

**INSTITUTE OF APPLIED SCIENCES
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Consequences and Recommendations

IAS ENVIRONMENTAL STUDIES REPORT NUMBER: 90

By

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1.0 INTRODUCTION

This report is the result of a request by aid donor Kevin Dawes of AUSAID and the engineering contractor, John Campbell of Sinclair Knight Mertz, to provide additional information to the baseline assessment carried out as part of the environmental impact assessment for the second installation of the pipeline for the Pacific Fishing Company (PAFCO) (Tamata and Lovell, 1995). This request is the result of a dramatic change in the nature of a coral reef near the site of the outfall of the first pipeline where algae is now observed to extensively cover the northern end of Balavu Reef, offshore from Levuka, Ovalau Island (Fig. 1).

A literature review was undertaken to provide insight into the nature of the alteration of the reefs biological composition. The sites were revisited briefly on July 11th and 12th 1996, just as the last clamps were being put in place on the reconstructed pipeline by the divers of Dive Operators (Fiji) Ltd. During this visit, an attempt was made to interview some of the PAFCO Management staff and other personnel on site including the representative of the sub-contractor (J S Hill) on site, Mr. Ishri Prasad.

The phenomenon involves a proliferation of the macro-algae, *Sargassum sp.*, which now overwhelmingly dominates the reef flat. The cause and consequences of this change is the subject of this paper. Examples from Fiji and elsewhere are cited to support the observations and conclusions. Though perhaps not yet manifested, the consequences of both waste water contamination and the risk of ciguatera resulting from the new macro-algal environment are discussed. The cause of this algal proliferation is important to define, particularly if it effects other reefs will cause concern among those people who use these reefs as a subsistence or artisanal fishery.

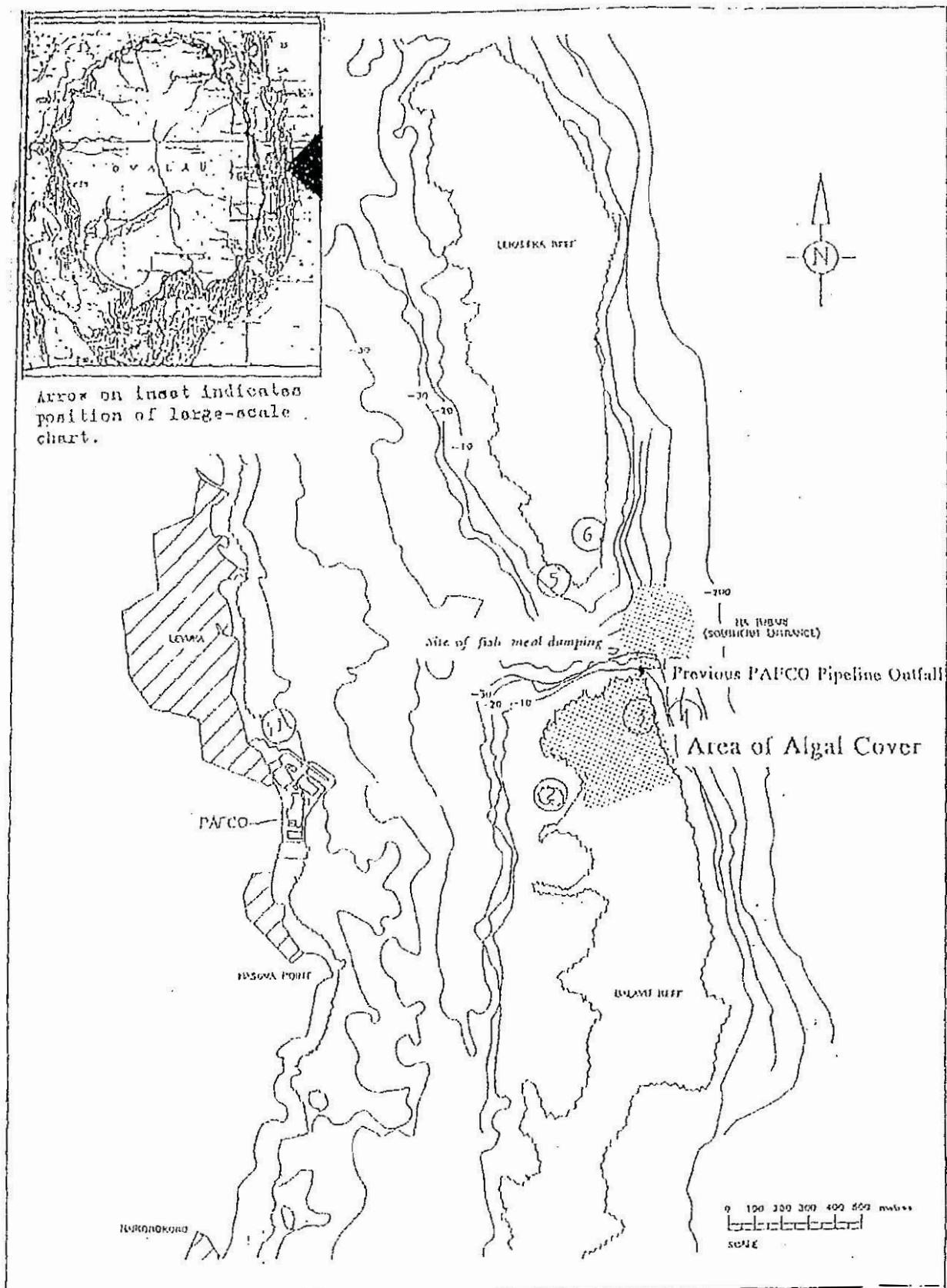


Figure 1: Chart of Levuka Harbour showing the location of the monitoring sites (numbered 1-6) established during the baseline study concerning the second pipeline (Tamate and Bale, 1995). Each site has a cluster of 3 quadrats to be used to assess the effect of the pipe and effluent (adapted from Riedel & Byrne - Irwin Atrop Pacific).

1.1 PREVIOUS BASELINE STUDY

Highlights from the report *BASELINE SURVEY AND WATER QUALITY FOR THE LAYING OF A WASTE WATER OUTFALL AT PAFCO* (Tamata and Lovell 1995) provide a summary of the initial observations.

"Summarising the general observations and the nature of the monitoring quadrats, the study sites represent a good deal of variability. This variability is expected due to the diverse physical whi results in the natural zonation on the reef. The occurrence of cyclone Kina presented another factor which affected the coral reef environment.

