FINAL MONITORING OF ENVIRONMENTAL IMPACTS OF DREDGING AT DENARAU

Aerial View of Denarau Resort Complex and Surrounding Environment, October 1997

INSTITUTE OF APPLIED SCIENCES
THE UNIVERSITY OF THE SOUTH PACIFIC

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1.0 INTRODUCTION AND BACKGROUND

The Denarau Island Resort located about 5 kilometers north-west of Nadi town is currently the largest development of its kind in Fiji. The resort consists of two 5-Star hotels, the Sheraton Royal and the Sheraton Fiji with plans for further hotel development, residential units and shopping centers. In fact the Denarau Master plan aims to create a fully integrated international resort destination in which an 18-hole golf course, a marina and a cultural center would make up part of the major attractions to the resort.

The development of the Denarau Resort by the previous owners EIE International Corporation in the early eighties had incorporated an extensive Environmental Impact Assessment Process. The Institute of Marine Resources (IMR) of the University of the South Pacific (USP) was involved in the biological and fisheries survey for the initial EIA in 1986 and 1989 (Raj and Seeto, 1986; Seeto *et al*, 1989). Reports of these environmental surveys have been incorporated by HGCL (Harrison & Grierson Consultants Ltd., NZ) and KRTA (NZ) Ltd.

The construction of the marina and navigation channel presented a major threat to the marine environment. This was to be the subject of an environmental monitoring programme agreed to by three entities: the government Town & Country Planning Department, the developer and the Institute of Applied Sciences (IAS) of the USP, in June 1991. The development consisted of the dredging of the north arm of the Nadi River to create a marina basin and navigational channel leading into Nadi Bay. The area prior to construction was an estuarine delta with intertidal flats. Seagrasses and infauna characterised the mouth of the estuary. **The aim of the monitoring programme is to assess the status of the marine environment and resources before, during and after the construction of the marina and navigation channel.**

1.1 *Environmental Monitoring Programme for Effects of Dredging*

Dredging for the marina and navigation channel commenced in early 1993. Prior to this, baseline studies of the marine life likely to be affected by the dredging were conducted in July, September and December of 1991 (Lovell *et al.*,) and again in July 1992 (Lovell & Odense, 1993). **The baseline studies showed thriving coral growth and healthy zones of seagrass in the foreshore.**

In the period between the baseline pre-dredging marine survey and the second series of monitoring in September and October of 1993, Fiji was hit by one of the strongest cyclones ever experienced locally: cyclone Kina in December 1992. Following the cyclone, a major flood hit the whole of Nadi in February 1993, flooding the Nadi town. The combined effects of these natural events caused devastating coral destruction and disturbance to the seagrass beds. Unfortunately, no immediate assessment of the damage done by these events was ever carried out. When the next monitoring was conducted in September and October of 1993, dredging and land -filling were well under-way. Therefore there was no way of differentiating between the effects of the natural events (cyclone & flood) and the dredging operation at the Nadi River estuary. **The combined effects nevertheless were a dramatic change from the status before commencement of dredging. Specific assemblages of corals, particularly *Acropora sp.* had suffered high mortality and in some cases 100%. Seagrasses were totally smothered.**

The final monitoring was approved by the current owners Tabua Investments in mid-1997. Site assessments were conducted on 7th, 8th and 9th October 1997. The principal object of this final monitoring study was to determine the recovery status of the coral reefs offshore, and the seagrass beds in the foreshore. Also of significance is the status of the water quality, particularly its clarity in the Nadi Bay.

This report presents our findings during the re-survey of the seagrass and coral reefs adjacent the Denarau area, as well as an update on the status of the water quality. The results of this survey reflect the nature of the biological communities after construction and during a period of marina operation. The Shortover Jet operation, which began operating from the Denarau marina is also a significant activity that has the potential to impact on the environment. In addition, during this study natural occurring events, such as cyclone Gavin may also have had an effect on the reefs.

1.2 Summary of Observations of Dredging Effects

1.2.1 Before dredging

The reports by Lovell *et al.* (1991) and Lovell & Odense (1993) clearly show by means of a series of photographs, the status of the coral reefs and the inshore seagrass beds before commencement of dredging. In brief, the major observations were:

- the Denarau foreshore was characterised by healthy zones of seagrass with the expected assemblage of benthic species;
- extensive beds of *Syringodium* sp. occurred in two distinct bands, above and below water levels but turbidity of water was limiting growth at depth;
- distinct band of *Halodule* seagrass further inshore from the *Syringodium*, and occurring peripheral to the *Syringodium* beds;
- prolific bivalve infauna included *Perglypta*,(common name venus clams or kaidawa in Fijian) *Vasicardium* and *Grafrarium* (common name venus shells or qaqa in Fijian) species;
- the coral composition of the quadrats had not changed much in the seven months from December 1991/January 1992 to July 1992. Changes observed were due to natural processes such as bioerosion, growth, death, and man-made activities such as coral removal, and anchor damage;
- in general, good coral growth was observed during the later studies (July 1992),with new colonies establishing after the November 1991 spawning.

