olaf in 2005, are also thought to have contributed to the lower levels of coral cover. Bleaching events, which were reported in American Samoa in 2002, 2003 and 2005, may also have had some impacts; as Lovell and Toloa (2002) noted several bleached corals during their survey in 2002.

In determining if rainfall and associated terrestrial run-off was having an impact on water quality in Fagaloa Bay, analysis showed that there was no significant correlation for salinity, sedimentation, turbidity and nitrogen between the two days (48hr) rainfall prior to sampling and the marine water quality parameter measured (i.e. acute runoff effect) across all sites (Table 18); suggesting that there are other chronic and systemic factors contributing to the degraded coral reefs observed in Fagaloa Bay. Similarly, in American Samoa, even though some temporal variations were established with higher sedimentation rates occurring between January and June (encompassing part of the wet season), there was no correlation with rainfall prior to testing (Fenner *et al*, 2008).

There was however, a significant correlation between phosphorous and rainfall in the previous 48 hrs before sampling for all sites (excluding 1, 5 and 13) over the water monitoring program period (Table 18). This phosphorous is soluble and is most likely sourced from fertiliser or sewage/animal effluent and not from volcanic weathering. There was also a significant correlation between iron concentration and rainfall in the last 48hrs, but only for site 2 (Table 18).

Table 18: Correlation coefficients of total rainfall within the previous 48 hrs and measured marine water quality parameters: August 2009-May 2010

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 14	Site 13	Site 12	Site 11	Site 9
Salinity	0.21	0.36	-0.58	-0.32	-0.31	0.19	-0.40	-0.28	-0.30	-0.14
TSS	0.15	0.14	0.29	0.17	0.18	0.29	0.28	0.28	0.33	0.42
Nitrate	0.19	0.16	0.05	-0.07	0.13	0.08	0.23	0.30	0.21	0.28
Ortho P	0.34	0.98	0.97	0.95	0.04	0.95	-0.10	0.97	0.99	0.99
Iron	0.03	0.93	0.11	-0.07	0.13	0.10	0.60	0.19	0.04	-0.15

In Fagaloa Bay, road construction, village expansion, agricultural development, and clearing within the watersheds for new garden land; would all contribute to increased sedimentation loads in the creeks and streams which eventually discharge into Fagaloa Bay. Seawalls along roadside and shore reclamations at Ta'elefaga and Lona may also influence circulation patterns. Poorly constructed human and pig waste disposal systems as well as increased turbidity and nutrients from erosion, also contributes to poor water quality in Fagaloa Bay. Overall, results suggest that land-based sources of inputs are having an impact on the water quality of Fagaloa Bay. Over-fishing could also be contributing to the decline of coral reef and other marine resources in Fagaloa Bay, as fish bio-mass was also low overall.

5.1 Recommendations

The possibility of using a submarine outfall and diffuser system for disposing the freshwater passing through the Ta'elefaga Hydro-power Station to the marine environment should be investigated. The most important factor in considering the environmental impacts of this type of disposal system is the very location of the outfall, this is important for stratification, but also understanding currents, coastal circulation and hydro-dynamics. Unfortunately, SPREP does not have the technical expertise to assess this, it is recommended that an appropriate technical engineer be hired to investigate this further.

Further education and outreach would also be pertinent. This would need to cover a range of activities, including:

- the results of the studies conducted by SMEC and SPREP;
- better land use practices, including alternative agricultural practices involving contour plantings, terracing and other erosion control measures;
- improving sewage disposal, as well as pig waste management;
- fisheries and marine resource management (and possible rehabilitation); and
- watershed management.

Some form of management committee could also be devised, that would focus on a holistic 'whole of Fagaloa Bay' approach to management, because at present, it would appear that more could be done to address environmental issues by local villagers.

Further work will also be required to fully understand the dynamics of the marine environment in Fagaloa Bay, and the possible links with environmental issues posed by the Ta'elefaga Hydro-power Scheme, particularly as the current marine monitoring program only provides an environmental 'snapshot' in time for Fagaloa and Uafato Bays, though one that can be used as a baseline for future studies.

Subsequently, a continuation of the marine monitoring program is also recommended.

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Appendix A: Letter of contractual arrangements

SMEC

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Friday 5 June 2009

Kosi Latu
Acting Director
Secretariat of the Pacific Regional Environment Programme (SPREP)
PO Box 240
Apia, Samoa

Dear Mr Latu,

Re: Sub Consultancy Agreement between SMEC International and SPREP – Assignment of Tasks to SROS, MAFF and MNRE

SMEC International confirms that SPREP can sub-consult or assign work under the above agreement only to the nominated parties shown in Schedule 6 of the agreement, namely:

- Samoa Ministry of Natural Resources and Environment (MNRE)
- Samoa Ministry of Fisheries, Agriculture and Forestry (MAFF)
- Scientific Research Organisation of Samoa (SROS)

All parties within the SPREP team should be aware and adhere to the conditions in the SMEC-SPREP sub-consultancy agreement, including those relevant clauses from the Head Contract between SMEC and the Asian Development Bank.

We look forward to working with SPREP and its partners on this portion of the Afulilo Environmental Enhancement Project.

Yours sincerely,

Peter Young
Regional Manager – Pacific
SMEC International Pty Ltd

Appendix B: Reconnaissance Report – 15th September 2009

Personnel: Jeff Kinch (SPREP), Caroline Vieux (SPREP) and Juney Ward (MNRE)

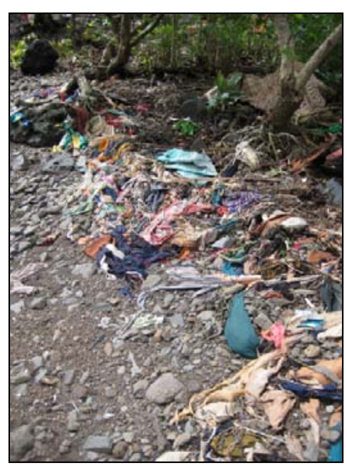
Weather conditions: 20 mph winds, scattered showers and squalls, sea 3-4 feet

On the morning of Tuesday, 15th September, we visited Fagaloa and Uafato Bays to determine the feasibility of conducting surveys for the outstanding coral monitoring sites, 1 and 2 in Fagaloa Bay and 1, 2 and Uafato Bay, and to ascertain other factors that maybe pertinent to the monitoring program given the current poor weather conditions.

The outstanding coral monitoring sites were not surveyed during the first visit in July because of bad weather. Uafato Bay, was however monitored by Samoa Fisheries Division for fish counts and coral substrates.

There are no vessels in Fagaloa Bay, so after inspection of the foreshore, it was decided that it could be possible for a team to wade out on the reef flat and enter the location from this point of enter to survey sites 1 and 2.

With regards to the foreshore, the only significant sign of rubbish is on the east side of the Ta'elafaga Creek entrance to Fagaloa Bay. These clothes, its is assumed, have been washed down from the Ta'elefaga Creek above the tail race of the Ta'elafaga Hydro-electric Station, where local village women are known to do laundry.



Following recent discussions between SPREP and SMEC on 'plumes' observed fanning out from the mount of the Ta'elefaga Creek on occasion, and the possibility that these maybe algae blooms, an inspection of this area was conducted. While the water was discoloured brown (the colour of tea), this was only really visible in the main channel of the Ta'elefaga Creek.

A visit to the mangrove estuary area was also conducted, a little bit of green filamentous algae was observed on the east side of the estuary area adjacent to the causeway which splits the estuary from Fagaloa Bay.

The only other area of green filamentous algae was in a 6 m diameter patch in the middle of the Ta'elefaga Creek entrance where it broadened out on to the flat of Fagaloa Bay. There were no signs of eutrophication, or any algae blooms.