What is unusual is the contrast between the two reefs on either side of Na Tumbani channel between Balavu and Lekaleka Reefs. The change which has occurred since the previous monitoring period on north Balavu Reef has been dramatic. It is covered with *Sargassum*, intertidally, with substantial coral death on the tops of the coral bommies or knolls. In contrast the channel and the adjacent intertidal reef area on Lekaleka Reef are characterised by a luxuriant coral assemblage on the top of the coral knolls and around the fringe of the reef flat. There is also dense proliferation of coral on the reef flat on Lekaleka reef. Unfortunately, the nature of the coral being almost wholly dominated by the genus *Acropora*, is generally sensitive to environmental change.

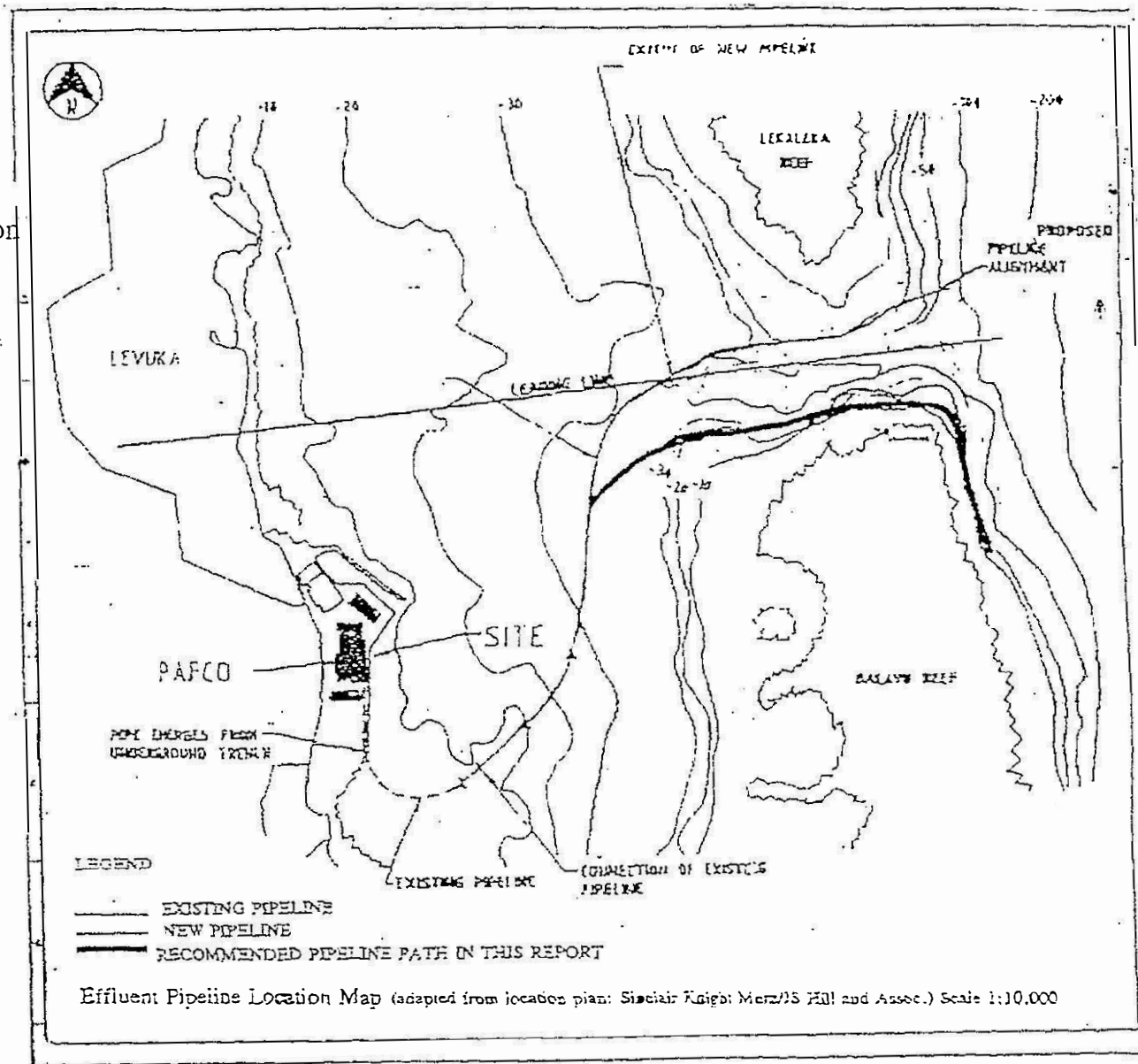
The difference in the nature of the two reefs may well be the result of the initial effluent outflow from the previous PAFCO pipeline. It is most probable that the effluent, which is high in nutrients, has stimulated the growth of the *Sargassum* which, once established, proliferated. *Sargassum* is often abundant on the intertidal foreshore of villages due to the ground water runoff conveying nutrients from septic systems into the marine environment. A proliferation of this algae due to sewage and other waste water runoff has been observed at Matamanoa Island (Nagaisima, 1995 in prep) and at Beacheomber Island (Brodie and Ryan, 1987). Detailed experimentation, in which corals were exposed to variation in the type and dilution of sewage, revealed a pronounced effect. The growth of algae was greatly enhanced at the expense of the corals. Coral morbidity and mortality under experimental conditions were apparently not directly related to effluent toxicity, but were the result of competition with the algae for space and especially light" (Marszalek, 1981)

If this is so, then the effect is likely to extend to the adjacent reef. As the effluent will be less saline than the seawater, it will float to the surface, being carried rapidly and for some substantial distance, depending on the tidal currents and the effects of wind drift. The tidal current flows strongly in through the passage on the flooding tide (Lloyd and Peter, 1989) and is subject to prevailing wind drift. It is hoped that the dilution effect will prevent such contamination but this will rely on placing the outfall sufficiently far from the channel so that the wind drift will convey the surface effluent onto Balavu Reef which has already been affected (Fig. 2).

The consequences of this are more serious as this reef is a source of food and used by Levuka village. With the altering of the nature of the reef flat to something similar to Balavu Reef, it will become less productive in terms of food products. Judging from the numbers of people observed engaged in this activity during the low tide survey (40 - 50 people), it is responsible for a substantial contribution to the village food supply. Failure to observe caution in the siting of the pipe or to have a contingency plan in place if problems develop, may result in compensation payments or render the pipeline unacceptable."

Figure 2:

Comparative diagram of the location of the existing pipeline and its proposed outfall with the path recommended by this report on the basis of minimising reclamation.



OTHER EFFLUENT HAZARDS

As well as the stimulation of algal growth, there is an adverse effect from the presence of elevated levels of phosphorus and nitrogen on the growth of corals, generally. Their skeleton loose strength, becomes crumbly to the touch.

Contamination by industrial wastes and toxic bioaccumulation may present another hazard to the disposal of sewage and industrial effluent near an area where fishing and gleaning occur. This may cause degradation and the poisoning of the artisanal fishery. Seafood may become contaminated, swimmers and gleaners maybe subject to bacterial and viral diseases (Westman 1974; Miller 1978; Beder 1989).

