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Nutrient Levels and Macro-Algal Outbreaks in Fiji's Coastal Water.

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Introduction

The Fiji Islands are surrounded by numerous fringing coral reefs which are an extremely important natural resource, valuable as local fishery areas, tourist attractions, and for protection of the coastline from the damaging effects of waves. Over recent years, there has been increased development of the coastline in Fiji which has lead to pressure on the surrounding reefs. Degradation of reefs has been observed as the result of factors such as increased erosion on land and siltation of reefs, water pollution, overfishing, and coral harvesting. 'Natural' events such as coral bleaching and crown of thorn starfish infestations have also episodically affected Fiji's reefs (Zann 1994). A summary of the major disturbances and their effect on coral reefs is shown below;

Disturbance	**Likely Effect on Coral Reefs**
Cyclones	Breaking of fragile coral colonies (e.g. Acropora sp.)
Sediment Discharge	Smothering of coral with silt and blocking light to corals.
Freshwater Discharge	Killing of coral organisms that are intolerant to low salinity conditions
Water temperature and/or UV light increase	Bleaching of coral (expulsion of photosynthetic zooanthellae)
Human trampling of coral	Breaking of fragile coral colonies, turning reefs to 'rubble' and subsequently reducing the chance of coral larvae resettlement
Nutrient/sewage inputs	Allow macro-algae to thrive which can smother coral and reduce settlement sites for coral larvae.
Overfishing	Reduce important species such as herbivores that help to clean the reef of algae.

Nutrients such as nitrate (NO_3^-) and phosphate (PO_4^{-3}) are naturally present in seawater and are essential for growth of phytoplankton and other algae which form the base of the ocean food chain. Nutrient levels in the tropical Pacific ocean are generally very low, as is productivity. However, coral reef ecosystems can maintain high productivity as they are very efficient at recycling nutrients between the coral polyp and the zooanthellae algae that live in symbiosis with the polyp. Elevated levels of nutrients in coral reef ecosystems can lead to the slow growing corals, which are adapted for a low nutrient environment, to be simply overwhelmed by macro-algae/seaweeds (Goreau & Thacker 1994; McCook 1999). A shift in species dominance from hard coral to macro-algae (seaweeds) has been observed in several coral reef systems (e.g. Hawaii, Caribbean, Belize) in the last few decades (Hughes 1994; McCook 1999; McClanahan 1999). The causes of these changes appear to vary in relative importance and magnitude among different reef localities. Increased nutrient levels may not always lead directly to macroalgal overgrowth of corals as other factors such as the abundance of herbivores (e.g. sea urchins, herbivorous fishes) to graze the algae is also important (McClanahan 1997; McCook 1999; Szmant 2002). Reef disturbances caused by cyclones and coral bleaching may also result in more substrate available for algae to colonise (e.g. see Coral Reefs special issue vol. 19, 2001; Szmant 2002). High levels of phosphorus can also lead to a reduction in structural density of stony corals, causing them to lose their strength and crumble (Kinsey & Davies 1979).

Macro-algal outbreaks on coral reefs result in death of live coral, loss of settlement sites for coral larvae, as well as a loss of habitat heterogeneity necessary to support a diverse range of organisms. As a consequence algal-dominated reefs have been noted to be lower in fish stocks, have less tourism appeal and coral biodiversity (Goreau & Tacker 1994; McCook 1999).

Research on coral reefs in other locations has established that the levels of nutrients that can be considered healthy for coral reef ecosystems are approximately 1 μmol/L of N as nitrate or ammonia (14 μg/L N) and 0.1 μmol/L of P as orthophosphate and organophosphate (3 μg/L P) (Bell 1992; Goreau & Thacker 1994; ANZECC 2000). However, nutrient levels in water may not be an entirely accurate indicator of nutrient pollution, as if large amounts of algae are present nutrients may be rapidly incorporated into algal tissue. In any case, it is important to note that these levels are much lower than that which would be detrimental to any other aquatic ecosystem. Hence it is extremely important that coral reefs are protected from excess nutrient inputs.

Many of Fiji's coral reefs are directly adjacent to the shoreline, and these "fringing reefs" are particularly susceptible to land-based pollution. The major sources of nutrients to Fiji's coastal waters are typically from human waste and chemicals (e.g. detergents, fertilisers). Poor (septic tanks, 1° treatment, pit latrines) sewage treatment is carried out in most areas of Fiji (Greenpeace 1997, IAS 2004). Unfortunately there is little water quality data available for the Fiji Islands apart from limited studies in some of the major harbours (Institute of Applied Sciences technical reports), the 'Coral Coast' of Viti-Levu (Mosley and Aalbersberg 2003) and a pristine location in the Astrolabe Lagoon, near Kadavu Island (Morrison *et al*. 1992). Anecdotal evidence suggests that many Fijian reefs are undergoing a phase-shift to become macro-algal dominated (Nunn & Naqasima 1994; Lovell & Tamata 1996; Coral Cay 2001) but unfortunately there has been insufficient long-term research in this area.

Overfishing and recent coral bleaching events (Cumming *et al*. 2002) may be a contributing factor but unfortunately no long-term monitoring data is available to confirm this hypothesis.

This report summarises recently collected data on nutrient levels in coastal seawater of Fiji with particular focus on areas which are important tourist destinations.

Methods

Sample Sites

The study locations (Fig 1.) chosen were:

1. The Mamanuca Islands of the western side of the main island of Viti Levu which contain numerous tourist resorts and several local villages.