A search for mollusks on the flat areas adjacent to the Ta'elefaga Creek entrance, showed only the dead remaining shells of oysters (though many small barnacles were observed attached to rocks), with one or tow dead shells of sand cockles.

A small parcel of kitchen waste was observed to have been dumped in this area, though this is not expected to be of any high volume, because only a few residents reside in the area of the Ta'elefaga Creek entrance.

A local village fisher was seen using a cast-net close to site 2, and a family was seen gleaning the reef flats near site 11.

Several groups of pigs were observed foraging and digging into the loose aggregate on both sides of the flat area around Ta'elefaga Creek. While this may cause increased sediment and some fouling of the marine waters, it is thought that this would not be enough to cause wide-spread degradation of neighbouring reefs or cause algae blooms. Foraging by pigs may also contribute to the decline in mollusk numbers.

Cattle were also observed on the shoreline near site 11.

A significant amount of rubble was observed on the reef flats near site 9, which is assumed to be a result of Cyclone Heta in 2004.

The road to Uafato Bay is in pretty reasonable condition at present. A local villager who owns a small dinghy was approached to provide support in the surveying of the three outstanding sites for Uafato Bay.

The weather is still not good with strong winds and rain period anticipated, though the ocean swell has dropped a little.

So all going well, the remaining outstanding sites will be surveyed by a team consisting of Caroline, Juney, Paul Anderson (SPREP's Marine Conservation Analyst) and another MNRE staff member who is from Uafato Village tomorrow, Wednesday, 16th September.

Appendix C: Survey report – 16th September 2009

Team: Caroline Vieux, Paul Anderson (SPREP) and Juney Ward (MNRE)

Weather Conditions: 19 knots easterly winds, rain periods, sea 3-4 feet

The purpose of the survey was to collect coral cover and coral recruitment data for the remaining sites of Fagaloa Bay and Uafato that had not been surveyed, due to bad weather conditions, in July.

Despite the persistent unfavourable weather conditions, wind and frequent rain showers, an attempt was made to surveys these sites.

Figure 1: View of Fagaloa Bay, 16th Sep.

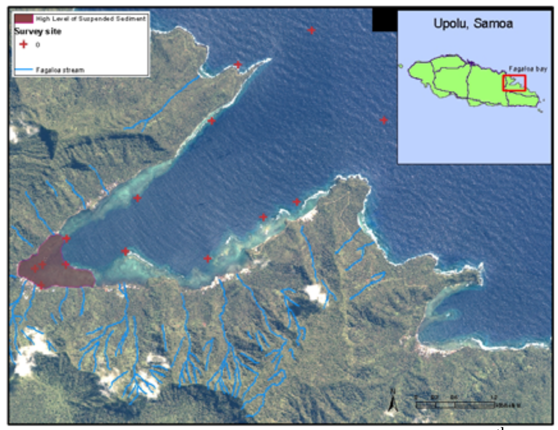


Figure 2: Sediment plume at Fagaloa Bay, 16th Sep.

Fagaloa Bay

Juney and myself swam over site 1 located in the channel, while Paul was operating the GPS to guide us to the exact location. Unfortunately the visibility was nil and despite being at the right location, no wall could be observed as shown in Ed Lovell's report. Despite poor visibility, no corals were observed either.

Two interpretations can be drawn from this:

- the channel has been filling up with the continuous sediment inputs and the wall has been diminishing, resulting in corals being smothered, or
- Lovell has recorded one location for site 1 but may have swum further out to record his data[1].

The plume was extending beyond site 2 (Figure 2) and subsequently impacted on the possibility of data collection.

[1] Lovell's pictures shows that the visibility was good enough to have pictures taken, which on the two attempts we have tried as not been the case. Ed has now been contacted to determine what month he did his survey.

Figure 3: Site 2 above water, 16th Sep.

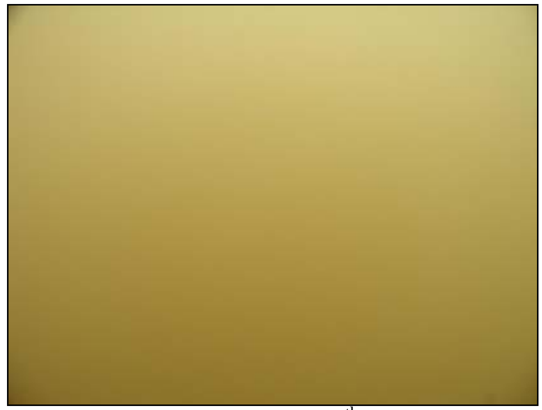


Figure 4: Site 2 underwater, 16th Sep.

Uafato Bay

At Uafato Bay, the wind was also blowing onshore, accompanied by a swell of 3 to 4 feet. The water was not brown as in Ta'elefaga but the visibility was very low due to the persistent rain that has been occurring in recent months season, resulting in some sediment loading and mixing of freshwater and sea water. Due to visibility problems, it was not possible to take suitable photographs for analysis.

The boat driver said that it requires several days without rain to clear the water.

Corals that were observed were well developed with many live tabular corals within the first three meters of depth. These corals used to be very abundant in most sites of Fagaloa Bay (as per Lovell's report) but have assumed to have been destroyed by cyclone Heta in 2004 and have not returned.

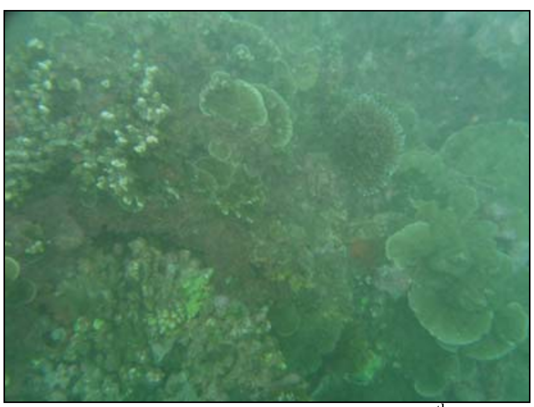


Figure 5: Outer slope at Uafato, Sept 16th.

Figure 6: Uafato Bay, Sept 16th.

Conclusion

In order to get a full set of data for future surveys, we will need to plan the surveys according to the weather conditions. This will involve setting a two-week window, which will involve reconnaissance visits to determine when weather conditions are optimal. For Uafato Bay, we now have a local contact, in the way of a boat operator (who assisted in this survey) and he will also inform when conditions are good for surveying.

Appendix D: Community consultation report

Marine Environment Monitoring Program for Fagaloa Bay, Samoa:
Assessing the Impacts of the Ta'elefaga Hydropower Plant

Report on Community-Consultations
7th – 15th July 2009

To be undertaken for SMEC International Pty.Ltd

as part of the

ADB TA 7212-SAM The Afulilo Environmental Improvement Project

Coordinated by;

Ulusapeti Tiitii
Senior Fisheries Officer,
Fisheries Division,
Ministry of Agriculture & Fisheries
Apia, SAMOA.

Introduction
This report will be based on a series of workshops carried out with the village communities of Fagaloa and Uafato Bays from the 7th – 15th July, 2009 to introduce the monitoring program to the communities. This monitoring program is to assess the status of the marine environment particularly the substrate cover (corals), water quality in and around the Fagaloa and Uafato Bays to determine freshwater discharge from the Ta'elefaga Hydropower plant and also any adverse effects on Fagaloa Bay marine environment. These monitoring and community consultations may also provide not only qualitative but quantitative information on any potential impacts both from the outflow or any other sources not related to the Ta'elefaga Hydropower which assist the government decision makers whether to increase the capacity of the Afulilo Reservoir or not.