RECOMMENDATIONS:

It is recommended that the outlet to the pipe is placed as far to the south of the channel as is practicable as there seems to be a substantial change in the nature of the reef near the previous outfall (Fig.2).

Careful monitoring of the effects of the effluent on Lekaleka reef is essential.

A contingency plan must be in place to divert the flow of effluent if a problem develops and to resite the outfall further away from the channel.

The overflow from the waste water well should be lengthened substantially. The seawater intake providing water to the cannery is adjacent to the present overflow and must, during times of overflow, take in faecal material from the waste water. This effluent has a large component of untreated sewage. This is a highly unsatisfactory practise and must cease **immediately**.

Figure Legend

Figure 3:

- (a,b) Thriving coral assemblages in the back reef areas of Balavu Reef prior to the pollution which has now inundated the coral (November, 1990).
- (c) The bleached corallum of a massive coral which has recently died as the result of shading and abrasion by the algae (June, 1995).
- (d,e) The algal covered reef flat with the PAFCO cannery in the background (June, 1995).

Figure 4:

- (a) Aerial photo showing the extent algal cover on the Balavu Reef flat (July, 1996).
- (b) Aerial photo showing Balavu Reef and the adjacent Lekaleka Reef. The seaward end of Na Tunbari channel between the reefs is where the second outfall will be sited. Due to the current structure of the channel area, concern is expressed that Lekaleka reef will be also be affected by algal growth and an effect on the artisanal fishery (July, 1996).
- (c,d) Coral growth on the southwest edge of Lekaleka reef (June, 1995).
- (e) Despite the presence of the pipeline, effluent still flow into Levuka Harbour. This frothy liquid waste is likely to comprise cleaning compounds (September, 1992).

2.0 HISTORY OF CHANGES TO BALAVU REEF

Environmental monitoring has been conducted on this reef since 1990 when the first monitoring sites were set up and photographs were taken of the reef flat and shallow backreef area. Inspections were conducted at 6 monthly to yearly periods until present, with the exception of 1994 when no monitoring was carried out. (Green, Lloyd and Lovell 1990; Green, and Lovell 1990; Green and Lovell, 1991; Green and Lovell, 1992; Green and Lovell, 1993; Tamata and Lovell 1995; Tamata and Lovell 1996a.

2.1 The phenomenon - Algal proliferation on Balavu Reef

Balavu Reef and the adjacent barrier reef, Lekaleka Reef, have been the subject of a recent baseline monitoring program to enable the effects of the present marine outfall to be assessed (Tamata and Lovell, 1995). As described in the baseline report, the survey observed that there was a proliferation of the macro-algae, predominantly *Sargassum cristatolum* on the north end of Balavu Reef. The reef flat was covered with an algal mat to the exclusion of the previously dominant organisms such as the hard corals. Several examples were observed where the corals were dying due to abrasion or smothering. Concern is expressed that the observed phenomenon may spread to adjacent areas which serve as important gleaning areas.

As the algal growth occurred between monitoring periods, the event or events which caused this effect need to be clarified. General observations include:

1) The change is relatively recent. More specifically, algal growth flourished in the period between 11th January 1993 when the last monitoring visit for the previous outfall was conducted, and 18th May 1995 during the baseline survey for the reconstructed outfall. The monitoring period after cyclone Kina on 11th January, 1993 reported that the reef flat was unchanged with respect to the abundance of macro-algae but suffering from wave and scour damage due to the storm (Green and Lovell 1992; Green and Lovell, 1993). The macro-algal proliferation was first observed during the baseline assessment for the reconstructed outfall which was conducted on 18 May 1995. This was again reported in the Progress Report of August 1995 (Tamata and Lovell, 1995). Subsequent analysis of a satellite image (Landsat TM) of Balavu Reef in the visible and infra-red spectrum taken during July, 1993, provides the first evidence of the algal presence.

The first pipeline began operation in late 1991. Its operation was intermittent. Problems with the pump operation, gas in the pipe due to air entrainment or organic decomposition prevented use and caused it to float to the surface occasionally. The pipe being broken several times due to anchor damage. Though the general period of pipeline operation is known, the precise quantities of material voided at the various openings and the periods of time involved remain unknown. Three areas of effluent escape were:

- i) the outfall at the end of the pipe,
- ii) the air vents which were present on elevated portions of the pipe generally around the northern perimeter of Balavu Reef and

- iii) the broken pipe located in mid-channel (approx. 450 metres) from the cannery.
- 2) The effect is localised to the northern end of Balavu Reef.
 - 3) The phenomenon has persisted for three years.

2.2 Possible Causes of the Phenomenon

Events which occurred during that time and considered to have bearing on the phenomenon:

- 1) Cyclone Kina had catastrophic effects on some of the coral reef environments. Exposed or branching corals were worst effected. The reef flat, as elsewhere, had patchy damage where in some areas rubble buried areas of reef. Sheltered corals were unaffected. The massive corals were most resistant though suffering abrasion during the storm.
- 2) An effluent pipeline was installed to convey cannery waste water to the outside of the barrier reef. The pipe was commissioned in September 1991 with the outfall on the northeast corner of Balavu Reef at the seaward margin of the channel, Na Tumbari or the South Entrance (Fig. 1).
- 3) Fish offal (bits of bones, flesh, guts, skin etc.) and fish meal remnants which accumulate whenever the Fish Meal Processing Plant breaks down are dumped in the channel adjacent the reef (Fig. 1). This generally is closest to Balavu Reef in close proximity to the effluent outfall.

The dumping of such high BOD material is not monitored. In fact it has been observed that when the weather is rough and wet, the fish waste is simply dumped in the harbour (pers.comm. Tamata/divers on site). Depending on the tide and wind time, this material could end up in the open sea outside of the reefs, or back on the fringing reefs and even on the shores along the north-eastern coastline of Ovalau.

3.0 Impact of Pollution on Coral Reef Ecology

Considerations of coral reef ecology is important to the understanding of the mechanism responsible for the increased dominance of the algae (see Appendix 1). According to Hatcher (1984), pollutants reaching coral reefs may alter reef community structure and enhance algal dominance by such factors as :

- Excluding grazers due to toxic, turbidity or increased predation effects.
- Reducing competition with other benthic organisms (e.g. coral) by inhibiting their growth or killing them.
- A clearing and/or modifying a large area of the substrata in a manner, or at a time which favoured colonisation by a formerly rare alga.
- Increasing the availability of potentially limiting nutrients.

