Nutrient levels in sea and river water along the 'Coral Coast' of Viti Levu, Fiji

Luke M. Mosley, William G. L. Aalbersberg

Institute of Applied Science, University of the South Pacific, Suva, FIJI ISLANDS
E-mail addresses: lukemosley@yahoo.co.nz
aalbersberg@usp.ac.fj

ABSTRACT

Nutrient (nitrate and phosphate) levels potentially damaging to coral reefs have been detected at several sites along the Coral Coast of Viti Levu, Fiji. Nutrient concentrations were determined using standard techniques on an autoanalyser capable of measuring to sub-micromolar levels. The mean nitrate level for 34 seawater samples was 1.69 mM and the mean phosphate level was 0.21 mM which exceeded levels considered to be harmful to coral reef ecosystems (>1.0 mM N, >0.1 mM P). It is proposed that these elevated nutrient levels coupled with overfishing of herbivore species have contributed to the recent widespread growth of macro-algae species along this coast. Nutrient levels were highest at sites located near hotels and other populated sites. At sites not significantly influenced by human activity, levels were comparable to that of non-polluted sites elsewhere in Fiji. Concentrations of nutrients in rivers along the coast were generally higher than in seawater. Urgent action is needed at community, regional and government levels to try and reduce the nutrient inputs to this coast.

1 INTRODUCTION

Coral reefs are an extremely important natural resource in the South Pacific and the rest of the world. They are highly productive and biodiverse ecosystems which are important as fishery resources, tourist attractions, and for protection of the coastline from the damaging effects of waves. Over the years, increased development of the coastline and utilisation of coastal resources have caused significant degradation of reef habitats and a loss of species diversity (Hodgson, 1999). These impacts have been observed as the result of factors such as increased erosion on land and siltation of reefs, water pollution, overfishing, and coral harvesting.

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 reefs 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 have been noted to have several deleterious effects (Goreau and Thacker, 1994; Koop *et al*., 2001). One of the effects noted in several locations is a shift in species dominance from the coral reef building stony (calcified) species to larger non-calcified macro-algae (Goreau and Thacker, 1994; McCook, 1999; Szmant, 2002). The slow growing stony corals, exquisitely adapted for a nutrient deficient environment may be overwhelmed by faster growing macroalgae which are freed of their nutrient constraints. This can result in mortality and loss of biodiversity of live corals and a loss of settlement sites for coral larvae. The overgrowth of algae may also result in a loss of fish and invertebrate biodiversity as a loss of habitat heterogeneity occurs compared to that presented by the live coral. Overfishing of algal-grazing fishes and invertebrates will also help the establishment of algae on coral reefs (McCook, 1999; 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 and Davies, 1979).

The major sources of elevated nutrients to coastal waters are typically from human waste and chemicals (e.g., detergents, fertilisers). Research on coral reefs in other locations has found that the levels of nutrients that may 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 and Thacker, 1994) although there is some debate on this issue as excess nutrients can be uptaken by algae and removed from the water (Szmant, 2002). In any case, it is important to note that these levels are much lower than those which would be detrimental to any other aquatic ecosystem. Hence it is extremely important that coral reefs are protected from excess nutrient inputs.

The objective of the present study, was to measure nutrient (nitrate and phosphate) levels along the 'Coral Coast' of the island of Viti Levu, Fiji. The Coral Coast is a very popular tourist destination with several large resorts and also several villages spread along the coastline. There is little published information on the nutrient levels along this coastline and in Fiji in general (see Zann, 1994). High levels of algal growth (e.g. *Sargassum* sp.) have been noted along the Coral Coast and other areas in Fiji in recent years and communities are concerned about deterioration in the coral and fish stocks (Nunn and Naqasima, 1994; Lovell and Tamata, 1996; Vuki *et al*., 2000). The coral reefs in the study area are directly adjacent to the shoreline, and these "fringing reefs" are particularly susceptible to land-based pollution.

2 METHODS

2.1 Study location and sample sites

The study location is in the Nadroga province on the southern coast of the island of Viti Levu in the Fiji Islands (Fig. 1), in an area commonly referred to as the 'Coral Coast'. For the purposes of this study, the Coral Coast was defined as starting at Komave village near the Warwick Hotel and ending at the Shrangri-La Fijian Resort. A total of 34 samples were taken on five different sampling dates (25/3/02, 8/4/02, 26/4/02, 27/4/02, 24/6/02) at a total of 19 different locations. Not all the sample sites were sampled on all the sampling dates. The sampling sites are listed in Table 1. Some sampling sites were chosen to be near to the tourist resorts, most of which are located directly next to the ocean.