This report is based on the communities' consultations carried out to inform villages on the monitoring program to assess their marine environment. The initial plan was for the Ministry of Natural Resources and Environment to coordinate this work, with the assistance from Fisheries Division, SROS and EPC. However, MNRE was unfortunately not participating in the whole process and then Fisheries Division was asked to carry out all these consultations on its own. The villages included, Salimu, Musumusu, Lona, Maasina, Taelefaga, Sauano, Samamea and Uafato.

Village communities consultations
Communities were arranged to meet at the village mayor's house or a village meeting house where all the matais came together to hear the purpose of our visit. All the villages prepared a kava ceremony as a good sign of appreciation and welcoming us to work collaboratively with them. Following that was the explanation on the purpose of visit and the monitoring program that would be carried out by the staff from Fisheries Division and the SPREP. The participation and involvement of the communities was so active and that made it easy to introduce the monitoring assessment activity. The number is always more than fifteen matais sitting in the discussion house with others just listening.

During our discussions, the matais raised concerns of increasing the capacity of the Afulilo Reservoir. They mentioned huge impacts of the outflow they noticed at their marine environment such as;

- Decreased number of fish
- Decreased number of shellfish
- Loss of marine habitats (corals)
- Disappearing of fish and shellfish that was seen in their marine environment
- Murky color of the sea water from time to time, especially when it heavy rains;
- Increased hours of fishing for fishers;

And in two villages, Lona and Ma'asina, the village people discussed the increased number of top shell, *Tectus niloticus* on their reefs. It was a new experience for them; however, we had tried our best to differentiate between the local species of trochus and the introduced species. However, they had made it clear that the species they meant is the introduced one. This was one benefit for our Division, knowing that the trochus species established well at the Fagaloa District Reefs. It is known that the species were introduced at the Aleipata reefs (Namu'a, Nuutele Islands), and their establishment on Fagaloa Reefs may be due to currents transportation. This also give us an insight of carrying out a trochus search on the Fagaloa area reefs sometimes this year.

Overall, villages are pleased to hear that there would be an assessment of their marine environment from this communities' consultation before the Afulilo development took place. Thus opportunity would raise their concerns of what they faced in their daily life and most importantly their future generations. With what they experienced in the past and today, they would not appreciate the idea of extending the Afulilo Reservoir and dumping the freshwater straight to the marine area. However, there were other possible solutions suggested such as, cycling the freshwater where it can be re-used by the reservoir to avoid the spread of mosquitoes around the area. It was reported by the members during the Ta'elefaga meeting that mosquitoes in their areas was one of the huge problems. Therefore, as discussed a report of the assessment will be delivered to them after the compilation and all their concerns included.

Lastly, all villages appreciated the effort of letting them aware of the program and all the activities involved to avoid confusion if new people seen in their lands. They also acknowledged the monetary gifts given after the kava welcoming ceremony, and lunch. The village mayors also added words of thanks as they were aware the hardship of putting together this work amongst Ministries, Organisations and other stakeholders.

To sum up all the discussions and ideas raised during the consultations all villages did not agree with the extension project unless there's an alternative to recycle the water rather than straight release into the marine environment. Those were the concerns we have to take into considerations before the development go ahead.

Appendix E: Marine water quality analysis methods

Parameters	**Method**
BOD5	APHA 5210:5-2
Phosphorus	AOAC 973.55
Dissolved Oxygen	APHA 4500-O A
Ammonia	APHA 4500- NH3
Nitrate	APHA 4500- NO3-
Turbidity	APHA 2130- B
Salinity	APHA 2520 B
Acidity	APHA -H+
Sulphur dioxide	APHA 4500-S^{2-}
Magnesium	AOAC 968.08 (SOP: C01.05)
T-Fe	AOAC 968.08 (SOP: C01.05)
T-Pb	AOAC 968.08 (SOP: C01.05)
T-Hg	APHA 3112 B

Source: SROS.
Notes:
APHA: American Public Health Association
AOAC: Association of Official Agricultural Chemists

Appendix F: Correspondence regarding Contract variations

SPREP
Secretariat of the
Pacific Regional
Environment Programme

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F: +685 20231
W: www.sprep

File: **AP 5/3/16**

7th December 2009

Taito Ulaitino Dr. Faale Tumaalii
Chief Executive Officer
Scientific Research Organisation of Samoa
PO Box 6597
APIA

Dear Taito

Following recent discussions between SPREP, SMEC and SROS with regards to revised changes to the water quality samplings for Fagaloa Bay under the '*Marine Environment Monitoring Program for Fagaloa Bay, Samoa: Assessing the Impacts of the Tae'elafaga Hydropower Plant*' project; please note the following:

1. The marine water quality sites (6,7,8 and 10) will be replaced with four freshwater water quality sampling sites as determined by SMEC;

2. These four new freshwater sites (replacing the four marine sites) will be collected by SMEC during their normal freshwater water quality sampling and tested by SROS as per the existing freshwater parameters developed for the project; and

3. Costs of testing of these freshwater water quality samples will remain under the SPREP marine water quality sampling program, and SMEC will continue to invoice SPREP as has been the usual procedure.

I thank SROS for their continued support of this project.

Yours sincerely

Kosi Latu
Acting Director

PACIFIC YEAR OF
CLIMATE CHANGE
2009

Afulilo Hydropower Improvement and Environmental Enhancement Project
ADB TA 7121-SAM

Project Office, Suite 206
John Williams Bldg.
APIA, Samoa
Tel:+685-20805

Feb. 22, 2010

Jeff Kinch, Sub-Consultant's Representative
Coastal Management Advisor
Secretariat of the Pacific Regional Environment Programme (SPREP)
PO Box 240, Apia, Samoa

Dear Mr Kinch,

Re: Sub Consultancy Agreement between SMEC International and SPREP-Amendment to Reduce marine water quality and ecological surveys.

As per clause 4.1 of the sub-consultancy agreement, SMEC wishes to amend the contractual agreement effective December 31st, 2009, as follows:

1. The number of ecological survey stations will be reduced by eliminating stations 6,7,8 and 10 located in Fagaloa Bay. And replaced by four additional freshwater stream sampling stations at Fagaloa and as such four water samples per month, following the existing freshwater parameter list.
2. Secondly, ecological surveys in Uafato Bay will also be stopped (based on mutual agreement).
3. Benthic organism (venus clam) metal burden testing for a three month period over a 6 month duration have confirmed that the two metals tested, namely mercury and lead were at or close to detection limits and well within levels permitted for human consumption, and posing no threat to the clam's lifecycle. Therefore it was agreed to eliminate this testing program.
4. The marine water quality testing results were carefully examined in November 2009 and the following parameters are to be dropped from the program: H_2S, Pb, Hg, ecoli and faecal coliform.
5. Water quality sample replication will be reduced to duplicates from triplicates—in order to maintain some quality control and reduce the overall cost of the survey.

Please adjust your billing amounts accordingly, and based on the discussions and spreadsheet prepared by Bill Moore and discussed with SPREP. We expect to see such adjustments starting with all 2010 invoicing.

We look forward to working further with SPREP and its partners.
Yours sincerely,

Geza Teleki
Team Leader
Project No.5040013, The Afulilo Environmental Enhancement Project
(TA4121-SAM,)

Project Office, SMEC International PTY Ltd.
2nd Floor, John Williams Building, Apia.