The persistence of the algal community after establishment, perhaps by a single event, may be due to several effects:

A macroalga which had previously been consumed incidentally (i.e. along with the turfing algal community in which it was embedded) by large herbivorous fish feeding non-selectively became recognisable to the grazers. The algae was avoided due to its relative unpalatability. This allowed the algae to reach a size where by it escaped smaller and became more unacceptable to the larger grazers size related escape from predation.

The macroalga was able to inhibit the colonisation of and/or out compete smaller forms for potentially limiting resources (e.g. light) due to its thallus morphology, which formed an overstory.

Micrograzers may use the macroalga as shelter, and feed on potentially competing microalgae. The food-size dependent selectivity of grazers may be primary important where preference is inversely related to thallus size, as it serves as a positive feed back, facilitating shifts from micro to macroalgal-dominated communities.

Chronic elevation of nutrients due to effluent or dumping of fish wastes stimulated growth of algae which were formerly limited by a nutrient deficient environment.

4.0 OTHER OBSERVATIONS OF ALGAL ABUNDANCE WITHIN FIJI

Within Fiji, high algal cover has been observed in areas thought to be subject to nutrient input. As cited earlier, the pollution of ground water and its effect on the marine environment adjacent the village is manifest in the dense growth of algae. Other examples are:

1. The proliferation of *Halimeda* sp. after the destruction of the *Acropora* overstory by Cyclone Kina near Levuka Vakaviti
2. A similar situation at Vuda Point, Ba where it was hypothesised that the breakdown of petrochemical spills has given rise to unusually high algal growth off shore.
3. The periodic blooming of the *Sargassum* along the Coral Coast during the summer months has altered the nature of the reefs.
4. Resorts such as Mana, Matamanoa and Beachcomber have all experienced a chronic macro-algal presence as the result of nutrients entering the coral reef environment.

As with Balavu Reef, the biomass increases dramatically during the summer months due to greater insolation and warmer water temperatures.

5.0 CAUSE AND EFFECT:

From the above points, it is evident that many factors may influence the presence and growth of macroalgae. Following is a discussion of the features considered important as the most important causal events.

5.1 Causal events

1) Substrate availability

Algal proliferation as a result of cyclonic damage is highly unlikely as the area as the area affected is isolated. This isolation of effect is indicative of a localised influence.

The isolation of the phenomenon was verified by aerial observation (2/7/96) (Fig. 4 a,b). Photographic documentation of the existing situation was made as well as observing the entire barrier reef system. Nowhere was there an algal abundance of the magnitude observed on Balavu Reef (inspection included the northern, leeward or western reefs, and the southern reefs which extend to Motoriki).

2) Abundance of herbivores

There is no evidence to suggest that there has been a reduction in herbivores in this area. Migration from other reefs, where normal community balance exists, would be expected. There has been no attempt to census these herbivores, but they appear to be in normal abundance.

3) Eutrophication (from Marszalek 1987):

Increased limiting nutrients is a factor which is conducive to algal proliferation and has been described in a number of publications. The fact that this event is coincident with the commissioning and use of the first pipe line, and dumping in the channel area of fish meal remnants and offal comprising fish heads and filleted skeletons, provides a strong case for associating cause and effect.

5.2 Eutrophication

Eutrophication is a form of artificial fertilisation. Whether it be sewage or cannery by-products, the presence of nutrients in abundance has been described in the literature as causing a shift in community structure to less desirable species. Coral reefs are particularly susceptible to this type of pollution because of the delicate balance allowing the coexistence of a large number of species. This balance is in part maintained by relatively low levels of available nutrients in tropical sea-water. This balance is upset by making available large amounts of nutrients which lead to a dramatic increase in the population of certain species, usually at the expense of other species. In the Balavu Reef situation, the brown algae *Sargassum* sp. has flourished to the exclusion of a large portion of the previously resident species, particularly the hard corals.

The compounds in the effluent that are generally considered to drive this effect are nitrates and phosphates. In the case of the cannery, the effluent may contain chlorine and other toxins which originate from cleaning agents, in addition to sewage and fish processing waste. The actual composition of the effluent is only categorically known.

This problem is now being researched, but both nitrogen and phosphorus are possible agents which cause the retardation of coral growth. Excess phosphorus has been implicated in the growth of the algae causing ciguatera or fish poisoning and in the outbreaks of the crown-of-thorns starfish due to the preference for the macro-algal habitat by the species life stages (Birkeland, 1982) (See Appendix 2 - The Incidence of Ciguatera Poisoning). The fouling of the seagrass beds through epiphytic growth with the subsequent smothering is another potential consequence of excessive nutrients in the environment.

Examples: Hawaii and Florida

A well documented, example of the effect of eutrophication resulting from organic wastes is that of Kaneohe Bay, Hawaii. By contrast, Southern Florida provides an example of the effect of sewage being minimised by good natural flushing. In both cases, problems created by sewage were solved by employing pipelines to convey the offending effluent away from the reef systems. This was the approach adopted by PAFCO to solve the pollution problem in the harbour but resulted in a undesirable situation due to the proximity of the reef area and local hydrography and prevailing wind conditions.

Kaneohe Bay was polluted by sewage for 30 years, until a diversion of effluent to a remote ocean outfall. The potential impacts of sewage on the fauna include nutrient loading; exposure to toxic substances such as heavy metals, pesticides, herbicides, chlorine; etc. and an increase in biochemical oxygen demand (BOD). Evidence suggests that nutrient loading was the primary cause of the coral mortality and changes in community structure. The basic effect of nutrient loading was to greatly stimulate the growth of some groups of organism at the expense of others leading to a shift in the community structure. Although productivity and biomass increased, corals as a group did not benefit from that increase. Increased levels of nutrients, especially nitrogen and phosphorus and food chain relationships resulted in the following changes in community structure in Kaneohe Bay:

- 1) phytoplankton and zooplankton grazers increased dramatically,
- 2) population of benthic filter feeders e.g. sponges and zoanithids increased in response to increased food supply (plankton and organic detritus),
- 3) the sediment-feeding sea cucumber appeared in large numbers.
- 4) the growth of benthic algae, was greatly stimulated,
- 5) coral decreased in abundance and survivors probably has decreased growth rates.

Thus the same conditions of fertilisation of the reef environment which promoted the growth

of phytoplankton, benthic algae, filter-feeders and many other organisms, also promoted the demise of the corals and destruction of the reefs.

Under eutrophic conditions, the relatively slow growth rate of corals can be fatal when in competition with fast growing organisms, especially benthic algae which compete directly for space and light. As on Balavu Reef, the corals died and the once luxuriant coral reef became a reef flat of fleshy algae. Recolonization by coral is inhibited because the reef substrate colonised by algae is inaccessible to coral larvae. Under normal (non-eutrophic) conditions the growth of algae would have been limited by nutrient availability, grazing by fishes and other natural controls.