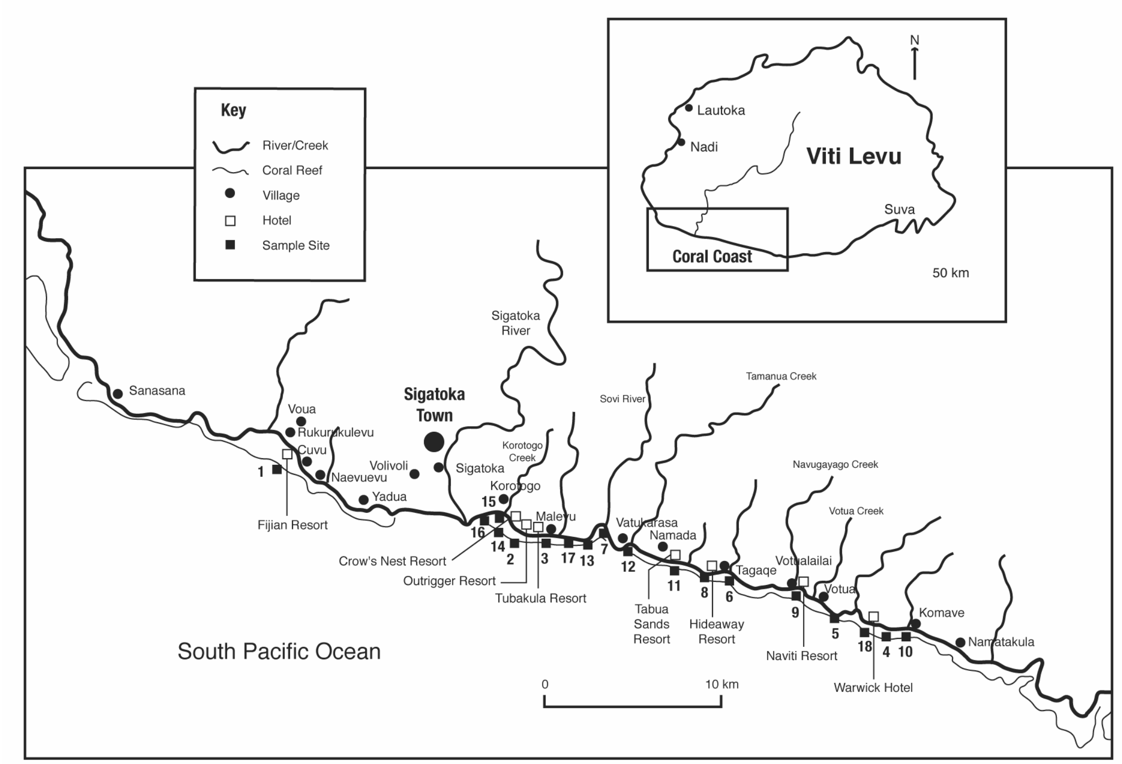

Figure 1 Map of Coral Coast, Viti Levu, Fiji Islands showing location of sampling sites, villages and hotels

Table 1 List of Sample Sites

Site Number	Location
1	Yanuca Island-ocean side
2	Outrigger resort: western side
3	Tubakula resort: eastern side
4	West of Navola village
5	East of Votua village
6	Tagaqe village
7	Sovi Bay beach
8	Hideaway resort: western side
9	Front of Naviti resort
10	West of Komave village
11	Tabua Sands resort
12	Vatukarasa Bay
13	Malevu village: eastern side
14	Crows Nest resort
15	Korotogo Bridge
16	Matai Kandavu beach
17	Between Malevu/Vatukarasa villages
18	Warwick Hotel

Other sites were chosen to be near some of the local villages while other sites were chosen to represent ‘background levels’ as there did not appear to be any pollution sources nearby. Exact sample location descriptions are available from the authors on request. The sites were sampled during a range of tidal states.

A number of rivers in the study area that flow out to the coastal waters were sampled on two consecutive sampling days (26-27/4/02). Each river was sampled close to where it crossed under the Queens Highway. By far the largest river on the coast is the Sigatoka River, which drains a large catchment area and has a large sand beach to the east of its mouth. There are mixed landuses in the river catchments, with villages, agricultural areas and forests present. It was raining moderately during the sampling time and the rivers were elevated above the level found during dry conditions. Rainfall in the Coral Coast area is highly variable and mainly orographic as the prevailing southeasterly trade winds reach the mountains of Viti Levu. Although Fiji experiences a distinct wet season (November to April) and a dry season, much of Fiji’s rain falls in heavy, brief localised showers. Annual rainfall in the study area data ranges from about 150 cm in the drier area at the far west of the study site to about 300 cm in the eastern areas (Leslie, 1997).