File: **AP 5/3/16**

01st March 2010

SPREP
Secretariat of the Pacific Regional Environment Programme

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Taito Ulaitino Dr. Faale Tumaalii
Chief Executive Officer
Scientific Research Organisation of Samoa
PO Box 6597
APIA

Dear Taito

Following further discussions between SPREP, SMEC and SROS with regards to another contract variation (refer to previous letter: 9th December 2009) regarding the water quality samplings for Fagaloa Bay under the '*Marine Environment Monitoring Program for Fagaloa Bay, Samoa: Assessing the Impacts of the Tae'elafaga Hydropower Plant*' project; please note the following:

1/ Testing for bethnic organism (venus clam) metal burden testing is to cease;

2/ The following parameters are to be dropped from the marine water quality testing program: H2S, Pb, Hg; and

3/ Water quality sample replication will be reduced by one replicate from triplicate testing to duplicate testing.

Because of unforeseen actions now required by EPC/SMEC, these changes are made in order to maintain some quality control and reduce the overall cost of the survey.

Subsequently, can SROS please revise their billing to SPREP in lieu of the reduced sampling and testing (bethnic organisms, parameters, and replication reduction), and adjust their invoices accordingly.

SPREP will continue to pay SROS as per existing arrangements.

I thank SROS for their continued support of this project.

Yours sincerely

Kosi Latu
Deputy Director

Appendix G: Rainfall data for Afulilo Reservoir

Date	Jul-09	Aug-09	Sep-09	Oct-09	Nov-09	Dec-09	Jan-10	Feb-10	Mar-10	Apr-10	May-10
1	3	6	11		10	32	25	14			8
2	6	1	27		6	30	20	89	3		
3	18	6	23		3	22	32	35	6		11
4	12		52				58	15	2	5	16
5	14				8	4	8	10		7	
6		4	46		10		20	14	4	3	14
7	4	28	58		12	16	8	12	8	4	5
8	2	2	8		9	26	5	26	10	8	6
9	1		5		16	40		13	14	2	
10	4	16	30		9	54		38	11	5	21
11	3	24	10		22	95		30	22	10	3
12		9	4		20		27	21	6	7	3
13	2	26			4		4	42		22	
14		2	4	1	35	2	3	20	2	16	15
15		7	6	68	40		12	21	3	18	30
16	25	12	3	42	20		6	32		2	4
17	2	8		14				37		3	24
18	4	6	5	8			17	10		10	2
19		7		22			4	6	1	16	3
20	6	5	3	30	6		6	4			1
21	2		8	3	2	4	3	6	4	6	
22	30			8	7		8	8	16	3	3
23	75			32	22		6	11	2	2	7
24	4	32		68			4	9		9	18
25	7	34		26			108	5	3		2
26		5		3	5	3	26				4
27	32			6	52	48	30	2			5
28	45		2		40	62	25		3	2	7
29	22				12	22	52		4	5	4
30	14	2			95	46	22		2	10	15
31	17	9		34		16	20				12
Total	354	251	305	365	465	522	559	530	126	175	243

Source: SMEC
Note: Shaded boxes denote date of marine water quality sampling

Appendix H: Tide data for Apia Harbour

Time	20/07/09	17/08/09	21/09/09	19/10/09	16/11/09	14/12/09	1/2/2010	22/02/10	23/03/10	19/04/10	19/05/10
0.00	0.58	0.80	0.41		0.43	0.61	0.24	1.05	0.97	0.74	
1.00	0.82	1.00	0.39	0.42	0.64	0.87	0.18	0.97	0.89	0.53	
2.00	1.05	1.16	0.47	0.63	0.89	1.08	0.28	0.83	0.77	0.39	
3.00	1.20	1.21	0.62	0.89	1.12	1.21	0.51	0.67	0.61	0.32	
4.00	1.22	1.10	0.85	1.13	1.26	1.24	0.81	0.52	0.43	0.34	
5.00	1.15	0.89	1.09	1.31	1.30	1.16	1.10	0.42	0.34	0.45	0.43
6.00	0.96	0.67	1.25	1.34	1.22	1.01	1.31	0.39	0.35	0.64	
7.00	0.72	0.48	1.30	1.24	1.02	0.80	1.39	0.42	0.41	0.82	
8.00	0.50	0.35	1.23	1.04	0.76	0.56	1.32	0.51	0.53	0.93	
9.00	0.35	0.33	1.07	0.78	0.52	0.37	1.11	0.65	0.66	0.99	
10.00	0.32	0.42	0.85	0.53	0.35	0.29	0.82	0.78	0.80	0.97	
11.00	0.45	0.63	0.62	0.35	0.25	0.29	0.50	0.89	0.89	0.91	
12.00	0.65	0.90	0.45	0.27	0.29	0.39	0.22	0.93	0.90	0.79	
13.00	0.89	1.14	0.39	0.31	0.44	0.58	0.10	0.90	0.84	0.62	
14.00	1.15	1.31	0.40	0.45	0.65	0.81	0.16	0.80	0.73	0.47	
15.00	1.34	1.37	0.49	0.69	0.87	0.99	0.34	0.68	0.59	0.40	
16.00	1.45	1.31	0.69	0.93	1.04	1.07	0.59	0.56	0.49	0.41	
17.00	1.41	1.13	0.91	1.12	1.14	1.07	0.88	0.46	0.40	0.52	
18.00	1.22	0.86	1.08	1.21	1.14	0.99	1.16	0.43	0.38	0.68	0.36
19.00	0.93	0.57	1.16	1.19	1.02	0.84	1.32	0.47	0.44	0.84	
20.00	0.65	0.33	1.16	1.07	0.82	0.64	1.32	0.58	0.57	0.99	
21.00	0.39	0.21	1.06	0.85	0.59	0.47	1.18	0.72	0.72	1.08	
22.00	0.24	0.21	0.89	0.62	0.41	0.39	0.95	0.87	0.88	1.09	
23.00	0.24	0.35	0.71	0.43	0.32	0.39	0.69	1.00	1.01	1.04	

Source: Ministry of Natural Resources and Environment-Meteorology
Note: Shaded boxes denote time of marine water quality sampling.
Measurements for 19/05/10 are not available due to technical problems, figures given are taken from the Australian Bureau of Meteorology.

Appendix I: Site descriptions

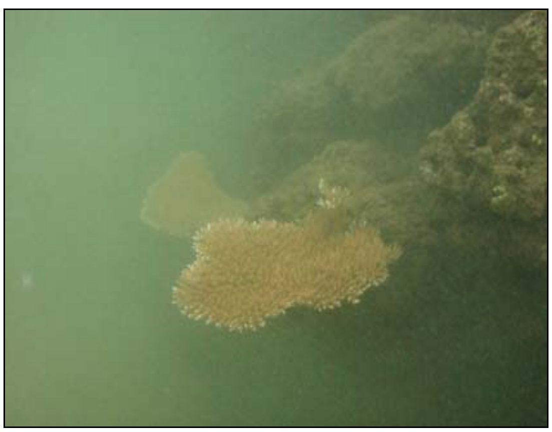
Site 1

This innermost site is located approximately two-thirds of the way along the cut in the reef at the apex of the bay. This zone is the inshore area around the channel resulting from the outflow of the Fagatoloa and adjacent rivers into the bay inhibiting the development of the reef.

The substrate is comprised of rubble, sand and silt. The water is often characterized by a brown colouration and flocculate matter, which probably originates from the organic material being conveyed into the bay. The reef crest is consolidated in the area of wave action but becomes increasing less prominent as it enters inshore. The bottom sediments are fine muds being easily disturbed and very soft and gooey to the touch.