2. The area commonly referred to as the ‘Coral Coast’ on the southern side of Viti Levu in the Fiji Islands. This area also contains numerous hotels and local villages. Some sampling sites were chosen to be near to the tourist resorts, most of which are located directly next to the ocean.

3. Muaivuso. A location near a village with large seagrass beds present.

4. A pristine location in the Great Astrolabe lagoon, near Kadavu Island to the south of the main island of Viti Levu.

Some sites were chosen to be near the resorts or local villages while other sites were chosen to represent ‘background levels’ as there did not appear to be any pollution sources nearby. The sites were sampled during a range of tidal states.

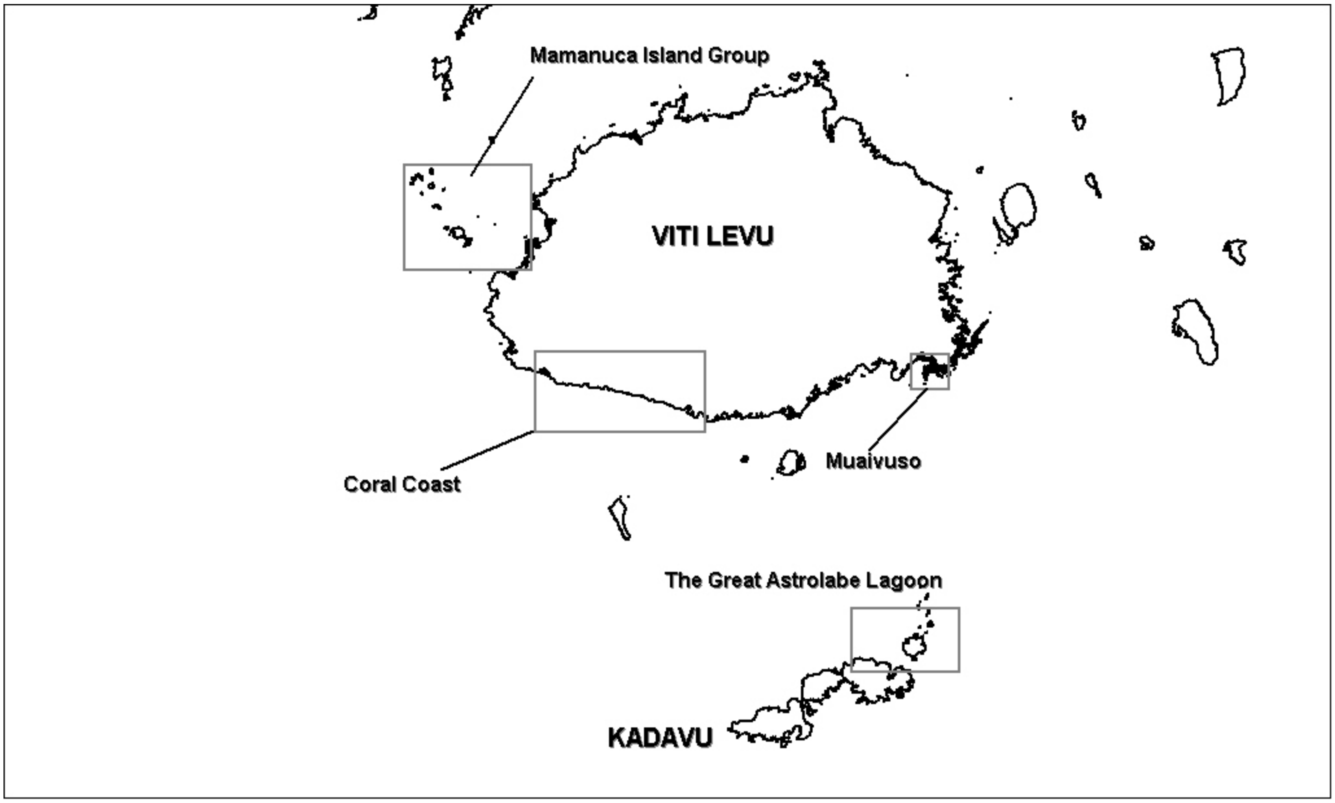


Figure 1 **Map of the Fiji Islands showing study areas**

Sampling and analysis

On the Coral Coast, samples were collected from near the shoreline at the various sites from a depth of about 10 cm below the water surface. In the Mamanuca Islands, Great Astrolabe lagoon and Muaivuso area the samples were collected mostly from a boat. Each sample was collected in an acid-cleaned polypropylene bottle, which was rinsed three times with the sample solution prior to collection. Filtering (Whatman GF/C, 1.2 μm pore size filters) of the samples was immediately carried out to remove any large particles, plankton and bacteria. Poisoning with mercuric chloride (1 drop saturated solution per 100 mL of sample) was also used to further aid in the preservation of the samples. During transport back to the laboratory the samples were kept in an ice cooler and upon arrival they were refrigerated at 4°C and analysed within 1 week.

Analysis of oxidised nitrogen (nitrate and nitrite) and phosphate in the samples was performed on an autoanalyser (Skalar San Plus) located at the National Water Quality Laboratory (Public Works Department, Kinoya) using the methods detailed by Kirkwood (1994). For the seawater samples, all nutrient standards were made in low nutrient seawater (LNSW) and this water was also used as the rinse liquid in the autoanalyser. This LNSW was prepared by collecting open ocean seawater (far away from any pollution sources) in a polyethylene bottle, leaving in the sunlight for at least 2 weeks, and pouring off the upper portion for use. It is considered necessary to use this LNSW for low level nutrient analysis in seawater, as contamination is likely at these levels if artificial seawater is prepared instead (Kirkwood 1994). Partway through the study we obtained a nutrient seawater standard reference material (MOOS-1, National Research Council Canada) which was diluted and analysed alongside samples. Results were acceptable indicating that the methods used were accurate. Salinity of the samples was measured using a calibrated conductivity meter. Locations (latitude and longitude) of samples collected by boat were recorded by GPS (datum WGS 84).