1.2.2 During dredging

(September/October 1993)

- massive destruction to specific coral assemblages, in some cases 100 % mortality to

Acropora sp.;

- in general, off-shore coral reefs (Alacrity cays) suffered more damage than in-shore reefs (Malan cays) implying that the cyclone (Kina) had greater impacts than the dredging for the marina;
- coral mortality was greater at depths less than 3 m, total inundation of the seagrass beds along the foreshore (Appendix B photos 1 & 2).

2.0 MONITORING APPROACH AND CONSTRAINTS

2.1 Constraints

The main objective of the initial baseline studies (1991, 1992) was to establish study sites and quadrats in the coral reefs and the seagrass beds. Four sites in Nadi Bay and one in the seagrass beds were established to assess the impact of the marina construction on these communities. Initially, assessment of water quality was limited to the deployment of six sediment traps, of which only two were retrieved. One of the constraints encountered was the difficulty of locating the sediment traps in the turbid, inshore waters.

Monitoring was conducted in September/October of 1993 and coincided with the actual dredging and land-filling operations. This study included for the first time a more detailed assessment of the water quality. As far as possible, the state of the water quality was correlated with the status of the coral reef sites. **However, the major problem with this monitoring was the difficulty of differentiating between the effects of both natural and man-made events: cyclone Kina in January 1993 and the floods which hit Nadi in February, and the dredging and land-filling operation, all of which contributed to severe damage in the coral reefs and seagrass beds and water quality in general.**

2.2 Monitoring Intervals and Frequency

The period of observation spanned 5 years and 10 months. The initial baseline inspection and establishment of monitoring sites was conducted on December 7, 1991. The first monitoring period was approximately seven months later on July 14, 1992. The second monitoring was fifteen months later on October 14, 1993. This was 1 year 11 months after the initial inspection. The present monitoring which was conducted on October 8th and 9th, 1997, occurred nearly four years after the second monitoring or 5 years 10 months after the initial inspection. Therefore, an important factor is the inconsistency of the monitoring periods.

3.0 METHODOLOGY OF FINAL MONITORING

(October 1997)

3.1. Water Quality

Five sites were assessed for water quality in Nadi Bay off Denarau. Sites were selected to cover as wide an area as possible, but more importantly, to include potential sources of pollution such as the inshore waters off the Sheraton hotels. The locations of the water quality study sites are shown in Figure 3.1. Parameters measured on site included temperature, pH, salinity, conductivity, turbidity and dissolved oxygen. These parameters were measured with the Horiba U-10 Water Multimeter at about 30 cm depth. Water clarity was measured with a white secchi disc attached to a chord marked out in meters.

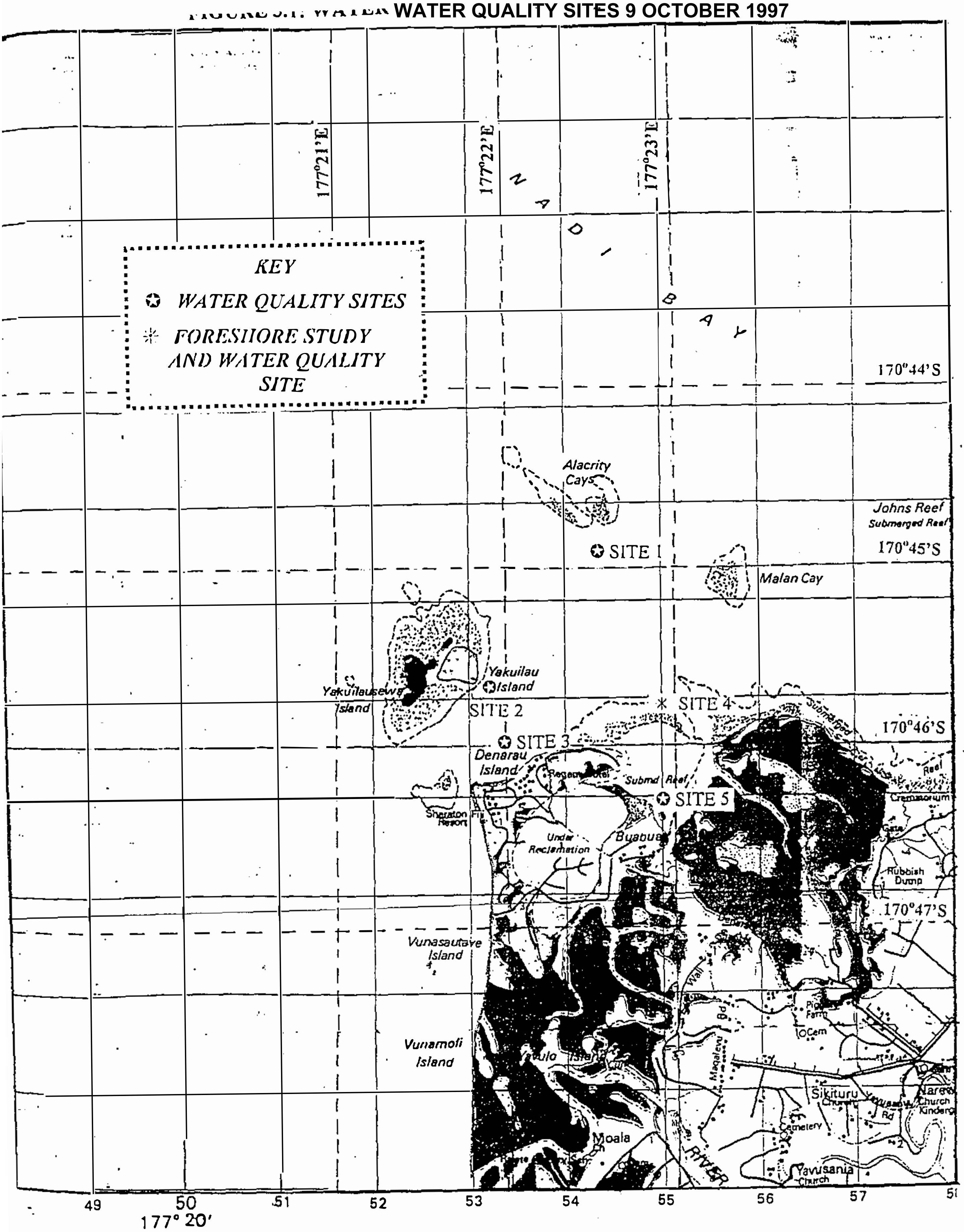
Surface water samples were collected to be analysed in the laboratory at the IAS for levels of Total suspended solids (TSS), Total dissolved solids (TDS), nitrates, phosphates, and Faecal coliform. The marina sample was assessed for hydrocarbons, as there was potential risks of oil contamination from boat traffic in the marina. Standard methods were used in the laboratory for the analyses. Nitrate concentrations were measured using the Cadmium Reduction/Colorimetric Method and Absorbance measurement on the UV Spectrophotometer. Phosphate levels were measured using the Molybdenum blue-colorimetric method and Absorbance measurement on the UV Spectrophotometer (APHA 1981 & IAS Methods of Analysis of Water, May 1992).