Subsequent to diversion to the ocean outfall. The response was very rapid. There was a decrease in plankton and suspended particulate which resulted in an increase in water clarity. Within weeks the filter feeders began to die in response to diminished food supply. One year after the diversion, the benthic flora and fauna of the bay had not returned to pre-sewage conditions (Smith et al 1981). Five years after the outfall diversion, the algal cover declined to 25% of its pre-diversion abundance and live coral coverage almost doubled (Maragos et al. 1985).

In the state of Florida, good natural circulation has allowed the reefs to cope with the nutrient loading originating from the coastal populations. Sewage pollution was successfully disposed offshore sewage from the densely populated coastal strip between Miami and Palm Beach. This approach was adopted in the interests of public health. Ten ocean outfalls discharge enormous quantities of sewage into the Gulf Stream Circulation. Good circulation through tides and coastal currents contribute to dilution of the effluent, conveying it away from the reefs.

6.0 EFFECTS

6.1 Health

Concern for the health of users of a polluted coastal environment is based on the fact that human pathogens are able to survive in seawater and cause infections in man (Edmond et al. 1979; Flora et al. 1975). The best known examples are outbreaks of infectious hepatitis and gastroenteritis from the consumption of shellfish harvested from sewage polluted water. The pathogens are in the form of bacteria, enteroviruses, protozoa, etc.

Sewage pollution was eliminated or at least significantly reduced by the upgrading of sewage treatment facilities resulting in the elimination of outfalls discharging untreated sewage and by extending the ocean outfall to the point of discharge that is remote from reefs and bathing beaches.

In tropical environments, ciguatera fish poisoning may result from the presence of a habitat which is conducive to the pathogen which thrives, living within the foliage of fleshy macroalgae. Its recorded presence in Ovalau gives cause for consideration of the problem (Appendix 2).

7.0 DISCUSSION

Studies confirm that nutrient rich effluent such as sewage or organic waste create a major stress to coral and are a stimulant to algal growth (Berwick and Faeth 1988, Littler and Littler 1985, Richmond 1993, Cuet et al. 1988). In the presence of elevated nutrients community structure will change to that of algal dominance with an increasing abundance of herbivorous, detrital and filter feeders. This has been considered as the underlying influence in regional distributions of coral reefs (Webber and Thurman 1991). If the nutrient source is removed through abatement or diversion, the community structure will revert to the natural situation in a reasonably short time (Maragos et al. 1985; Smith 1977; Smith et al. 1981; Evans et al. 1985).

7.1 Previous Disposal

The waters adjacent the PAFCO cannery have, since its inception, been a convenient way of disposing of its liquid wastes. This waste has been characterised by fish fats and oils, sewage and other suspended material that has made swimming in these waters objectionable. The material is generally transported along the coast for several kilometres, with much of the solid, buoyant material being deposited on the beach or in the intertidal zone. In the depauperate reef area, anoxic sediments occur due to its high organic content, the fouling of moored boats and the smell of the decomposing material are some of the consequences.

Apart from the impact of sewage and other semi-solid organic matter, large solid pieces of bones have been discharged along the pipeline. Divers laying the pipeline have found a heap of bones, approximately 3 m wide and 5 m high in about 50 m of water within the harbour, between buoys 1 and 2, at the site where the reconstructed pipeline had broken recently. The divers have also encountered a bigger pile (as high as 10 m) of such material in the deeper part of the channel, most probably where the first effluent pipeline was damaged by boat anchors. The presence of bones are indicative of the release of additional nutrients from the decomposition of fleshy portions of the fish waste as well as the liquid effluent. This presents an additional source of effluent in the proximity of the reef.

This filtering process for the fish processing wastes has not operating efficiently. The basket in the filtering tank is clearly inadequate for the volume of waste passing through. At the time of the recent visit, the PAFCO Maintenance Superintendent was aware of this problem and attempting to rectify it. (Per.comm., Tamata/Kumar, July 1996).

In the absence of the option for an on-site treatment (John Cooke, AIDAB consultant, pers. comm.), the decision to construct a pipeline to convey effluent from the PAFCO cannery beyond the adjacent barrier reef appeared as a welcome alternative. It has been considered successful in clarifying the waters inshore during its brief period of operation. Unfortunately, it has had an effect on the adjacent barrier reef which has yet to be evaluated fully in terms of its consequences. Ocean disposal for an island nation where land is at a premium, can be a convenient method if the right circumstances exist. Even with some problems eventuating, it may be preferable when all costs and benefits are analysed.

7.2 Inadequate Record Keeping

Unfortunately, a fuller understanding of the effect of the effluent or fish offal disposal has been greatly compromised due to the inadequate record keeping by PAFCO management. During the recent visit to PAFCO on July 11th and 12th, the PAFCO Maintenance Superintendent confirmed that no record is kept of the days when fish meal remnants are dumped in the sea, or when the fish meal plant broke down. The only way to get such information was indirectly from the daily production records. Unfortunately, we have not been able to view these records despite repeated requests to PAFCO Management.

It is important to be able to differentiate between the effect of the fish meal dumping and the effluent, as the meal waste dumping will cease with the repair or purchase of processing equipment. Concern will then remain for the effect of the piped effluent. At this stage, there is a date for the commissioning of the first pipelines operation but there is no quantification or other flow through data. Furthermore, the down time due to pipeline damage or pump is unknown. The periods and quantities of the dumping of the fish meal unknown.

7.3 Incomplete Facility

Regrettably, much of the liquid wastes continue to empty into the waters adjacent the plant (Fig. 4e). When the sewage pumps are non-operational or, as in the present case, the pipeline is receiving on, the raw sewage is dumped within the harbour which contaminates the shores and waters of Levuka. Ironically, the proximity of the sewage overflow pipe to the canneries seawater intake, increases the risk of entrainment of sewage polluted seawater for the processing of the fish for human consumption.

During the recent visit to PAFCO on July 11th and 12th, a bright orange liquid discharge was draining from the freezers in the ice plant directly into the harbour inside the wharf area, next to the Ports Authority Office. This liquid is discharged during normal freezer maintenance operation and it is presumed to be very toxic, having a high ammonium concentration, according to workers interviewed. In fact it was pointed out that the liquid kills all life forms with which it has direct contact. This explained why the concrete seawall and stones in the area appeared very clean with no sign of algal encrustation or molluscs as observed on the southern parts of the wharf.

Unfortunately, the continued presence of the inshore effluent diminishes the value of the pipe. High coliform and nutrient levels continue to be recorded inshore despite its successful operation. The nature of the slick is visually undiminished. The presence of the gas vents further offshore has created the presence of a new slick. While it is true that the bulk of the waste is transported offshore, that which continues to be voided inshore results in poor water quality that is far below acceptable standards. The consequence of transporting the water offshore has created additional problems both in terms of health and environmental effects.