The Nitrogen:Phosphorous (N:P) ratio was calculated by dividing the molar concentration of oxidised nitrogen by the molar concentration of phosphate. In open ocean seawater, N and P are theoretically found in a ratio of about 15 N:1 P which is also the ratio of their utilisation by phytoplankton. Hence this ratio may give an indication as to whether a water sample is enriched with either N (ratio > 20) or P (ratio < 7) relative to unpolluted levels.

Results

Nutrient levels

The results from analysis of nutrients in coastal water are outlined below for the various study areas. It should be noted that the naming of a particular village, hotel or tourist resort as a sampling location does not necessarily imply that they are the source of any increased nutrient levels that are observed. In many situations where non-point discharges occur (e.g. septic tanks to groundwater) it may be difficult to pinpoint the sources of nutrients without long-term extensive sampling. As we did not measure ammonia or organophosphate in the samples, the levels found can be considered to be the minimum amount of dissolved nitrogen and phosphorus respectively that may be present.

Coral Coast, Viti Levu

Nutrient levels found in Coral Coast coastal waters are shown in Table 1. In several samples, nutrient levels were elevated above levels considered to be healthy for coral reef ecosystems (see Mosley and Aalbersberg 2003 for more detail).

Some of the highest levels of nitrate were found at sites which are located near the Korotogo hotels-Outrigger Resort-Tubakula Bungalows area. This is one of the most intensively developed areas on the coast with one very large resort, several smaller resorts and guesthouses, a couple of local villages and a number of private dwellings. More intensive sampling is needed to try and determine the major sources of these nutrients to this area and other locations where elevated levels of nutrients were found. The nature and quality of waste discharge from the resorts along the Coral Coast is variable. Some discharge partially treated effluent direct to the ocean, some discharge to land and others to municipal sewage treatment plants (see IAS 2004). The local villages, many of which use pit latrines or septic tanks for treatment of their waste, are also likely to be discharging nutrients in groundwater to the ocean. There are also a number of small pig farms situated near the rivers or on the coast, and when the pens are washed down they are likely to discharge high levels of nutrients.

There was no clear relationship between salinity and tidal state versus the nutrient levels as has also been observed in a similar study in Guam (Marsh Jr. 1977). The rivers are definitely a major source of nutrients to the coast though, as nutrient concentrations in the rivers are generally higher than the seawater samples (Mosley and Aalbersberg 2003). This may be due to the influence of phosphate fertilisers on agricultural land in the catchments as phosphorus levels in non-fertilised soils in the area are generally very low (Leslie 1997).

Table 1 Nutrient Concentrations in coastal waters of the Coral Coast

Sample Site and Date	Salinity	Oxidised-N (μM)	Phosphate (μM)	N:P ratio
28/2/2002				
Fijian resort: channel mouth near shell station	31.1	0.31	0.16	2
Fijian resort in channel across from shell station	31.6	2.46	0.23	11
Fijian resort Sacred point	29.1	2.85	0.18	16
Fijian resort in front of oceanfront pool	31.9	1.06	0.15	7
Fijian resort causeway	29.3	1.20	0.05	22
Right hand side of Outrigger resort	32.3	7.26	0.03	208
Left hand side of Tubakula resort	31.0	24.11	0.07	328
25/3/2002				
Just pass Navola village	34.3	0.61	0.11	6
Just before Votua village	34.8	0.38	0.07	5
Just before Tagaqe school	34.6	1.24	0.07	17
Sovi Bay beach	35.0	0.35	0.09	4
Right hand side of Outrigger resort	35.0	1.33	0.10	13
8/4/2002				
Just before Votua village	33.3	1.52	0.12	13
Hideaway resort: far right hand side	33.2	1.80	0.12	15
Hideaway resort: in front of pool	33.2	0.34	0.07	5
Sovi Bay beach	31.7	3.39	0.15	23
Left hand side of Tubakula resort	33.5	0.57	0.09	6
Right hand side of Outrigger resort	33.1	3.87	0.11	35
Fijian resort in front of oceanfront pool	33.5	0.70	0.08	8
Fijian resort: channel mouth near shell station	30.2	2.45	0.24	10
Fijian resort causeway	33.7	1.00	0.11	9
Front of Naviti resort	27.4	2.30	0.33	7
After Komave village	31.4	2.14	0.15	14
26/4/02				
Hideaway resort: far right hand side	34.3	1.35	0.17	8
Front of Tabua sands resort	33.1	0.98	0.13	8
Vatukarasa Bay	33.9	1.15	0.18	6
Sovi Bay beach	31.8	1.85	0.20	9
Left of Malevu village	33.6	1.07	0.14	8
Left hand side of Tubakula resort	33.7	0.56	0.11	5
Right hand side of Outrigger resort	34.0	0.37	0.15	2
Front of Crows Nest resort	32.7	0.44	0.16	3

Korotogo river mouth	33.9	0.25	1.51	0
Matai Kandavu beach	34.0	0.10	0.28	0
27/4/2002				
Right hand side of Outrigger resort	33.5	5.90	0.29	20
Between Malevu/Vatukarasa	34.1	0.71	0.20	3
24/6/2002				
Right hand side of Outrigger resort	31.9	7.01	0.25	28
Left hand side of Tubakula resort	32.5	3.32	0.25	13
Left of Malevu Village	33.0	1.82	0.17	11
Sovi Bay beach	32.7	3.92	0.30	13
Right of Hideaway resort	32.7	1.51	0.19	8
Naviti Resort	33.0	1.05	0.28	4
Before Votua village	32.7	0.27	0.13	2
Warwick resort	32.7	2.81	0.31	9
After Komave village	32.2	0.98	0.12	8
MEAN± SD		**2.29±3.77**	**0.19±0.22**	**12±17**