The hydrocarbons (oils & grease) concentrations were measured using the Partition-Gravimetric Method (APHA, 1989). The health status of the water was assessed by measurements of Faecal coliform concentrations. Faecal coliform counts were assessed using the Membrane-Filtration method (APHA, 1981).

3.2 Coral reef sites

The offshore coral sites were visited, photographed and assessed, as were the seagrass beds. The mud flat within the harbour was also visited.

SITES 9 OCTOBER 1997
FIGURE 3.1: WATER WATER QUALITY SITES 9 OCTOBER 1997



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3.2.1 Survey methods for coral reef sites

The survey methods followed the protocol of the baseline study and previous two monitoring periods. This involved a re-survey of the coral reefs by diving inspection and the re-photography of the sample quadrats. The survey techniques employed follow the general methodology as detailed in Survey Manual for Tropical Marine Resources (English et al. 1997). Broad scale data collection was by means of diving observation (Done et. al., 1981, Done, 1989) with more detailed studies employing the line transect and sample quadrat inspection (Marsh, Bradbury and Reichelt 1984, De Vantier et. al., 1985). The methods are similar to those used for the survey of general marine benthos following Done (1989, 1991), and Lovell and Toloa (1994), Lovell (1997).

3.2.2 Monitoring programme

Four monitoring sites established during the initial survey were re-photographed and re-assessed with respect to the coral composition. The sites assessed were Alacrity Cays sites 1 and 2, Malan Cay (site 3) and Yakuilau reef (site 4). At each of these sites, three quadrats were established. These quadrats were to be re-surveyed and re-photographed throughout the monitoring period. They consisted of one-metre square quadrats which were positioned using reinforcing bar driven into the reef surface. The sites are photographed using a Nikonos 15mm lens and a square metre framer to allow subsequent monitoring replication. The quadrat detail is described in the field. A set of photographs is laminated for use as a visual framing reference allowing accurate re-photography of the

The report format compares the four periods of assessment by photographic comparison.

3.2.3 Photography underwater

Habitat and specimen shots are taken with Nikonos underwater cameras. This involved the use of extension tubes and close-up lenses for the macro-photography; a 15mm lens for habitat and assemblage shots. Lighting was ambient or by a SB 102 flash.

3.3 *Survey methods for In-shore Seagrass beds*

The foreshore previously inhabited by the seagrass beds (south of the breakwater) was surveyed during low tide on Wednesday afternoon, 8 October 1997. A transect was laid out from the high water mark (0m) out to the low water mark (150m). Quadrats (1m^2) were taken every 10m with the exception of the first 10m whereby two quadrats were taken. Sediment type flora and fauna were assessed in each quadrat.

3.4 *Methods for Sediment Analysis*

3.4.1 Particle size analysis

Four sediment samples were taken from Denarau for particle size determination. Three samples were from the beach and foreshore, and one from the mangroves. The foreshore and beach samples were taken from quadrats 8 (75m), 16 (140m) and 17 (150m), along the transect used in the foreshore survey.