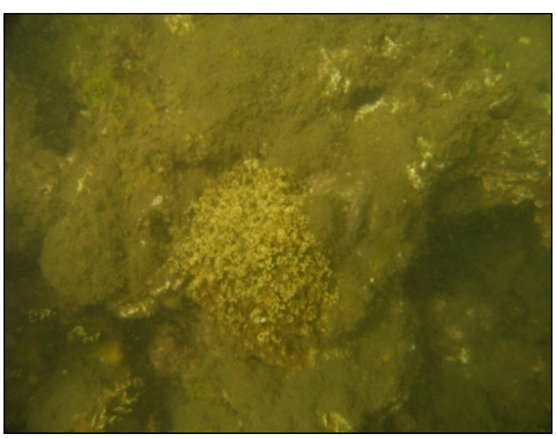
The profile is that of a channel of 1.4 m below the low water springs in the area of the transects. This depth increases to 8m at the entrance. The channel has an abrupt profile on the northern edge where it descends off the horizontal reef flat vertically to a soft muddy bottom. The reef wall is irregular and undercut to varying degrees. The wall diminishes with the shallowing channel. The southern side of the channel is less abrupt in its profile with some large massive *Porites* present on the inclined slope (Lovell, 2002).

It has not been possible to use the photo-quadrant method on this site due to the high turbidity. While Lovell had observed a surprising great abundance of fast growing tabulate *Acropora spp.*, they seem to have disappeared as no Acropora was observed.

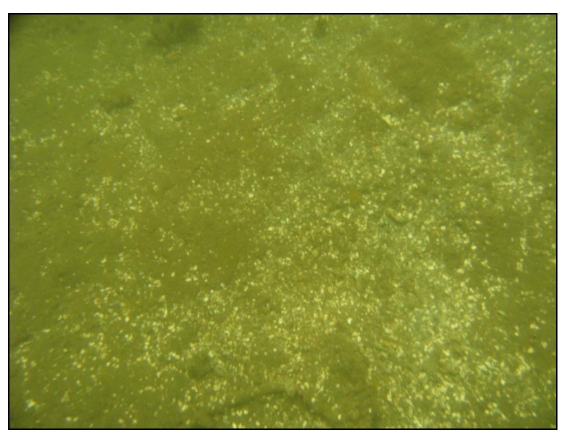


Tabular Acropora on the channel wall (2002)

Montipora spp. (2002)



Sediment accumulated on the channel wall (2002)



Sediment accumulated in the channel (2002)

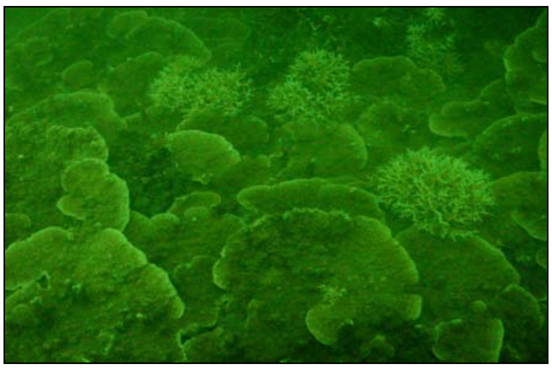
This site appears more degraded than in 2002 where Lovell had recorded a live coral of cover of 26%. Despite not having exactly recorded the coral cover for this site, it is very unlikely to be above 5% and the benthic composition would be dominated by mud.

From the recruitment data, no new recruit has been recorded on this site for the genera considered, Pocillopora, Porites and Acropora. This does not mean that there is no recruitment at all but the most common genera are not meaning that the environmental conditions are not good enough. These environmental conditions are characterized by high sedimentation resulting in high turbidity preventing the coral to receive enough light for them to grow normally and the smothering of both existing corals and potential recruits.

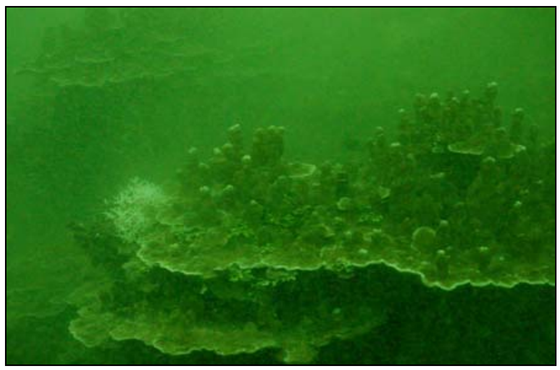
Site 2

This zone is subject to inshore influences but being outside of the channel and in the bay environment has given rise to a large increase in species numbers and abundance. The environment is less subject to the degree of variation in environmental parameters of ambient light, salinity and siltation than the channel (Lovell, 2002).

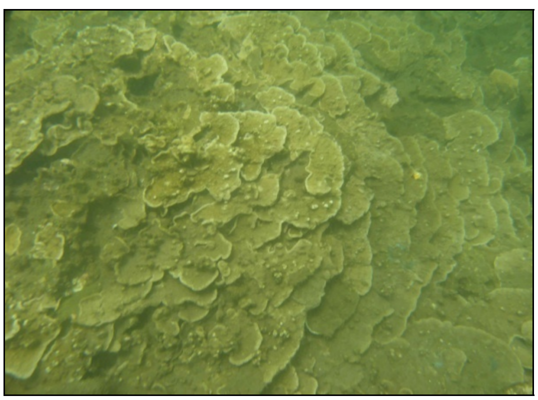
From an inter-tidal reef flat, the reef crest and reef slope are rocky with most exposed areas covered with coralline algae. The slope descends to 10m where a talus margin gives way to a soft fine sand bottom. The wall is steep with an irregular margin and characterized by undercuts, overhangs and intermittent shelves (Lovell, 2002).



Montipora sp. and *Seriatopora hystrix* (2002)

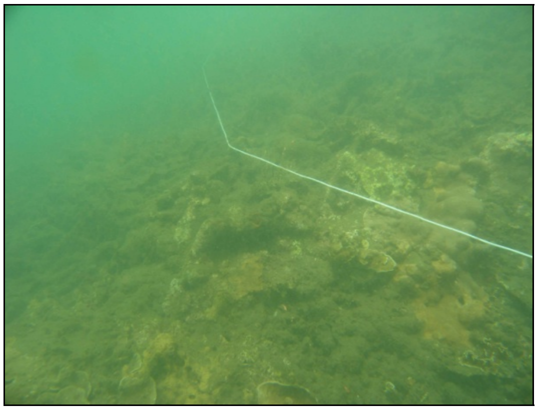


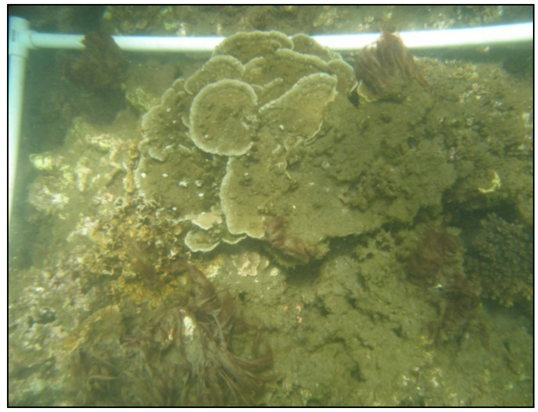
Porites rus (2002)



Montipora sp. below the wall (2009)

Coral rubble mixed with sediments (2009)


Slope below the wall with few corals (2009)


Sediments and filamentous algae on wall (2009)

Some issues with the camera settings have prevented the analysis of the pictures but we can observe that the environment below the wall is still comparable to 2002 with additional silt. *Montipora sp*. ant *Porites rus* are still present. However the coral settlement on the wall has changed, the tabular Acropora spp. has gone and some that have not been swiped away have died. Mud/sediments and filamentous red algae are observed on the wall as well as non-branching corals and among those encrusting species.

The recruitment is the second lowest with only 6 recruits recorded (0.7/m²). This means that there is no recovery of the tabular Acropora spp. that used to be on the wall likely due to the presence of silt as well as the high turbidity that often occurs in this site.