Mamanuca Islands and Nadi Bay area

In the Nadi Bay area, relatively high levels of nutrients were found in the waters in front of the Sheraton Fiji and Sheraton Royal resorts and the area around the mouth of the Denarau Marina. Possibly sources include sewage discharges from the resorts, discharge from boats in the marina, and river-borne nutrients entering into the sea. High levels of nutrients were also found in front of Veiseisei village and in the 'black discharge' from the Lautoka Sugar mill. Nutrient inputs resulting from fertilizer use on agricultural land on Viti Levu are also likely to enter into Nadi Bay from rivers and further long-term study of these inputs is needed. At many sites in the Mamanuca Islands, the levels of oxidised-N were generally lower than found on the Coral Coast although phosphate was slightly higher. The N:P ratio was low (ca. 5) indicating that nitrogen was more limiting than phosphate. It is noted that many Mamanuca resorts had poor or inappropriate sewage systems (IAS 2004) and algal problems. This indicates that there is a nutrient problem but possibly other complex factors are involved such as depletion of herbivorous fish and invertebrates (see Coral Cay 2001 and below for further discussion).

Table 2 Nutrient Concentrations in coastal waters of the Mamanuca Islands and Nadi Bay area

Sample site and Date	Lat	Long	Salinity	Oxidised-N	Phosphate	N:P ratio
10 July 2003				µM	µM	
Sheraton Fiji 100m offshore	017 46 457	177 21 891	33.1	1.75	0.20	8.9
Sheraton Royal 100m offshore	017 46 031	177 22 242	33.2	0.81	0.15	5.5
Mouth of Denerau Marina	017 45 588	177 23 195	33.5	0.35	0.11	3.3
Mangroves North of Marina	017 45 785	177 23 685	33.6	0.84	0.10	8.5
Malan Cay	017 45 110	177 23 684	33.3	0.87	0.11	8.1
Wailoaloa Beach (near Traveller's Lodge) 100m offshore	017 45 806	177 25 601	33.3	<0.1	0.08	N/a
Airport Strip River Mouth	017 45 139	177 25 885	33.3	0.64	0.10	6.4
Downtream Sabeto River	017 44 193	177 25 201	33.4	0.42	0.11	3.8
Mouth Sabeto River	017 43 988	177 25 045	33.1	1.06	0.25	4.3
Lomolomo cemetery River Sabeto Split North	017 42 764	177 35 167	33.4	0.45	0.10	4.8
Lomolomo cemetery North Sabeto River Split Mouth	017 42 578	177 25 209	33.1	0.50	0.13	3.9
2km off Sabeto River mouth	017 43 628	177 24 399	33.2	0.45	0.08	5.3
2km of Lomolomo Cemetery River	017 42 710	177 24 266	33.2	0.00	0.06	0.0
Vuda River Mouth	017 41 777	177 24 878	33.3	0.42	0.09	4.8
Veiseisei Village 5m off reef	017 41 537	177 24 645	34.3	0.94	0.44	2.1
Vuda Pt Oil Tanks	017 41 130	177 23 456	33.2	0.41	0.07	6.1
Vuda Point Marina Mouth	017 41 073	177 23 167	33.1	0.51	0.08	6.6
Dreketi Inlet	017 39 773	177 22 954	33.1	0.42	0.06	6.9
Saweni Bay Beach Resort	017 38 775	177 23 610	33.2	2.87	0.06	50.3
Lautoka Sewage Area Reef Side	017 37 092	177 25 516	33.3	0.70	0.13	5.3
Off Sewage plant 1km	017 36 984	177 25 485	33.1	0.67	0.08	8.1
Lautoka Sugar Mill	n/a	n/a	31.9	7.13	10.04	0.7
Mid lagoon off Saweni 1	017 37 652	177 22 760	33.2	0.39	0.05	7.8
Mid lagoon off between Tivua and Vatunaqalau Islands	017 37 952	177 21 673	33.3	0.61	0.06	10.1
Mid Lagoon 3 End of Tavua	017 38 211	177 20 699	33.1	0.35	0.05	6.5
Mid Lagoon 4 towards Bounty	017 38 956	177 20 033	33.1	0.59	0.10	5.9
Mid Lagoon 5 edge of Bounty	017 39 434	177 18 745	33.1	0.44	0.14	3.0
Bounty Resort front	017 40 568	177 18 669	33.1	0.56	0.08	7.2
Bounty Island back	017 40 536	177 18 364	33.2	0.54	0.09	5.9
South Seas North	017 41 549	177 18 930	33.2	0.58	0.10	6.1
South Seas South	017 41 683	177 18 801	33.1	0.58	0.09	6.3
Treasure East	017 39 363	177 16 298	33.3	0.74	0.14	5.4
Treasure South	017 39 392	177 16 087	33.2	0.34	0.10	3.5
Treasure West	017 39 223	177 16 073	33.2	0.43	0.12	3.4