The fourth sample was obtained from the mangroves and identified as mangrove mud (MM). The mangrove community is situated a few meters from the riverbank, however the Shotover Jet Operations do not use this area of the river. Mangrove soils have been described as being waterlogged and anaerobic and proportions of clay, silt, sand and grain size usually dictate the permeability of the soil to water (English *et al.* 1994). This property also determines its erosive ability and rate of erosiveness, which is one of the major points of concern regarding the Shotover Jet operations in the mangroves. Consequently changes in physical composition need to be monitored.

All samples were analysed in duplicates using the particle size analysis - hydrometer method adapted from N.Z. Standard Specification 4402 (Thomas 1981). Sediments like soils can then be classified under the Wentworth Grade Scale (English *et al.* 1994) according to the particle diameter sizes (Appendix C Table 1).

4.0 RESULTS OF FINAL MONITORING SURVEY

4.1 Status of Water Quality in October 1997

Water quality results are appended (Appendix A Table 1). Interesting observations arise when comparing the water quality data for 1993 and 1997 (Appendix A Table 2) and are discussed in detail in the following section.

4.1.1 Temperature, pH & Salinity

For the three parameters, no unusual values or variation were observed during the fieldwork. Surface water temperatures ranged from 23.7 °C to 25.3 °C; pH values varied from 8.09 to 8.17, the range expected for sea water. Salinity values were slightly lower than expected for seawater, nevertheless values were very similar around 27 parts per thousand (ppt). Salinity for seawater usually ranges from 30 - 35 ppt. A comparison of these results to 1993, indicates there was no major difference (Appendix A Table 1).

4.1.2 Conductivity & Dissolved Oxygen (DO)

Again no unusual variation was observed with conductivity values ranging from 42.5 mS/cm to 42.9 mS/cm. Dissolved oxygen values were similar for the 5 stations, ranging from 7.20 to 7.76 mg/L. Such values satisfy the required DO concentration for aquatic life, which is 6 mg/L or more dissolved oxygen (Draft Sustainable Development Bill, 1996) and compare well with those of 1993 (Appendix A Table1).

4.1.3 Clarity

1993. The 1993 clarity values ranged from 1.7 meters (seagrass zone) to 5 meters (close to Alacrity Cay, approximately 3 kilometers offshore from the Nadi River mouth). **This time, clarity of the water in Nadi Bay has deteriorated with values ranging from 1.0 meter to 2.15 meters.** This observation has significant implications on the objective of the whole monitoring programme, and is discussed further in section 5.1 (Appendix A Table 1).

4.1.4 Total dissolved solids (TDS) and Total suspended solids (TSS)

The range of values for Total dissolved solids has not changed significantly since 1993 when TDS varied from 37.7 to 39.9 g/L. The range this time is 30.3 to 41.6 g/L. Total suspended solids concentrations on the other hand has shown significant increases at all stations, since the 1993 monitoring (Appendix A Table 2). The range of TSS in 1993 was 5.2 - 54.8 mg/L. This time the range has increased to 28.0 - 223 mg/L. The station close to Alacrity cay (station 1) is the critical case. This site appears to be the most affected of all the stations, i.e. clarity for the site had decreased from 5 m in 1993 to 1.5 m in 1997 and TSS had increased from 29.6 mg/L in 1993 to 223 mg/L in 1997 (Appendix A Table 2) and has significant implications in terms of monitoring

4.1.5 Nutrients - nitrates and phosphates

Nitrates and phosphates were not assessed in 1993. This time, they were included in the study because of their potential impacts on coral reefs and productivity in general. Nitrates and phosphates are derived from the biological breakdown of organic matter.
Levels of nitrates in the water were <34 ug/L for 3 stations. These are low enough to be of no concern. The only high value obtained was 237.8 ug NO3/L, near the Sheraton Hotel, which may be indicating some organic matter discharged from shore. Nevertheless, these are within the usual range expected for open oceans (30 - 300 ug/L).

Levels of dissolved phosphates varied from 27.1 to 38.7 ug/L. Such values are within acceptable range for marine life. For normal coral reef growth, concentrations up to about 70 ug/L have been found for fringing reefs in Australia (Blake & Johnson, 1988).

4.1.6 Hydrocarbons and faecal coliform

Levels of hydrocarbons (4 - 7 mg/L) are of no concern at this stage. They are within acceptable range for marine life (PAF guidelines 1992). Faecal coliform (FC) are used as an indication of sewage pollutants/pathogens. However, the levels of faecal coliform (FC) at sites indicated relatively clean waters from a human perspective. The recommended faecal coliform levels for recreational waters is < 200 organisms/100 ml (USEPA

Guidelines <300/100 ml for World Health Organisation (WHO) Guidelines). **All stations except the site close to Yakuilau Island showed complete absence of faecal coliform.**

4:2 *Coral Reefs Result*

The.results are presented as a summary of the changes that have occurred at the site as well as a detailed assessment of the photos. Comparisons of photographs during these periods are presented as figure legends with description and comment.

On each of the Alacrity Cays, sites were established and are referred to as site 1 & 2. Both suffered total mortality of the genus *Acropora* subsequent to the flood of February 1993. The sites in comparison with their previous condition and with respect to the other sites are in a substantially degraded state. Re-establishment of the *Acropora* component has been minimal. The situation has been one of high coral cover on establishment, which showed little change at the first monitoring session. Subsequent to the flood, total mortality was experienced by the predominant *Acropora* colonies. Only the skeletal coralla were observed. The present monitoring has revealed the sites without the skeletal material and a coral fauna dominated by *Porites* with some *Favid* skeletons. *Acropora* recolonisation is sporadic with some colonies representing 3 years growth and the larger size classes 1 to 2 years old.