2.2 Sampling and Analytical Methods

Samples were collected from near the shoreline at the various sites from a depth of about 10 cm below the water surface. 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 nitrate and phosphate in the samples was performed on an autoanalyser (Skalar San Plus) 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 siphoning 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).

Salinity of the samples was measured using a calibrated conductivity meter. It should be noted that some of samples noted as river water, had elevated salinity due to tidal influence at the time of sampling. This is likely to lower the concentration of nutrients observed.

3 RESULTS AND DISCUSSION

The concentrations of nutrients in the seawater samples collected are displayed in Table 2. The nitrate values ranged between 0.10 – 7.01 μM with a mean of 1.69 μM. The phosphate levels ranged between 0.07 – 1.51 μM with a mean of 0.21 μM. In several samples, nutrient levels were elevated above levels considered to be healthy for coral reef ecosystems. In comparison to the levels found at unpolluted sites elsewhere in Fiji (Morrison *et al.*, 1992, mean level of 0.74 μM nitrate and 0.07 μM phosphate) the mean levels in the present study were over two times greater. The ammonia or organophosphate in the samples was not measured and the nutrient levels found can be considered to be the minimum amount of dissolved nitrogen and phosphorus respectively that may be present.

We argue that these increased nutrient levels have helped lead to a “phase shift” in which coral reef building species are being overgrown with macro-algae in several Coral Coast locations. This algae is mainly *Sargassum* sp. and its widespread occurrence is a relatively recent (last 5-10 years) phenomenon (see Morton and Raj, 1981). Due to the large amount of algae present, the nutrient levels measured probably underestimate the problem, as much of the nutrient input would be rapidly utilised by the algae. *Sargassum baccularia* can increase its tissue nutrient levels by up to 40 % following artificially introduced nutrient pulses (Schaffelke, 1999). It should be noted that these nutrients are not in fact removed from the ecosystem, as when the algae die, their organic matter will eventually be broken down and nutrients re-released to the water column. Algal-dominated reefs in other parts of the world have been noted to be lower in fish stocks, have less tourism appeal and coral biodiversity (Goreau and Thacker, 1994; McCook, 1999). However, it should be noted that increased nutrients may not lead directly to macroalgal overgrowth of corals. The influence of other factors such as the abundance of herbivores (e.g., sea urchins, grazing fishes) to graze the algae also is important (McClanahan, 1997; McCook, 1999). These herbivore species are often eaten by local people in the area and may be overfished as well as suffering from a degradation of their habitat. The coral bleaching events and crown of thorn starfish infestations which have occurred in Fiji (Vuki *et al.* 2000) may also have opened up substrate for algal colonisation (see Szmant, 2002).

Some of the highest levels of nitrate were found at sites 2, 3 and 7 on a number of sampling dates although levels for the samples taken near high tide (26/4/02) were considerably lower. These sites are located in 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 (see Fig. 1). 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 is variable. Some discharge partially treated effluent direct to the ocean, some discharge to land and others to municipal sewage treatment plants. 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.

Table 2 Seawater nutrient concentrations and nitrate:phosphate (N:P) ratios

Sample Site and Date	Time from low tide (h:m)	Salinity	Nitrate (mM)	Phosphate (mM)	N:P ratio
25/3/02					
2	4:59	35.0	1.33	0.10	13
4	3:59	34.3	0.61	0.11	6
5	4:14	34.8	0.38	0.07	5
6	4:34	34.6	1.24	0.07	17
7	4:49	35.0	0.35	0.09	4
8/4/02					
1	2:18	33.5	0.70	0.08	8
2	1:38	33.1	3.87	0.11	35
3	1:28	33.5	0.57	0.09	6
5	0:23	33.3	1.52	0.12	13
7	1:18	31.7	3.39	0.15	23
8	0:38	33.2	1.80	0.12	15
9	3:58	27.4	2.30	0.33	7
10	0:54	31.4	2.14	0.15	14
26/4/02					
2	6:06	34.0	0.37	0.15	2
3	5:56	33.7	0.56	0.11	5
7	5:31	31.8	1.85	0.20	9
8	4:41	34.3	1.35	0.17	8
11	4:56	33.1	0.98	0.13	8
12	5:06	33.9	1.15	0.18	6
13	5:46	33.6	1.07	0.14	8
14	6:16	32.7	0.44	0.16	3
15	6:21	33.9	0.25	1.51	0.2
16	6:26	34.0	0.10	0.28	0.4
27/4/02					
2	1:17	33.5	5.90	0.29	20
17	1:02	34.1	0.71	0.20	3
24/6/02					
2	0:40	31.9	7.01	0.25	28
3	0:30	32.5	3.32	0.25	13
5	0:40	32.7	0.27	0.13	2
7	0:10	32.7	3.92	0.30	13
8	0:05	32.7	1.51	0.19	8
9	0:27	33.0	1.05	0.28	4
10	1:02	32.2	0.98	0.12	8
13	0:20	33.0	1.82	0.17	11
18	0:53	32.7	2.81	0.31	9
MEAN			1.69	0.21	8
SD			1.60	0.24	7