Treasure North	017 39 251	177 16 101	33.2	0.74	0.08	9.6
Beachcomber North	017 39 239	177 15 470	33.3	1.11	0.28	3.9
Beachcomber East	017 29 340	177 15 457	33.3	0.38	0.10	4.0
Beachcomber South West	017 39 280	177 15 339	33.2	0.83	0.14	5.9
Between Beachcomber and Yadua	017 38 295	177 11 161	33.2	0.36	0.08	4.7
Yadua South Beach	017 37 865	177 07 700	33.2	0.77	0.12	6.3
Yadua North Island	017 37 521	177 07 783	33.2	0.85	0.14	6.1
11 July 2003						
Tokoriki Middle Lagoon West	017 34 530	177 05 220	33.5	0.84	0.09	9.0
Tokoriki North Inside Lagoon	017 34 390	177 05 330	33.8	0.04	0.10	0.4
Tokoriki South Inside Lagoon	017 34 690	177 05 270	35.8	0.18	0.07	2.5
Tokoriki East Back of Island	017 34 610	177 05 680	33.7	0.25	0.10	2.5
Yanuya South East Village 5m off Reef	017 35 870	177 04 060	35.9	0.40	0.13	3.0
Yanuya North East Village 5m off reef	017 35 780	177 04 010	35.9	1.09	0.15	7.4
Yanuya North West Village (Algae Bay)	017 35 770	177 03 720	35.9	0.69	0.12	5.9
Yanuya South West Village (Algae Bay)	017 35 900	177 03 840	35.9	0.70	0.12	6.0
Tavua South West Village Inside Bay	017 36 860	177 05 100	36.0	0.48	0.10	4.8
Tavua North West Village Mouth of Channel	017 36 750	177 05 070	34.2	0.48	0.09	5.5
Tavua East No Village 5m off reef	017 36 940	177 05 850	34.9	0.41	0.10	4.1
Yadua North West	017 37 510	177 07 670	35.0	1.76	0.15	11.6
Yadua South West Beach	017 37 830	177 07 640	35.0	0.48	0.07	6.5
Matamanoa Mid resort	017 38 400	177 04 040	34.4	0.75	0.10	7.1
Matamanoa Kitchen Side	017 38 410	177 03 940	34.0	1.43	0.16	8.8
Matamanoa Kitchen Pipe	n/a	n/a	32.9	1.29	0.22	6.0
Matamanoa Heli-pad	017 38 270	177 04 100	35.9	0.48	0.11	4.4
Matamonoa West	017 38 210	177 03 750	0.0	0.48	0.13	3.7
Mana North Staff Quarters	017 40 230	177 06 030	34.6	1.43	0.13	11.2
Mana North Side Resort	017 40 300	177 06 300	34.2	0.52	0.08	6.3
Mana South side Resort	017 40 520	177 06 260	36.1	0.72	0.11	6.5
Mana South Side Backpackers	017 40 570	177 06 470	36.1	0.48	0.08	5.8
Mana Channel	017 41 170	177 06 950	35.1	<0.1	0.12	N/a
Castaway Resort South Beach	017 44 080	177 07 670	35.8	0.88	0.13	7.0
Castaway Resort West Beach Sunset	017 44 000	177 07 640	34.8	0.75	0.07	10.2
Castaway North East resort	017 43 910	177 08 360	35.0	0.68	0.11	5.9
12 July 2003						
Navini South East side Shore	017 42 330	177 13 550	34.7	0.29	0.10	2.8
Navini East Side Shore	017 42 270	177 13 580	35.8	0.34	0.11	3.1
Navini North West Side Shore	017 42 280	177 13 490	35.9	1.11	0.14	8.2
Malamala (Daytrip Island) North Side	017 43 320	177 16 610	35.8	0.94	0.12	8.0

Malamala (Daytrip Island) South Side	017 43 490	177 16 300	33.2	0.75	0.09	8.4
Solevu Village North East Malolo	017 44 700	177 11 170	33.3	0.61	0.09	7.1
Solevu Village North West Malolo	017 44 610	177 11 170	33.2	0.49	0.10	4.7
Yaro Village North Malolo Islands	017 43 940	177 10 760	33.1	0.54	0.10	5.2
Yaro Village Mouth of Channel	017 43 940	177 10 610	33.2	0.20	0.10	2.0
Malolo Resort NorthWest Side	017 44 570	177 08 710	33.1	0.68	0.10	6.7
Malolo Resort South Side	017 44 630	177 08 780	33.1	0.68	0.11	6.3
Wadigi Resort North	017 44 960	177 08 620	33.1	0.95	0.13	7.3
Wadigi Resort West	017 45 170	177 08 420	33.1	0.25	0.12	2.1
Wadigi Resort South East	017 45 160	177 08 820	33.1	0.61	0.10	6.4
Lako Mai Resort Malolo Island	017 45 200	177 09 180	33.4	0.90	0.14	6.4
Lako Mai Staff Village Malolo Island	017 45 480	177 09 330	33.1	0.79	0.16	5.0
Malolo Island Facing Plantation	017 49 960	177 10 090	33.0	0.52	0.11	4.6
Small Reed Between Malolo Islands and Musket Cove Resort	017 46 110	177 10 680	33.1	0.36	0.10	3.6
Musket Cove Marine End Between Malolo Island and Malololailai	017 46 130	177 1/40	33.5	0.61	0.08	8.0
Musket Cove Inside Marina by bridge	017 46 260	177 11 690	33.1	0.34	0.12	2.9
Plantation Bay Side	017 46 470	177 11 400	33.1	0.68	0.11	6.1
Plantation West Side of Resort	017 46 690	177 11 220	33.0	0.54	0.10	5.2
Malololailai Island South East Side	017 47 160	177 12 210	33.3	0.55	0.15	3.7
Malololailai Island South of Coconut Plantation	017 47 030	177 12 650	33.2	1.43	0.16	9.0
Namotu North East	017 50 650	177 11 100	33.1	0.61	0.26	2.3
Namotu West	017 50 500	177 11 030	33.2	0.88	0.19	4.6
Ocean Sample In between Barrier reef of Namotu and Tavarua	017 51 700	177 11 600	33.3	0.51	0.15	3.5
Tavarua North East	017 51 240	177 12 370	33.7	1.56	0.17	9.3
Tavarua North West	n/a	n/a	32.4	1.79	0.13	13.7
Mid Lagoon towards Sonaisali 1	017 50 660	177 14 960	32.5	0.20	0.10	2.0
Mid Lagoon towards Sonaisali 2	017 50 120	177 16 840	33.3	<0.1	0.10	-0.2
Mid Lagoon towards Sonaisali 3	017 49 690	177 18 170	33.1	0.35	0.10	3.7
Mid Lagoon towards Sonaisali 4	017 49 560	177 20 430	33.2	0.48	0.10	4.7
River Plume Sonaisali South	017 49 950	177 20 700	33.2	0.48	0.10	4.5
River Mouth Sonaisali South	017 50 210	177 21 170	33.1	0.25	0.10	2.6
Nadi River Mouth Sonaisali North	017 48 730	177 21 600	33.2	0.54	0.08	6.6
Nadi River Mouth Southern Tip of River	017 48 440	177 21 630	33.1	0.61	0.11	5.7
Denerau South Golf Course just south of Trend West	017 46 930	177 21 890	33.3	0.41	0.13	3.3
MEAN± SD				**0.71±0.76**	**0.21±0.97**	**5.86±5.11**