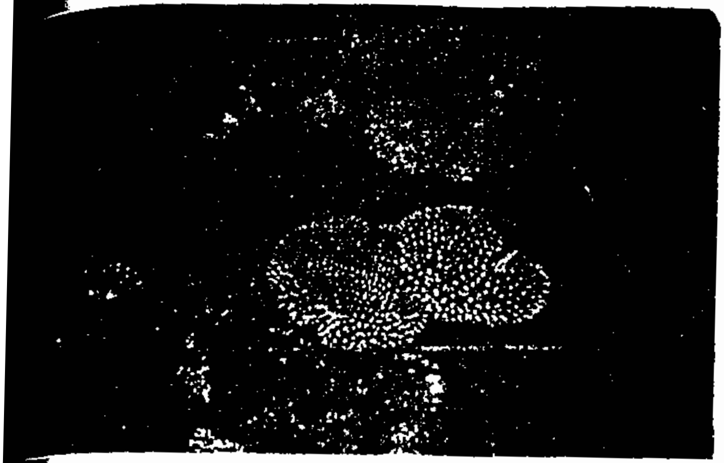
4.2.1. Alacrity Cay: Site 1

(Figure 4.2.1 a-h : Figure 4.2.2: i-l)

a) Quadrat 1: Established and photographed in December 7, 1991, this quadrat reflects the *Acropora* dominated growth that characterises the Alacrity and Yakuilau sites.
b) Quadrat 1: July 14, 1992, the coral assemblage has been reduced with three large colonies of *Acropora* missing from the previous photo. As this is a shallower site, wave action would have a prominent effect. It is likely that this is the result of anchor damage as tourists frequent this area because of the cay and its protected anchorage. Prior to the flood it was a attractive snorkeling location.
c) Quadrat 1: October 14, 1993, the coral assemblage has been altred with the mortality

URE 4.2.1: (a-h) ALACRITY CAY: SITE 1

a)



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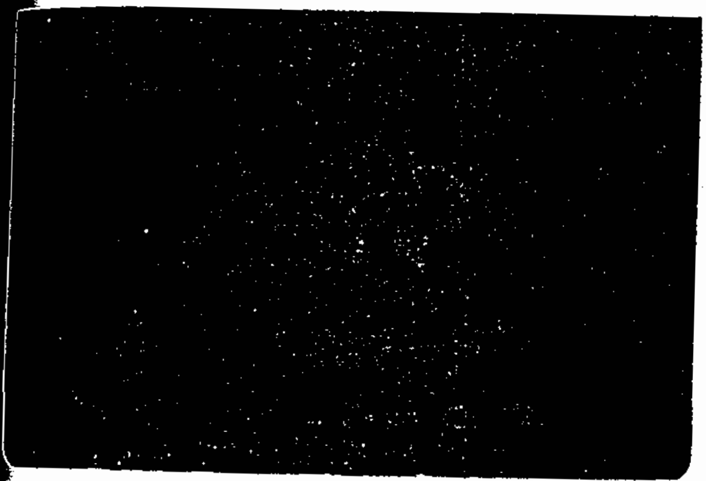

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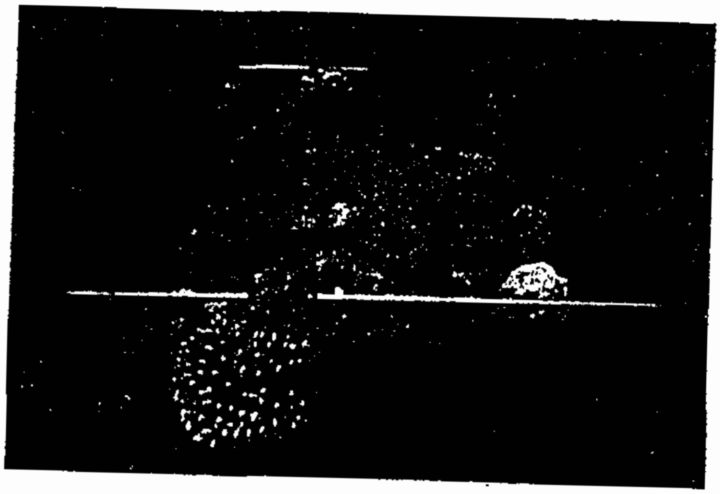