8.0 CONCLUSIONS

Several factors may have contributed to the growth of the algae on the northern end of

- 1) Cyclone Kina may have predisposed the reef to the algal proliferation by the denuding portions of the substrate but this factor is considered of minor importance.
- 2) It can only be inferred that the nutrient levels were elevated by effluent from the first waste water pipe as its operation was sporadic and its area of influence variable during the period being considered. In the recent monitoring of the outfall, elevated levels of both nitrogen and phosphorus have been detected in the vicinity of the outfall (Tamata and Lovell 1996a). Similarly, it is inferred that nutrient levels have been elevated by the dumping of fish meal by PAFCO at the mouth of the channel. In both cases, tidal action would have conveyed the nutrients into the lagoon system and on to the reef (Lloyd and Peter, 1989).
- 3) The PAFCO Management needs to improve on the regulation of and monitoring of the effluent leaving the plant, in particular the screening of fish waste passing through the pumps, to ensure the large solids are retained in the factory and reused or composted. During the July 1996 visit, the Plant Maintenance Superintendent was reportedly working with Sinclair Knight Merz on a system of improving the screening process for the fish waste taken out in the pipeline.
- 4) The fish meal problem was being addressed by the PAFCO Management at the time of the site visit in July 1996. The Plant Maintenance Superintendent was considering a number of quotations for a new fish meal plant to replace the existing one.

9.0 RECOMMENDATIONS

- 1) Due to the prevailing currents, wind drift and wave action, 2nd pipeline outfall should be sited adjacent the area already affected by algal growth on the seaward edge of northern Balavu as far south as possible (Fig. 2). In this manner, the algae abundance on the reef flat may serve as a natural sink for the nitrogen, phosphorous and other undesirable components of the effluent. Likelihood of contamination of the adjacent reef which is a popular part of the subsistence fishery is reduced.
- 2) Monitor the levels of nitrates and phosphates near the outfall and on the areas of Balavu and Lekaleka reefs affected and likely to be affected by nutrient elevation to gain a better understanding of the perceived effect.
- 3) Further analysis of the outfall to determine toxicity or presence of potentially harmful components such as coliform levels and heavy metal.
- 4) Monitor the presence of toxins or contamination (faecal, heavy metals, etc.) in the food items traditionally gleaned from the reef.
- 5) Establish the nature of the effluent by obtaining the current cannery disposal plan.

- 6) Establish a construction schedule for the entrainment of all of the liquid effluent into the outfall system.
- 7) Establish procedures and accountability for the recording of the nature and quantities of waste disposed offshore.
- 8) To lessen the affects on the offshore reefs, provide some level of pre-treatment of the effluent on-site before ocean disposal.
- 9) Monitor the presence of *Gambierodiscus toxicus* in the macro-algae on the reef flat.
- 10) Establish both a system for the monitoring of the prevalence of ciguatera poisoning and for the incident of ciguatoxin in fishes likely to be concentrating it.

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APPENDIX 1: ALGAE - THE ECOLOGY OF ABUNDANCE

The purpose of including an example of a ship wreck which resulted in unusual algal dominance is that it provides a good description of alternative hypotheses which must be resolved before reaching an informed conclusion as to the origins of the unexpected proliferation of macro-algae.

(From Hatcher, BG 1984. A maritime accident provides evidence for alternate stable states in benthic communities on coral reefs. *Coral Reefs* 2:199-204).

The bulk carrier *M.V. Florida* grounded on Myrmidon Reef on the Great Barrier Reef, Australia in June, 1976. The vessel's initial impact was on the windward margin where it grounded on the reef crest coming to rest on the reef flat. A large quantity of powdered rock was deposited on the reef flat. It was subsequently washed away within months.

Documentation of the effect of the wreck was in April, 1980, four years after the event. The grounding is an example of a permanent change in the reef flats algal community. The wreck precipitated an apparently stable macroalgal dominated shift from the microalgal dominance due to the disruption and temporary pollution resulting from a ship grounding and the dumping of its cargo (Hatcher, 1984).

Algal Response

Elevation in dissolved phosphate did not cause an increase in macro-algae.

A thin layer of filamentous and coralline algae had grown over much of the rubble in the areas worst effected. Within eight months, this had died back and the algal cover was much the same as the surrounding area in appearance. The algal cover in the zone greatest affected remained higher in percentage cover than the adjacent areas.

Likely effects of the ship grounding:

- Effect localised
- Presence of a macroalgal bloom sometime occurs (Walker & Ormond, 1982; Hatcher 1984) though not in this study. Either the presence of herbivores was sufficient to crop the algae in what is a relatively small area. Wellington & Victor (1985) found there to be a proliferation of algal development after wide spread coral death due to the El Nino events of 1982-83 increasing the area of available substrate. In this case, it is presumed that the nature of the substrate was not suitable for settlement.
- The initial increase in pollution by the phosphate cargo was the result of the most soluble fractions dissolving and dispersing.
- The residual presence of the cargo may effect resettlement. In the case of phosphate, it may be found to reduce the rate of calcification (Simkiss, 1964; Kinsey and Davies, 1979).

Examination of a wreck 5 years after the event has given rise to speculation that the shipwreck caused a permanent change in the nature of the algal community. An area characterised by a microalgal (unilayered assemblage of turfing and coralline algae) environment developed a macroalgal assemblage (fleshy red algae, *Asparagopsis taxiformis*, which developed an overstory). Due to its size and general unpalatability to grazers, the macroalgal community persisted as an alternative stable state.

Functionally these two assemblages are distinct as the microalgal community is constantly grazed (Hatcher 1982) while the bulk of the primary production in the macroalgal communities enters detritus food webs (Mann 1982 in Hatcher 1984). The macroalgal overstory overgrows the live coral resulting in less than 1% coral cover. Micro invertebrates (primarily amphipoda and crabs) were much more abundant in the macroalgal-dominated community (Hatcher, 1984).

From Hatcher (1984) "Temperate hard-bottom communities are subject to dramatic shifts from macro to microalgal dominance (North 1971; Mann 1977), which can result in new and apparently stable communities with an altered species composition and reduced algal standing crop, productivity and commercial yield (Chapman 1981; Wharton and Mann 1981). Such changes in the fundamental structure of marine benthic communities have usually been shown to be the direct result of destructive grazing by benthic echinoderms in numerical or behavioural response to reduced predation (Estes and Palmisano 1974; Lawrence 1975; Bernstein et al. 1981). But the underlying causes of the shifts and the relative stability of the new community structure remain obscure (Mann, 1977). Are they simply a result of natural cycles in the relative abundance of predators and prey (North 1971; Rosenthal et al. 1974)? Or are they perturbation-related changes between alternate stable states (sensu Holling 1973; Sutherland 1974), requiring another perturbation or natural catastrophe to return the community to its original structure (Jones 1975; Pearse et al. 1977; Simenstad et al. 1978)?