Muaivuso

Nutrient concentrations in the coastal water near Muaivuso village are shown in Table 3. Most samples had nutrient levels which were below or close to those considered healthy for coral reef ecosystems. On average levels of nutrients were higher in the marine protected (*tabu*) area than at the control site. It was raining quite heavily at the time of sampling and this is likely to have increased the concentration of nutrients in the creek entering to the West of the *tabu* area. There are large seagrass beds present in the tabu area which would uptake nutrients and may result in a reduction of nutrient concentrations to acceptable levels in the surrounding coral reef areas. The N:P ratio was low (ca. 6) indicating that nitrogen was more limiting than phosphate.

Table 3 Nutrient Concentrations in coastal water near Muaivuso (Viti Levu). Sampled on 27/3/2003.

Site	Lat	Long	Salinity	Oxidised-N (μM)	Phosphate (μM)	N:P ratio
Tabu site: 1	18 07.36	178 20.20	33.5	1.03	0.14	7.4
Tabu site: 2	18 07.90	178 20.77	33.8	1.03	0.11	9.1
Tabu site: 3	18 08.18	178 21.36	34.3	0.86	0.13	6.4
Tabu site: 4	18 08.47	178 21.43	33.9	0.76	0.17	4.4
Control site 1	18 07.93	178 22.93	34.0	0.24	0.06	4.1
Control site 3	18 08.09	178 22.66	34.1	0.36	0.09	3.9
Mean± SD				**0.71±0.34**	**0.12±0.04**	**5.9±2.1**

Great Astrolabe Lagoon, Kadavu

Nutrient concentrations in the Great Astrolabe Lagoon (Kadavu) water are shown in Table 4. On average nutrient concentrations are quite low compared to the Coral Coast and Mamanuca Islands. Average values are comparable to the average values found by Morrison *et al*. (1992, Oxidised N = 0.83, N:P ratio = 9.5). Elevated nutrient concentrations were found in front of Jona's resort and Waisomo village which suggest localised nutrient inputs. The N:P ratio was very high at these sites indicating nitrogen inputs and/or uptake in excess of phosphorous.

Table 4 Nutrient Concentrations in Great Astrolabe Lagoon (Kadavu)

Date	Site	Lat	Long	Salinity	Oxidised-N (μM)	Phosphate (μM)	N:P ratio
16/8/2002	Jona's Resort, Ono	18 56.351	178 28.980	33.0	2.79	0.11	25.2
16/8/2002	Waisomo village, Ono	18 55.557	178 28.483	35.1	1.31	0.03	43.7
16/8/2002	Kavala Bay	18 57.889	178 25.339	33.2	0.77	0.15	5.1
16/8/2002	Nakasaleka village	18 56.718	178 22.696	28.6	0.38	0.07	5.1
16/8/2002	Gasele village	18 56.650	178 18.109	34.7	0.91	0.14	6.5
16/8/2002	Daku village	18 57.342	178 16.441	35.2	0.73	0.13	5.7
16/8/2002	Dive Kadavu	19 00.391	178 09.540	35.3	0.56	0.09	6.1
13/8/2002	Vunisea Bay	19 02.815	178 09.489	31.7	0.40	0.10	4.1
15/8/2002	Tabu in Ono Reserve	19 00.815	178 29.969	35.1	1.11	0.12	8.9
13/8/2002	Control in Ono Reserve	18 57.486	178 30.852	35.2	0.99	0.11	9.0
15/8/2002	Naiqoro passage	19 00.815	178 29.969	35.2	0.99	0.09	10.8
Mean± SD					**0.99±0.30**	**0.10±0.03**	**11.8±11.3**

Summary of nutrient levels in coastal waters

A summary of the nutrient results from all sites is shown in Table 5. There was considerable variability in nutrient levels within and between the different locations. In general, the Coral Coast had the highest nutrient levels with the mean oxidized-N levels over two times greater than those at other sites. The Mamanuca Islands had the highest phosphate levels on average. It is noted that caution must be applied when correlating nutrient levels to the potential risk of problems with algal overgrowth of coral. If large amounts of algae are present, due to their rapid uptake of nutrients from the water, average nutrient values may not necessarily give a true indication of the effect or significance of nutrient inputs (Szmant 2002). Therefore low mean nutrient levels should not be a reason for complacency if algal problems are being experienced.