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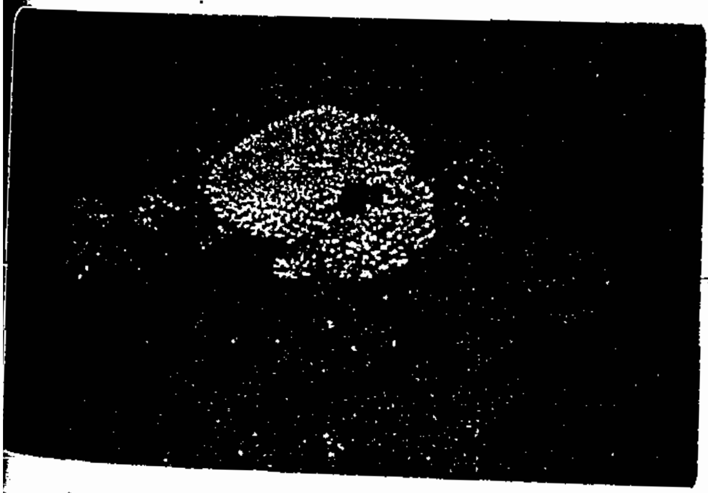

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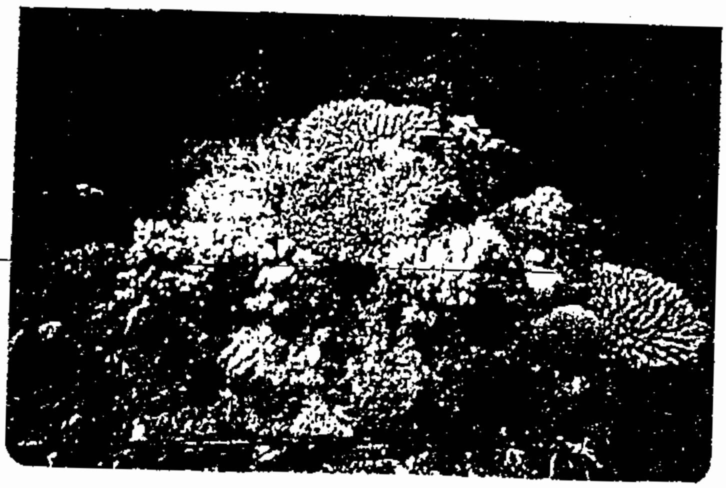

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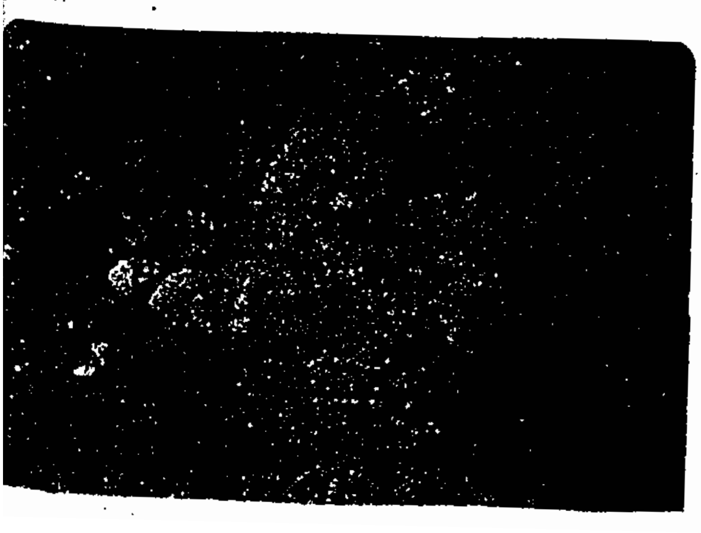

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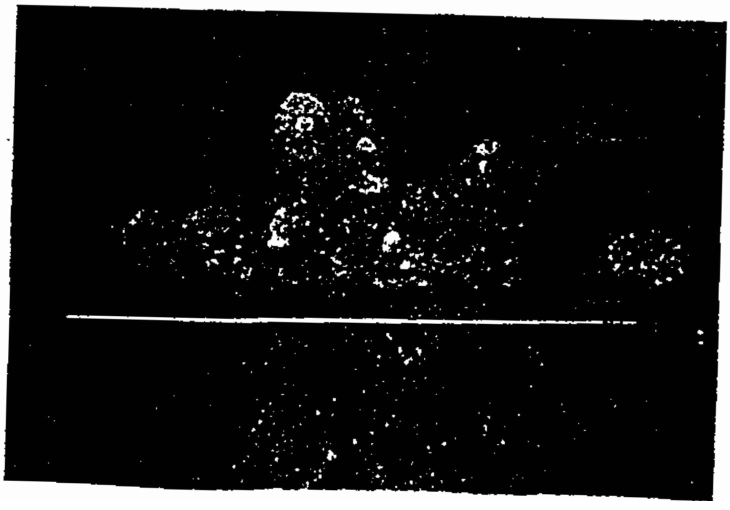


of the *Acropora* assemblage. The colonies of *Psammocora contigua* and *Porites* spp. are dominant being resistant to the flood runoff. Only one dead colony of *Acropora* remains indicating the effect of wave action during Cyclone Kina.

d) Quadrat 1: October 8, 1997, the coral assemblage has not recovered it's *Acropora* dominance with the site remaining barren. A partially dead colony of *Acropora* is evident. From its growth rate an age of three years old can be inferred. Growth is evident in the *Porites* colonies though the *Psammocora contigua* exists only as a small remnant.

e) Quadrat 2: Established and photographed in December 7, 1991, and reflects the *Acropora* dominated growth that characterises the Alacrity and Yakuilau sites.