Macroalgal dominance has been induced in coral reef habitats by the exclusion of grazing organisms (Ogden 1976; Lassay 1980), and by fertilisation (Banner 1974). Hatcher documented an apparently stable macroalgal dominated shift from the microalgal dominance due to the disruption and temporary pollution resulting from a ship grounding and the dumping of its cargo of Pozzalin."

The mechanism for the precipitation of this shift in stable states may be attributed to the Pozzalin spill temporarily enhancing the growth of the benthic algae within the affected zone by:

- a) Excluding grazers due to toxic, turbidity or increased predation effects (Dollar and Grigg, 1981).
- b) Increasing the availability of potentially limiting nutrients (Kinsey and Davies 1979, Hatcher and Larkum 1983; Entsch et al. 1983b) or fertilisation (Banner, 1974).
- c) Reducing competition with other benthic organisms (e.g. coral) by inhibiting their growth or killing them (Bak et al., 1978; Dollar and Grigg, 1981).
- d) A clearing and/or modifying a large area of the substrata in a manner, or at a time which favoured colonisation by a formerly

The persistence of the community after the perturbation was because:

- 1) A macroalga which had previously been consumed incidentally (i.e. along with the turfing algal community in which it was embedded) by large herbivorous fish feeding non-selectively (Montgomery et al. 1981) became recognisable to the grazers. The algae was avoided due to its relative unpalatability (Tsuda and Bryan 1973; Norris and Fenical 1982). This allowed the algae to reach a size where by it escaped smaller predators and became more unacceptable to the larger grazers size related escape from predation (Hay 1981)
- 2) The macroalga was able to inhibit the colonisation of (Connell and Slatyer 1977, and/or out compete smaller forms for potentially limiting resources (e.g. light) due to its thallus morphology, which formed an overstory (Littler and Littler 1980).
- 3) Micrograzers used the macroalga as shelter, and fed on potentially competing microalgae (Lobel 1980; Brawley and Adey 1981b) . The food-size dependent selectivity of grazers may be primary important where preference is inversely related to thallus size, as it serves as a positive feed back, facilitating shifts from micro to macroalgal-dominated communities.

Hatcher (1984) discounted the hypothesis of coincidence. Cyclones represent another disturbance which doesn't give rise to such a phenomenon. As well the possibility that the perturbation is continuing due to the sustained release of some chemical other than those measured. This association of the wreck or its cargo and the macroalgal-dominated community and is maintained by this regime. It includes the presumption that the epilithic algal community will return to the microalgal-dominated state following the termination of the perturbation, as a result of physical attrition and recolonisation by better competitors under conditions of intense grazing. This point has been discounted as the Pozzalin doesn't contain nutrients which will selectively enhance the growth of *Asparagopsis* (Segot and Codomier, 1981) nor are they toxic to fish (Doudoroff 1957; McKee and Woll, 1963). More importantly, the major constituents of both the cargo and the hull (e.g. iron), occur in oxidised states which are relatively non-reactive biologically (Stumm and Morgan, 1970).

It is Hatcher's contention that some forms of pollution on reefs, which may have insignificant immediate effects may have significant long term secondary effects on community structure by precipitating a shift between alternate stable states.

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APPENDIX 2

The purpose of including a description of ciguatera poisoning is that the pathogen, a algal flagellate protozoan, has been identified from the Ovalau barrier reef system. The micro-habitat in which the toxic *Gambierdiscus* occurs in its benthic form, is within the foliage of macroalgae such as the *Sargassum* which comprises the algae discussed. The risk remains uncertain without further assessment of the presence of the *Gambierdiscus* in the macroalgae and the bioassay of the fish likely to be effected.

THE INCIDENCE OF CIGUATERA POISONING

Ciguatera poisoning is a significant public health problem in the Pacific. Fiji, according to South Pacific Commission reports of 1991, had the highest number of cases reported in the Pacific with 1,207. They were second to Kiribati with 1,159 cases in 1992. In reality there are probably many more that go unreported. Though deaths from such poisoning are rare, the illness can manifest severe symptoms and the recovery is slow.

Ciguatera poisoning results from eating reef fish that have previously consumed toxic epiphytic dinoflagellates or from eating predators of these reef fish. There are several types of fish poisoning in addition to ciguatera. These include *clupeoid poisoning* (sardines, anchovies or herring) which are plankton feeders and ingest the toxin from feeding on the phytoplankton. Mullet are herbivorous which to a lesser extent feed on the plankton and drift algae occasionally exhibiting *mullet poisoning*. *Tetrodon poisoning* is the result of a toxin characteristic of the group which include the puffer fish, toad fish and trigger fish. *Scombroid poisoning* involves the tunas and mackerel and is the result of an allergy or histamine reaction to the fish by some individuals. *Shellfish poisoning* is the result of concentrating toxins present in the plankton. *Crab poisoning* is confined to the Xanthid (non-swimming) reef crabs and may be the result of the ciguatera producing algae as well as other toxic species. *Canned fish poisoning* is the result of bacterial contamination in the canning process resulting in the worst instance in a life threatening illness like botulism.

The incidence of the various poisonings are as follows: Ciguatera 90%; Clupeotoxism 4% (daniva and other sardines); Tetrodotoxism .5% (puffer fish); Crab poisoning .5%; Shellfish poisoning 1%; Scombrototoxism 1% (tunas); Mullet poisoning 2%; Deepsea fish gonad and liver poisoning .5%; Canned fish poisoning .5%.

The number of fatal cases from the consumption of marine foods in Fiji, in recent years (1955-1983) is: Ciguatera 1; Clupeotoxism 9; Tetrodotoxism 2; Crab poisoning 2; Shellfish poisoning 1; Canned fish poisoning 2.

THE PATHOGEN

The microscopic dinoflagellate algae *Gambierdiscus toxicus* is the source of ciguatoxin into the food chain, leading to fish poisoning in humans. The dinoflagellates attach themselves to the branches and thallus of marine algae and are then passed up the food chain by being consumed by herbivorous fish, which are then consumed by carnivorous fish. Humans are poisoned after consumption of either type of toxic fish.

Curiously not all strains of the *Gambierdiscus* produce the toxin making simple counts of the dinoflagellate population as indications of the risk less useful.

Ciguatera is one of the most potent and stable marine toxins known. It is resistant to heat and cannot be destroyed by cooking or freezing. Ciguatera do not alter the smell, taste or coloration of the toxic fish tissues. As well as in the muscular tissues, the ciguatera concentrates in the liver, viscera, organs, roe and head. The fish, feels no ill effects from the toxin. The higher the fish are in the food chain the more concentrated is the toxin in their tissues and the more severe the symptom from eating.