Considerable variability was found in the N:P ratios. In general it appears that at on the dates samples the most sites were more enriched with phosphate relative to oxidised-N compared with the ratios expected from theory (N:P ca. 15).

Table 5: Summary of the nutrient results (mean±standard deviation)

Location	**Number of samples**	**Oxidised-N (μM)**	**Phosphate (μM)**	**N:P ratio**
Coral Coast	44	2.29±3.77	0.19±0.22	12±17
Mamanuca Islands	105	0.71±0.76	0.21±0.97	5.9±5.1
Great Astrolabe Lagoon	11	0.99±0.30	0.10±0.03	11.8±11.3
Muaivuso	6	0.71±0.34	0.12±0.04	5.9±2.1

Further sampling needs to be performed to detect seasonal trends in nutrient concentrations and N:P ratios. Analysis of ammonia should also be included in subsequent coastal water analyses as due to the poor sewage treatment in many locations a substantial amount of nutrients may be entering in the form of ammonia. However, rapid uptake of ammonia by algae is likely to occur and oxidation to nitrate will occur naturally in the water column.

Algal overgrowth observations

In the course of our nutrient sampling we made several qualitative observations of reef health, which given the lack of more rigorous long-term biological monitoring data, we outline below. On the Coral Coast, high levels of algae, dominated by *Sargassum* sp. as well as other species such as *Turbinaria ornata*, *Padina* sp., *Gracilaria maramae*, *Dictyota* sp. and *Enteromorpha flexuosa* are currently found in the back reef and lagoonal areas at many locations. In some locations, notably those in the vicinity of sewage inputs, *Sargassum* sp. have obtained almost complete coverage of the inner reef flat, and are particularly abundant on dead or dying coral heads (Figs. 2 and 3). Earlier reports from unimpacted reef sites on the Coral Coast noted that *Sargassum* sp. was dominant only on a narrow band on the seaward edge of the reef summit and was close-growing (Morton and Raj, 1980), although it was noted at a few sites near large tourist hotels with increased sediment and nutrient inputs that *Sargassum* sp. was present at high levels close to the shoreline (Raj *et al*. 1981; Gawel and Seeto, 1982). Recently (last 5-10 years), the *Sargassum* and other algal species appear to have greatly increased in range and severity. Although algal species are more dominant and larger at sites receiving direct nutrient inputs from septic tank and sewage discharges, high levels of algae are also present in areas not obviously affected by nutrient discharges. At sites we revisited from earlier reports (Morton and Raj, 1980) we have observed a great loss of coral diversity. For example, we resurveyed the Korolevu reef platform and found few living corals (<10%, mainly *Porites* sp.) whereas Morton and Raj (1980) noted a wide variety of coral species dominated by large table species (*Porites* sp., *Millepora* sp., faviids, *Symphyllia* sp., *Galaxea* sp.) and sub-canopy species (e.g. several *Acropora* sp., several *Pavona* sp., *Merulina ampliata, Fungia fungites*, *Echinopora horrida*, *Hydnopora mayeri*, *Acrhelia horrescens*, *Turbinaria peltata*). Instead what we found was large canopy species were mostly bleached and covered in algae (Fig. 4), high levels of coral rubble substrate and algae were present (Fig. 5), and sub-canopy coral species were nearly non-existent. Some herbivore species are present (see Fig. 6) but others (e.g sea urchins, *cawaki*) appear to be sparse, except in marine protected (*tabu*) areas.

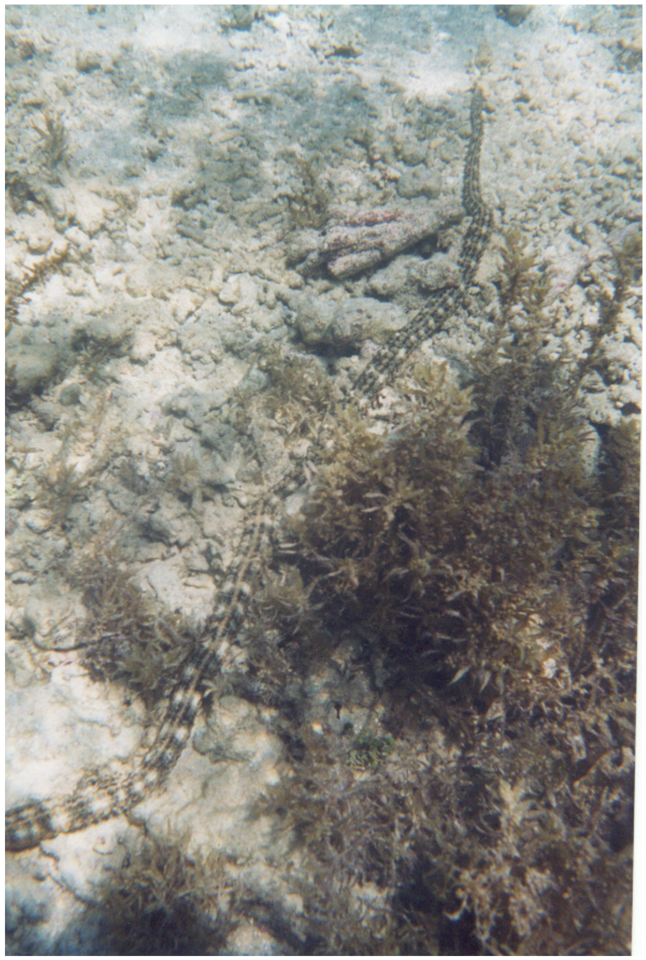
Fig. 2: *Sargassum* smothering back reef area at Qalito Back Reef (1-2 m depth)

Fig. 3: Algal overgrowth (*Sargassum* sp.) on a *Porites* sp. coral head at a back reef site.