Table 3 River water nutrient concentrations and nitrate:phosphate (N:P) ratios

Sample Site and Date	Salinity	Nitrate (mM)	Phosphate (mM)	N:P ratio
26/4/02				
Votua Creek	0.2	6.9	0.53	13
Tamanua Creek	0.1	7.7	1.27	6
Sovi River	0.3	24.7	1.04	24
Sigatoka river	4.9	5.0	1.37	4
27/4/02				
Sigatoka River	0.1	14.7	3.40	4
Korotogo Creek	18.8	1.9	1.01	2
Navugayago Creek	0.1	15.0	0.50	30
MEAN		10.8	1.30	12
SD		7.8	0.98	11

The mean N:P ratio in the present study was 8 (Table 2) which compares to a mean of 10 found by Morrison *et al*. (1992). In open ocean seawater, N and P are found in a ratio of about 15 N:1 P which is also the ratio of their utilisation by phytoplankton. Hence this ratio gives an indication as to whether a water sample is enriched with either N (ratio > 20) or P (ratio < 10) relative to unpolluted levels. There was considerable variability in this ratio between different sites in the present study but in general it appears that the seawater within the fringing reef on the Coral Coast is more enriched with phosphate than nitrate. Site 15 (Korotogo River) and the nearby site 16 had a very low N:P ratio indicating enrichment with phosphate, possibly from fertiliser use in the river catchment or detergent discharges from the neighbouring village. In contrast, Site 2 often had an elevated ratio indicating enrichment with nitrogen (Table 2). 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, 1977). The rivers are definitely a major source of nutrients to the coast though, as nutrient concentrations in the rivers were generally higher than the seawater samples (Table 3). However, where most of the rivers meet the ocean there is an area where no reef is present due to the freshwater discharge. Therefore the effect of the nutrient input is probably a lot less than inputs to a more enclosed area of the reef. The mean N:P ratio in the rivers was higher than in seawater but was also very variable. The large Sigatoka River had a low N:P ratio of 4 which may be due to the influence of phosphate fertilisers on agricultural land in the catchment. Phosphorus in non-fertilised soils in the area is generally very low (Leslie 1997).

The elevated nutrient levels are of concern given the importance of the Coral Coast for the local communities and as a tourist destination. A large number of tourists come to Fiji to see tropical reefs, colourful fish and to swim in clear, clean water (not floating algae). If the reef ecosystems and biodiversity contained there 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 along the Coral Coast is likely to increase as the reefs are broken down by wave action and not regenerated.

Immediate action is needed at community, regional and government levels to try and reduce the nutrient inputs to the Coral Coast. An integrated approach to coastal management is required to manage and control land-based sources of wastes before they enter the marine environment. Research in Jamaica has established that a population size of less than 500 people per 100 m of shoreline is the maximum that can be sustained without very good sewage treatment (Goreau and Thacker 1994). We feel that tertiary and biological sewage treatment is necessary for all areas on the Coral Coast with a population density greater than this, and particularly at the resorts. Although improved treatment systems would need some capital investment, in the long term the benefits will offset this expenditure. One resort (Shrangri-La Fijian) is currently utilising biological treatment ponds with aquatic plants present that uptake significant amounts of nutrients from the resort's sewage effluent (Mosley, unpublished data). This approach is one that could be more widely adopted, as it is relatively low cost. On a government level, water quality standards specific for coral reefs should be developed into legislation and effluent discharges made to conform to them. Other practical options to consider may be a ban on the use of phosphate detergents in the area, the use of composting toilet systems in the villages and small resorts, and establishing more marine protected areas.

The finding of elevated nutrient levels along the Coral Coast is important not just as an academic or scientific exercise. Over the last 30 years, researchers in Jamaica have documented the death of their healthy coral reefs. Urgent action is needed if reefs along the Coral Coast of Fiji do not suffer the same fate.

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