The majority of fish implicated are the carnivorous fishes with the larger the size, the greater the risk. Herbivorous fish are included in a list of likely affected groups: groupers; rock cod; mullets; parrot fish; trigger fish; surgeon fish wrasses; emperor fish; barracudas; snappers; moray eels; trevallies.

THE RISK

Following is a first level assessment of the likelihood of an increase in the incidence of ciguatera as the result of the increased algal cover on Balavu Reef. Assessment of the risk is based on the following factors: the known presence of ciguatera poisoning; the seasonal period in which the algae is likely to be most prolific; the ecology of the pathogen; the nature of the disturbance and its perceived effect promoting the toxic algal development; and the presence of local fish liable to the poisoning.

The qualitative assessment of the risk is based on recognising the presence of factors which may promote the development of the toxic algae and have contributed to outbreaks of the disease elsewhere.

● Presence of ciguatera poisoning: Fiji has collectively a high level of ciguatera poisoning (SPC 1993), but this is of little particular concern as the island environments are so varied and cover such a large area. More locally, samples taken near Ovalau contained ciguatera toxin (Yasumoto 1981). This gave reason for the cautioning of the consumption of Ogo (*Sphyræna plicata*) and Danu (*Lutjanus bahar*). Contrary to this is the anecdotal information that there is very little fish poisoning at the adjacent island of Naigani. The Danu which are suspect elsewhere are not found to be toxic. This may be due to the islands proximity to the mainland and the periodic freshwater influence of the mainland.

● The seasonal period at which time the incidence of poisoning is the highest: The annual peak in ciguatera poisoning is November/December in the South Pacific (Bagnis 1973). The SPC figures for 1991 and 1992 don't reflect this with occurrences in every month with several non-summer season months with high values (SPC 1993). As the algal mat on Balavu reef has persisted for three years, seasonality is not a factor and may reinforced the cumulative effect of the toxin in the food chain.

● The ecological requirements of the pathogen *Gambierdiscus toxicus*: The natural habitat is generally considered the fore reef slope with an environment which has,

moderate wave action. They prefer areas where there is some wave action which may be due to the presence of a mucous sheath which impedes nutrient transport with out agitation. Kaly and Jones 1990, however, found large numbers of the toxic algae on the reef flat in Niutao, Tuvalu.

Low salinity and strong light intensity deter the growth of *G. toxicus* (Yasumoto et al. 1980). The results explain why *G. toxicus* is not abundant near the mouth of rivers or in shallow lagoons with bright sandy bottoms.

●The nature of the disturbance and its perceived effect on promoting the toxic algal development: Increases in ciguatera poisoning have been attributed to human disturbance on the coral reef which affect the biological nature of the reef (Cooper, 1964; de sylvia and Hine, 1972; Tebano, 1984; Naughton, 1985). Alteration to the reef through dredging and the construction of causeways. In Marakei Island, in Kiribati, ciguatera has become common with the alteration of the natural lagoon circulation due to causeway construction. 'Coral fragments may provide new surfaces for algal settlement. It has been found that coral damage and dredging may trigger the onset of ciguatera fish poisoning (Tebano, 1984b; Tebano and McCarthy, 1991). This type of poisoning was not known in Mainana till after a channel was constructed at the western side of the island. On the islands of Marakei and Nikunau where ciguatera fish poisoning is a daily tale, this got worse and even spread out to the neighbouring villages' (Tebano, 1990).

Kaly and Jones (1990) provide a review of the circumstances which give rise to fish poisoning.

"Bagnis (1969) (cited in Banner, 1976) reported the appearance of toxic fishes within 1.5-2 years when the atoll of Hao (Tuamotus) was converted to a nuclear staging base in 1965 by the French. Reef apparently became toxic in a pattern spreading out from the centre of disturbance, first appearing in herbivorous fish and later the carnivores. Some worker have identified blasting for the construction of boat channels as a probable cause for an increase in fish poisoning (e.g. Kubenski, 1979; Tebano, 1984). Other disturbances have also been implicated in fish poisoning, such as: storm (Bagnis, 1979; Tebano, 1984); dieback of corals (Yasumoto et al. 1980a,b) and any other form of disturbance (Withers, 1982; Yasumoto et al., 1984). When interviewed, the people of Kiribati associated areas of toxicity with ship wrecks, bombing (WWII), sewage, rubbish dumping and many other forms of disturbance (Cooper, 1964; Tebano, 1984; McCarthy and Tebano, 1984). McCarthy and Tebano (1984) pointed out, however that the apparent association between wrecks and ciguatera in Kiribati, derived by interviewing fishermen, might have arisen because wrecks (and presumably other human structures) provide a convenient spatial and temporal marker for an otherwise obscure phenomenon."

A mechanism for the link with disturbance was first proposed by Randall (1958). He suggested that the toxicity in fish was caused by an alga which was the first to grow on new substrata. Wrecks, rubbish, etc. all provide new substrata,

either in themselves, or by destroying corals. Later, Yasumoto (1977a,b) attributed poisoning to a dinoflagellate *Gambierdiscus toxicus* which lived under the surface mucous layer of algae, eaten by fish (Yasumoto, 1979, 1980a,b; Bagnis et al. 1980). The "host" algae carrying the toxic dinoflagellate have included red, green and brown forms (though not turtle grass, or much on sand) with finely branching forms harbouring the greatest numbers of cells (Shimizu et al., 1982; Ballantine et al., 1985; Taylor, 1985.).

The study by Kaly and Jones (1990) when considering the effect of human influence on the ciguatera outbreak in at Nnuta, Tuvalu concluded that it had no direct effect on the distribution of the toxic algae.

Due to considerations of the biology of *Gambierdiscus* involving dispersal, growth and accumulation in the food chain, there is a lag time for disturbance to manifest itself as ciguatera. Several accounts indicate that this is generally considered to be 12 to 18 months but may occur in less than a year.

In summary, the dinoflagellate *Gambierdiscus* has been described from the barrier reefs surrounding Ovalau. The wholesale colonisation of northern Balavu Reef by a dense carpet of the macroalgae create a situation conducive to conditions which would allow for its population growth. This is the circumstance required for ciguatera to be introduced into the food chain. As a result, some fish consumed from this area may result in fish poisoning. The situation will be exacerbated if the potential is realised resulting in a similar alteration of the adjacent Lekaleka Reef due to the proximity of the second outfall.

At this stage the presence of ciguatera poisoning attributable to this area has not been reported. The potential for its occurrence is described in this report so that the consequences of man-induced environmental changes should be carefully investigated prior to undertaking engineering options which may have undesirable long term environmental consequences.

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