Fig. 4: Channels in the inner-reef flat near Korolevu showing algal coverage extending over mostly dead coral surfaces.

Fig. 5: *Turbinaria* and *Sargassum* sp. on the inner reef flat at Korolevu Reef Platform

Fig. 6: A synaptid grazing at a site dominated by *Sargassum* sp. with large amounts of coral rubble.



In the Mamanuca Islands, serious algal problems are also currently being observed in many areas. Zann and Lovell (1992) conducted a study of reef health in the Mamanucas. Reefs within 100-500m of tourist resorts (Malolo, Mana Island, Beachcomber), and of a village (Yanuya) were seagrass and algal dominated, while equivalent reefs away from human habitation were coral dominated. Nunn and Naqasima (1993 and 1994) noted problems with erosion and growth of brown algae (*Sargassum*, *Turbinaria*, *Padina* sp.) around some areas of Elevuka (Treasure) Island. Nutrient levels were variable but quite elevated during two sampling visits. Tamata *et al*. (1994) studied environmental impacts of the Denarau Marina Development Project. They recorded massive destruction to specific coral assemblages (*Acropora* sp.) compared to their previous study (Lovell and Odense 1993). However, this may have been attributed to a major cyclone and floods rather than dredging operations during construction of the marina. The more robust corals (*Porites, Leptastrea and Favia* sp.) were not affected. Seagrass beds were found to be completely smothered by silt from dredging operations. Nunn (2001) noted shoreline erosion in the islands of Eluvuka (Treasure) which was attributed to several possible reasons such as wave and cyclone action, lack of sand replenishment, sea level change, building of artificial shoreline structure, and loss of sand production due to degradation of sand-producing algae and coral on its fringing reefs. Recent evidence suggests that the problem of algal overgrowth and destruction of reef habitats has increased in the Mamanuca Islands. Coral Cay (2001) documented algal dominated reefs and a lack of herbivore species in several locations. In our current study we also observed large outbreaks of *Gracilaria* sp. at many resorts (Figures 7). These outbreaks result in large masses of algae washing up on some resort beaches, necessitating large scale removal operations (Fig. 8) to preserve a resorts' tourist appeal.

Fig. 7: Algae (*Gracilaria* sp.) growing on a reef flat nearby to a resort

Fig. 9: Algae (*Gracilaria* sp.) having to be barged and dumped from a resort after it collects and decomposes on their beach presenting an unattractive sight and smell

Summary

The elevated nutrient levels and algal outbreaks are of concern given the importance of Fiji's reefs for the local communities and as a tourist destination. Although it is difficult to pinpoint the exact cause of the problems due to the lack of any consistent long-term data on the biology of Fijian reefs and water quality, it is clear that increasing nutrient inputs have played a role. Regardless of exact causes, Fiji's people and tourism income will suffer if the situation is not improved. Large numbers of tourists visit Fiji and expect to see tropical reefs, colourful fish and to swim in clear, clean water. Algal covered reefs and rotting algae on beaches is an unattractive alternative. If the reef ecosystems and biodiversity are degraded further the income and image of the resorts will suffer. The local villagers will also be affected as tourism is a major source of employment in this part of Fiji, and many still rely on fish caught from the reefs for their daily food. In addition, coastal erosion is likely to increase as the reefs are broken down by wave action and not regenerated. Given the findings in the current study, urgent action is required if Fiji's reefs are to be restored to their natural condition.

Recommendations

We make several recommendations to stop the decline of Fiji's coastal ecosystems from excess nutrient inputs:

1. The Sustainable Development Bill should be implemented to enable environmental enforcement. Water quality standards specific for coral reefs (e.g. see ANZECC 2000) should be developed into this legislation and effluent discharges made to conform to these standards. The Environment Department should be properly resourced to enforce the environmental regulations.
2. Resorts should improve their wastewater standards as per the recommendations made in the IAS (2004) report. The Hotel Industry Association should develop a code of practise for waste management.
3. More marine protected (*tabu*) sites should be established and tighter controls put on the taking of undersize fish.
4. Resorts that currently collect and dump and/or bury algae that washes up on their beaches should try and find alternative means of disposal. This might include contained composting on land, possible use for agar manufacture, and if marine disposal is necessary, do so far away (several km) from any island. The problem with burying or dumping waste is that the nutrients within the algae are eventually released when the algae decompose. They are then released back into the water and cause the problem to re-occur by stimulating more algal growth.
5. Reefs should be protected from disturbances such as trampling and harvesting of coral.
6. Long-term biological and nutrient monitoring sites should be established on the Coral Coast, Mamanuca Islands and Great Astrolabe Lagoon. Seasonal trends should be studied in more detail and nutrient levels in algae measured at various sites.
7. Phosphate-free detergents should be used where practical due to the finding of N:P ratios suggesting that phosphorous was in excess. More research should be performed on the possible effect of the runoff to the coastal environment of fertilisers (N:P:K and others) used in the sugar industry.
8. Composting toilets and communal septic tank effluent disposal schemes (away from the coastline) should be utilised where possible for villages and small hotels.

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