Site 3

Located opposite Salimu Village on the northwest side of the bay, this zone is still subject to some of the inshore influences of the freshwater run-off (i.e. dilution and turbidity). The run-off causes both a decrease of the salinity (dilution) as well as an increase of the turbidity with the input of muddy water carrying soil from the land. The site is slightly protected by the reef at Musumusu so the force of the surf is diminished. There is a prominent reef crest. Anecdotal description of the currents indicates that the current flows down the northeastern side into the bay, bringing clear water (Lovell, 2002).

This reef flat is broad with a shallow lagoon. The reef slope descends down a vertical 8m wall and is characterized by overhangs. At the base of the reef slope, a sand floor extends into the bay (Lovell, 2002).

The benthic composition at site 3 is dominated by the “substrate” category, rock (41% cover). The second most encountered type of benthos is the algae, Halimeda spp. (30% cover). Halimeda is a green calcareous algae that is not considered as an indicator of nutrient enrichment. The “coral category” comes third with 27% benthic cover and the category is dominated by the encrusting coral Montipora.

In 2002, the “coral” category dominated the benthic composition with just over 50% cover, “algae” was only 6% of the cover whereas the “substrate” is roughly the same (36% cover).

As stated by Lovell in 2002, this site is subject to freshwater run-off from the Salimu stream but there is no evidence that the run-off from the tailrace is having an impact here as other streams do come down from the mountains close to the site and are more likely to have more direct influence. The changes observed in benthic composition are likely to be due to Cyclone Heta in

2004 as all the fragile tabular corals (*Acropora sp*.) have disappeared and have been replaced by non-branching coral, Halimeda algae as well as soft corals.

A total of 13 recruits (coral below 5 cm) have been counted at the site after two surveys, this is a very low, with only 0.7 recruit per square meter. This indicates extremely slow recovery in this area. This fact could be explained by an increased sedimentation in the area that has contributed to the spread of the Halimeda algae that it is preventing coral recruitment (see first part of this report).

Mounds of *Porites cylindrica* (2002)

Soft corals and *Halimeda* (2009)

Site 4

This site is not subject to the inshore influences like sites 1 and 2, as it is located midway along the northwest margin of the bay.

This site, located at a depth of 6 meters, is exposed to oceanic swell with surf of varied size breaking on the reef crest. A prominent projection of reef is subject to the full force of the swell entering the bay. The intensity of surf is seasonal. As the wind shifts easterly, swell enters the bay more consistently. During the summer, the northerly swells become prominent. With the correct swell direction substantial surf may be experienced on the reef projections that extend into the bay opposite of Musumusu, north of Maasina and north of Lonu (Lovell, 2002).

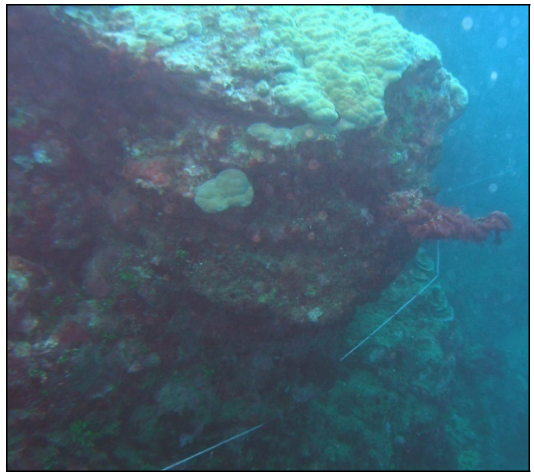
This location is one of the broader reef flat areas. From the inter-tidal reef flat and wide reef crest, the reef slope descends down a wall 5-6m vertically and is characterized by overhangs. At 7m, a sand floor extends into the bay (Lovell, 2002).

The benthic composition at this station is dominated by the “substrate” category and more precisely rock. The “coral” category comes second and is dominated by the Diploastrea spp., which is a massive/encrusting genus. Compared to 2002, the Diploastrea corals are still present but the overall coral cover has decreased from 59 to 32 %. Branching/tabular corals were not observed in 2009 likely due to 2004 Cyclone Heta is likely to have wiped these corals out that may have been weakened or already killed by the 2 consecutive bleaching events of 2002 and 2003.

A total of 27 recruits have been counted, making 1.5 recruits per m². Two third of the recruits are encrusting *Montipora sp*. and only 7 out of 27 are the branching corals, namely *Pocillopora sp.* and *Acropora sp*.. The recovery of the site is very slow. It had already been 5 years since the cyclone and the recovery for the branching genera such as Pocillopora and Acropora should be around 10 years (Coles et al., 2007) and in this case the branching corals have not started the recovery when it should be nearly halfway through.

This site is not subject to inshore influence and, as a consequence, the freshwater discharge from the tailrace does not have any impact.


Wall with tabular *Acropora* sp. (2002)


Wall with missing tabular *Acropora* sp. (2009)

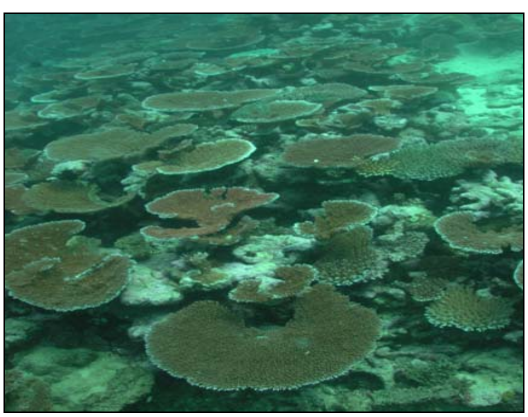
Site 5

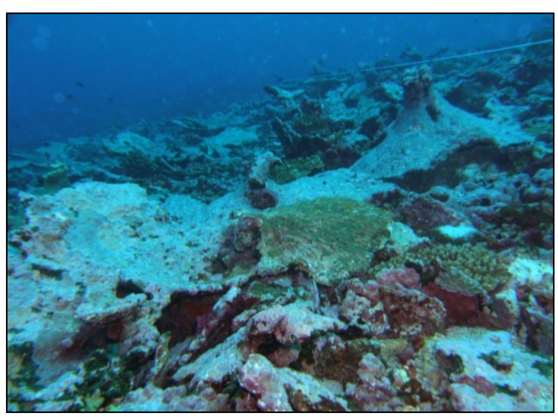
This site is located behind the prominent headland northeast of Musumusu, at a depth of 6 meters, with a dominant spur and groove seascape (Lovell, 2002). Being in the outer part of the bay, this area is exposed to oceanic swell that is less affected by the depths further into the bay. Comments on seasonality made about the Musumusu site 4 apply.

This area is one of the narrowest fringing reefs in the bay with very little in the way of a reef flat (Lovell, 2002).

The benthos at site 5 is dominated by coralline algae that constitute 67.5% of it. "Coral" only accounts for 13.44% of the benthos mainly constituted of branching *Acropora sp*. and encrusting *Montipora sp*. This benthic composition is totally different from 2002, as it was dominated by corals (75%) . As described in the introduction for this site, it is very exposed to oceanic swells and has been severely impacted by Cyclone Heta, especially the very fragile tabular coral *Acropora hyacinthus*. These have now been broken down almost completely.

A total of 66 recruits have been recorded, making 3.7 recruit per m² with 2/3 of the recruits being branching corals, *Acropora sp*. and *Pocillopora sp*. This site is a good control in terms of recovery as it is not impacted by terrestrial influences and especially sedimentation.