f) Quadrat 2: July 14, 1992, the coral assemblage is more luxuriant though partial death is apparent in the central *Acropora* colony.

g) Quadrat 2: October 14, 1993, the coral assemblage has been drastically altered with the removal of the larger colonies of *Acropora, digitate,* a soft coral, *Psammocora,* and two massive colonies of *Goniastrea* sp. after the events of cyclone Kina and the subsequent record flooding of the following February.

h) Quadrat 2: October 8, 1997, four years later, good growth of *Porites* colonies and a surface covered by *Halimeda* show a greatly altered reef assemblage. A small colony of *Pocillopora damicornis* is thriving on the tip of one of the marker stakes

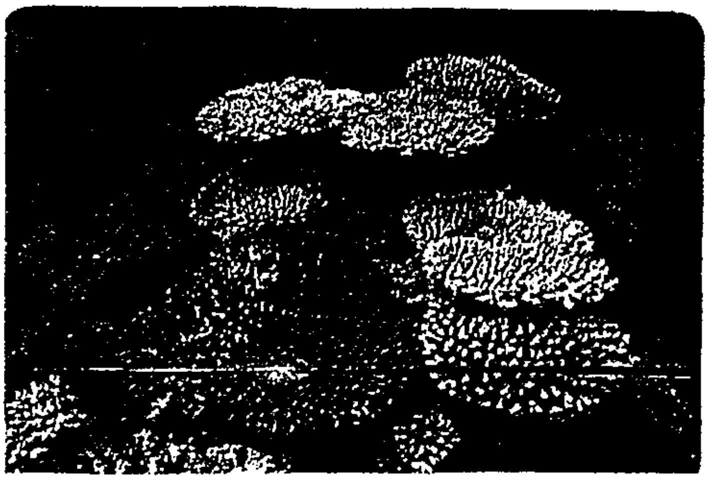
i)Quadrat 3: Established and photographed in December 7, 1991, this quadrat reflects the *Acropora* dominated growth as in quadrat 1 and 2. The *Acropora* has monopolised the substrate with colonies whose growth rates indicate growth for 4 to 6 years. This indicates the degree of growth expected since 1985 when the presence of two cyclones, Eric and Nigel affected this area.

j) Quadrat 3: July 14, 1992, the coral assemblage is similar to quadrat 1 with the exception of the death of the largest colony. This death was attributed to the coral-eating starfish *Acanthaster planci* that was observed nearby.

k) Quadrat 3: October 14, 1993, the coral assemblage has been dramatically affected by the cyclone and flood with much of the coral removed. All coral with the exception of the

.2.2
ite 1 i)

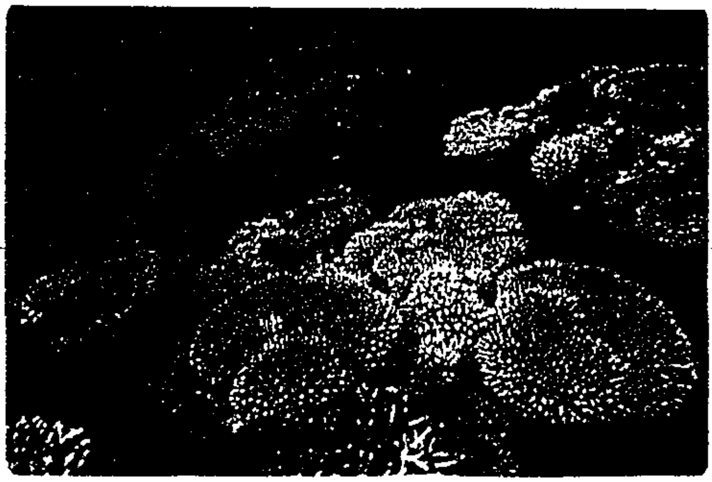
j)



l)

ITY CAY: SITE 2

b)



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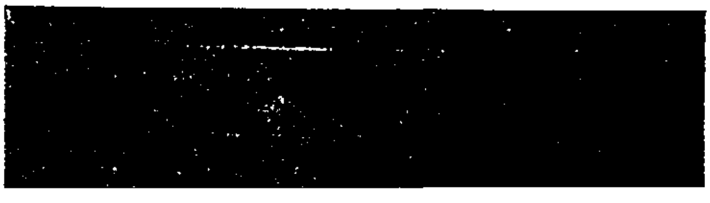