Tabular *Acropora* sp (2002)


Destroyed tabular *Acropora* sp (2009)

Site 9

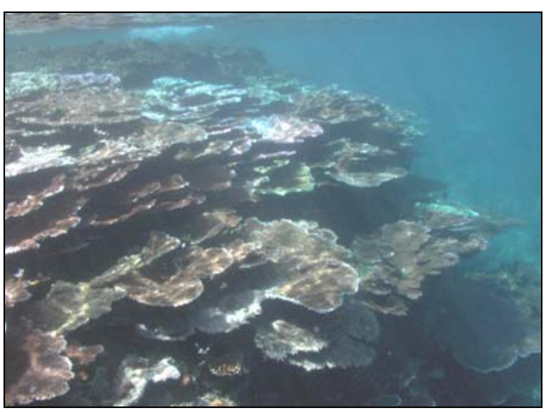
This location is on the southeast side of the bay at its most outer extension as site 8 has not been surveyed and the depth is 6 meters. This site differs from those on the northeast side of the bay by being characterised by lee-shore conditions and is broader in width. This area is exposed to oceanic swell coming from the north to northeast which is characteristic of the summer season. A river empties into the bay, causing the reef to narrow in front of Samamea.

A reef flat and shallow lagoon margins the reef slope landward. Sub-tidally, the reef slope is characterised by reef patches and a channels connecting to the reef flat. The river area has a well defined channel caused by the outflow (Lovell, 2002).

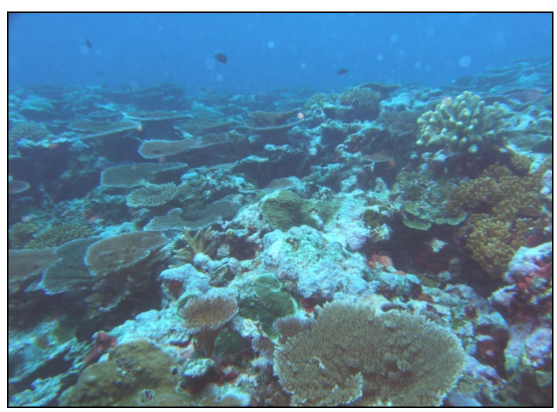
The benthic composition is dominated by coral, 45.6% cover, and the pink encrusting coralline algae, 39.3% cover. Encrusting *Montipora sp.* (15.8%) and branching *Acropora sp.* (19.4%) constitutes most of the coral population. Soft corals (6.4%) also occur at this site. Unlike the previous sites, the overall coral cover has not decreased too much when compared to 2002 data, i.e., from 51.9% to 45.6%. However there has been a change in the coral composition, as the branching *Acropora sp.* cover has decreased from 50% to 19.4%. *Montipora sp*. cover has increased from 1% to 15.8% and the coralline algae cover has increased from 1 to 39.3% in 2009.

These data shows that this site has also been impacted by Cyclone Heta but much less so than the northeast side of the bay as there are still some tabular *Acropora sp.* present. It is likely that the cyclone has taken out the biggest plates, leaving the smallest ones. Some of the free space left by the bigger plates has been replaced by the encrusting *Montipora sp*. It is likely that these *Montipora sp*. were already present but that their development was prevented by the shade of the bigger tabular *Acropora sp*. After these were uprooted, the *Montipora sp.* have rapidly grown. The high occurrence of coralline algae is also a sign of the cyclone damage. Its high occurrence is a sign that the substrate is very favorable for new recruits. This is demonstrated by the recruitment surveys as site 9, which shows the highest recruit's abundance, with 86 recruits recorded in two surveys, or 4.7 recruits per m^2. *Acropora sp.* and *Montipora sp*. dominate the recruit composition, with respectively 42 and 28 recruits with the other 16 comprised of *Pocillopora sp.* (15) and *Porites sp.* (1).

Site 5 also showed high coralline occurrence but a lower recruitment rate compared to this site. Site 9 still has enough adults to repopulate the area where site 5 has very few, and is subject to larvae coming from further away, and which, are highly dependent on favorable currents.



Tabular Acropora sp. (2002)



Tabular Acropora sp. (2009)

With the bays circulation pattern carrying water along the shore in a clockwise fashion into the head of the bay past the Ta'elefaga Creek outlet, there is little chance that the discharge is impacting this site.

Site 11

This site is located on the reef slope in the area northeast of Lona Village just south of the point at a depth of 6 meters. It is similar to station 10 and the Samamea site in that it is also subject to river run-off. The oceanic swell regime is much reduced due to protection from a series of reef points.

There is a major freshwater run-off influence which exits at Lonu. The outflow affects the nature of the reef with a complete absence of reef where the river enters the bay. The Lonu catchment is large and the run-off is substantial.

Surveys for this site have recorded an algae cover of 40.3%, a coral cover of 32.8% and a substrate cover of 26.5%. Coralline algae and Halimeda counts are 30% and 10% respectively. The massive coral *Porites sp*. dominates the coral composition with constituting half of the total coral cover and the substrate is exclusively made of rock.

As in the previous sites, the coral cover has decreased, with *Acropora sp*. the most impacted, exhibiting a change from 22% in 2002 to less than 2%. In this case, it is likely to be a consequence of Cyclone Heta, though the influence of the river run-off may also be having an impact. The run-off maybe more important than before if land uses have changed and it is possible that more soil is now carried by the river. Lovell also had observed large patches of branching corals, these, however were not seen in the recent surveys.

The recruitment at this site is much lower than at sites 9 and 10. A total of 31 recruits have been recorded, making 1.7 recruits per m².

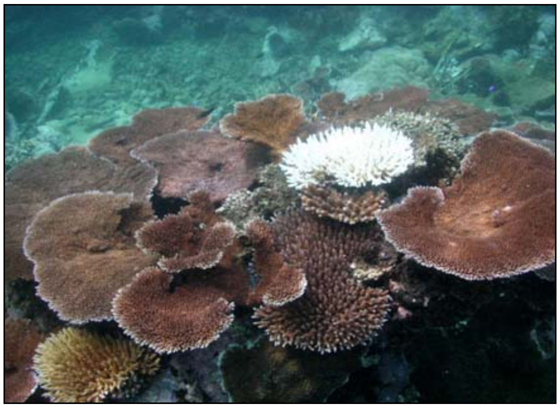
It is very unlikely that the tailrace is having an influence at this site because of the circulation pattern mentioned for Site 9.

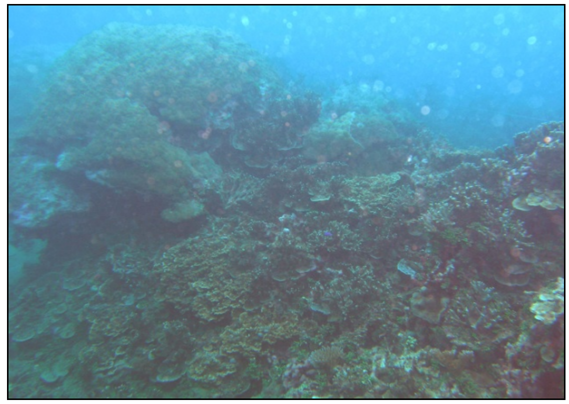
Site 12

This site is located to the west of the bay's most prominent projection of reef between Lona and Maasina. This area receives more wave action than anywhere else in the bay with the exception of Sites 7 and 8 along the headlands at the mouth of the bay (Lovell, 2002).

The benthic composition is dominated by the substrate (56%) which is a mix of rubble (14.8%), mud (9.2%) and rock (31.8%). The coral cover is 23.2 % and is mainly comprised of *Porites sp*., both massive and branching (14.6%). The algae cover is 13.2% with 9.4% being Halimeda. Soft corals occur at this site with 7.2% cover. The decrease of the global coral cover compared to 2002 (from 38.53% to 23.2%), especially, amongst the *Acropora sp.* (from 30% to 1%) can be attributed to the damage from the currents and waves generated by cyclone Heta in 2002 as well as the bleaching events of 2002 and 2003 that had already killed or weakened the corals.

A total of 48 recruits or 2.7 recruits per m² have been recorded. Fifty percent of the recruits are *Porites sp* whereas only 8 Acropora sp have been counted. This shows that *Porites sp*. is spreading more and is more adapted to the current environmental conditions than *Acropora sp*. The overall recruitment is lower than Sites 5, 9 or 10 as rubble, mud and Halimeda algae that can be found on the bottom tend to smother new recruits.





Tabular Acropora spp. sp. (2002) Mix of branching and massive (2009)

It is very unlikely that the tailrace is having an influence at this site because of the circulation pattern mentioned for Site 9, 10 and 11.

Site 13

This site is in the area near Maasina on the southern side of the bay at a depth of 6 meters. This location has the most wave sheltered environment in the bay, being protected by the irregular reef on the southeastern side and particularly the reef projection between Maasina and Lonu. As with sites 9, 10 and 11, this site is subject to river and creek outfall. The run-off enters a shallow inshore lagoon present on the reef flat creating an environment where the biota has to cope with periodic dilution. The outflow has limited the reef development in front of Maasina Village where a channel approaches the beach.

The benthic composition for this site is dominated by the "substrate" category mostly represented by rock (39% cover) as well as some mud and rubble, both around 2.5% cover. The second most represented category is algae with 28.3% cover consisting mostly of *Halimeda sp*. with 21.7% cover and the remaining 6.7% being coralline algae. The coral only comes third with 27.4% cover and almost 21% of this cover being *Porites sp*. The 2009 *Acropora sp*. counts were only 0.5% in comparison to 13% in 2002. The overall coral cover has decreased from 52.6% in 2002 to 27.4% in 2009. *Porites sp*. has decreased from almost 37% in 2002 to 20% in 2009 and the soft coral has disappeared completely.

The algae population has increased since 2002; *Halimeda sp.* was reported for this site in Lovell's report but with a cover the cover of only 4.6% and it is now 21.7%. Coralline algae species were not observed in 2002.

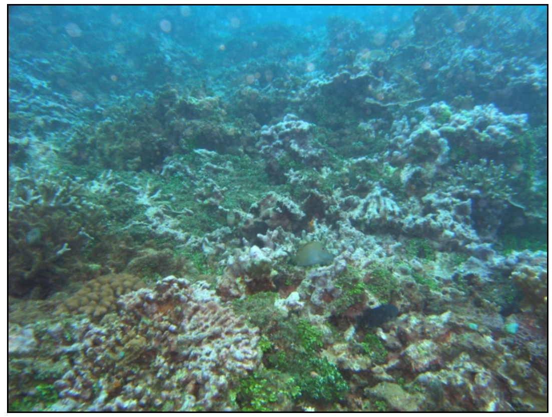
The coral recruitment at site 13 is the second lowest in the bay after site 3, with only 16 recruits or 1.8 recruit per m² recorded. Among these 16 recruits, 12 are branching coral, Acropora (8) and Pocillopora (4). This low recruitment rate can be explained by the benthic cover by Halimeda, which does not provide a good habitat for coral larvae colonization.

This site was the most luxuriant one in 2002 and had the greatest it has been seriously degraded. As mentioned earlier in this report, a recent study on the coral reefs of Nha Trang Bay in South China relates anthropogenic impacts and especially the deposition of terrigenous material to the decrease in coral cover and diversity and the spread of *Halimeda sp*. (Latypov, 2006).

As this site is subject to river influence from the Maasina creek, it is possible that the sediment input from the river has increased and degraded the environmental condition for optimal coral growth.

According to the current circulation pattern, the site does not seem to be affected by the Ta'elefaga hydropower plant as well.

Acropora and *Porites* spp. (2002)



Dead *Acropora sp*. (2009)

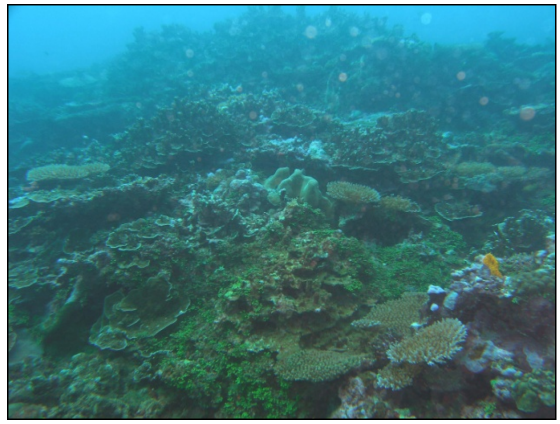
Site 14

This site is located on fringing reef between Maasina and Ta'elefaga at a depth of 6 meters and 230 meters from the Ta'elefaga Creek discharge. The reef area is affected by the inshore conditions for the Fagatoloa River and other watercourses flowing into the apex of the bay. Despite its inner bay nature, this area is subject to wave action though much reduced in comparison with other outer sites (Lovell, 2002).

The benthic composition is dominated by live coral cover (43.5%), closely followed by algae (38.1%). The "substrate" category counts for 16.9% of the benthic cover. Our transect was run at 6 meters and not at 2 like Ed Lovell in 2002 so we will not be able to compare the figures. On the other hand, the 2002 report observed that this site was impacted by the freshwater discharge at Ta'elefaga: "With the development of the power generation facility, there is a more consistent source of water entering the bay. Since that time, the dilution by the bay waters has proved adequate for the survival of the reefs within half a kilometer from the outfall. The run-off deposits silt into the system and the general wave action concentrates it toward the end of the bay. This action is also responsible for re-suspending it.

In 2002, Lovell described the visibility as very poor. In our surveys, the visibility was good even with weather conditions during that survey week being windy and rainy. Coral cover at Site 14 proved to be one of the highest along with sites 9 and 10 toward the mouth of the Bay. Corals represented at this site, included *Acropora sp.:* 11%, *Fungia sp*.: 0.5%, *Montipora sp.:* 11.9%, *Pocillopora sp*.: 2.5%, *Porites sp*.: 8.2% and Other Live Coral: 9%. Despite the presence of *Halimeda sp*., contributing to almost 17% of the cover, the coral recruitment at this site (30 recruits or 3 recruits per m^2) is nearly twice as high as the neighboring site 13 (1.8 recruit per m^2) and comparable to site 5 (3.7 recruits per m^2) at the mouth of the bay.


Reef structure (2002)


Reef structure (2009)

Appendix J: Terrestrial Run-off associated impacts on coral reefs

Activity	**Nutrient loading**	**Particulate organic matter**	**Turbidity**	**Sedimentation**
Direct effects of terrestrial run-off on the growth and survival in adult corals				
Fecundity	-ve		-ve	-ve
Fertilsation	-ve	-ve	?	?
Embryo development and larval survival	-ve	-ve	?	?
Settlement and metamorphosis	-ve	-ve	-ve	-ve
Recruit survival			-ve	-ve
Juvenile growth and survival			-ve	-ve
Direct effects of terrestrial run-off on coral reproduction and recruitment				
Calcification	-ve	+ve	-ve	-ve
Tissue thickness		+ve	-ve	-ve
Zooanthallae density	+ve*	+ve	+ve	-ve
Photosynthesis	+ve	+ve	-ve	-ve
Adult colony survival	?	+ve	-ve	-ve
Direct effects of terrestrial run-off on organisms that affect coral cover				
Crustose coralline algae	-ve			-ve
Bio-eroders	+ve	+ve		-ve
Macro-algae	+ve	+ve	-ve	-ve
Filter feeders		+ve	+ve	-ve
Coral diseases	+ve			+ve
Coral predators		+ve		

*Nitrogen only. Note: ? indicates that a response is unlikely; empty cells indicate that insufficient data are available.
Source: Fabricus (2005).