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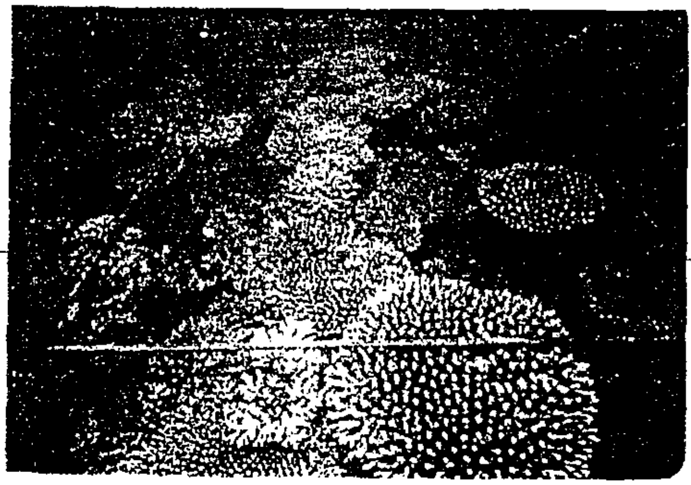
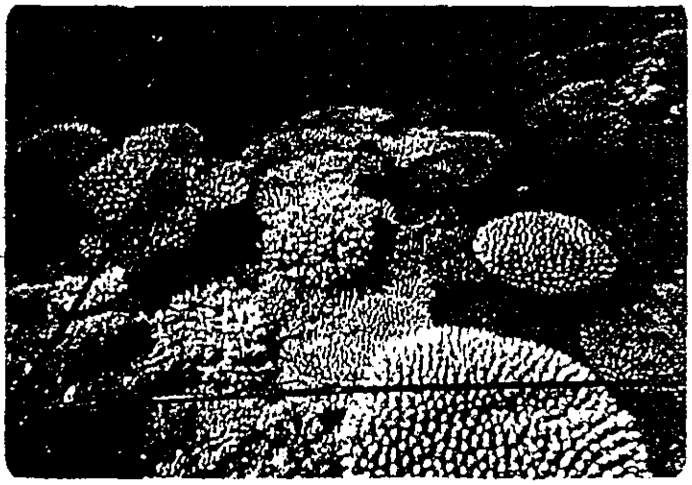
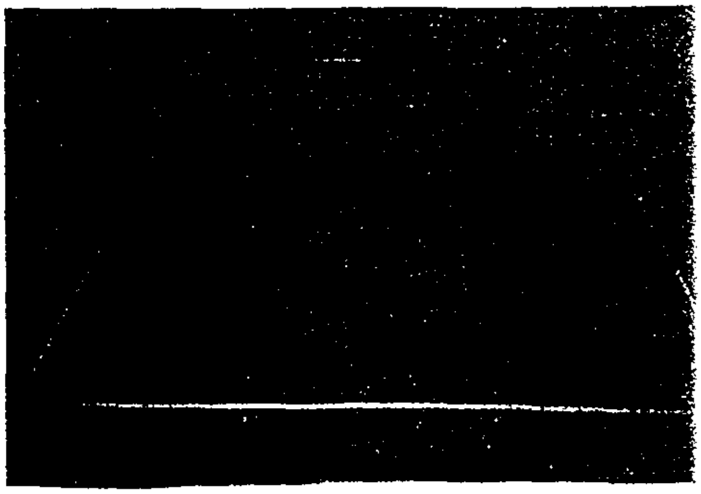
i) j)

k) l)

the *Porites* colony died.

l) Quadrat 3: October 8, 1997, the reef, which formerly hosted good luxuriance, is now characterised by depauperate *Porites* colonies. *Acropora* specimen is growing on one of the stakes.

4.2.2 Alacrity Cay: Site 2

(Figure 4.2.2 a-d : Figure 4.2.2A h-l)

a) Quadrat 1: Established and photographed in December 7, 1991. This quadrat shows the same trend *Acropora* occurrence at the studies onset.

b) Quadrat 1: July 14, 1992, the coral assemblage has shown further development.

c) Quadrat 1: October 14, 1993, the coral assemblage has suffered nearly total mortality with cyclone Kina and the flood. The colony skeletons still in place reflect the protected environments..

d) Quadrat 1: October 8, 1997, the coral assemblage is barely evident with the area hosting only a few colonies of small *Porites*. The coral skeletons have vanished.

e) Quadrat 2: Established and photographed in December 7, 1991, reflects the *Acropora* dominated growth.

f) Quadrat 2: July 14, 1992, growth of the *Acropora* assemblage is good. The *Pocillopora* colony is missing revealing a *Porites* colony, which continues to show good growth throughout the sample period.

g) Quadrat 2: October 14, 1993, the *Acropora* assemblage has been removed after the events of cyclone Kina and the subsequent record flooding of the following February.

h) Quadrat 2: October 8, 1997, there has been good growth of *Porites* colonies. A surface covered by *Halimeda* shows a greatly altered reef assemblage.

i) Quadrat 3: Established and photographed in December 7, 1991, this quadrat reflects the *Acropora* dominated growth like quadrat 1 and 2. Larger colonies of *Acropora* have monopolised the substrate and, like the other Alacrity sites colonies growth rates indicate growth for 4 to 6 years. This is the degree of growth expected since 1985 when the presence of two cyclones, Eric and Nigel in 1985 would have affected the site.

j) Quadrat 3: July 14, 1992, good colony growth was observed. A large colony of *Pocillopora* is successfully competing with the *Acroporas*.

k) Quadrat 3: October 14, 1993, the coral assemblage has suffered total mortality due to the cyclone and flood.

l) Quadrat 3: October 8, 1997, the reef is comprised of algal cover and coral rubble.

4.2.3 Malan Cay: Site 3:

(Figure 4.2.3 a-h ; Figure 4.2.4 i-l)

a) Quadrat 1: Established and photographed in December 7, 1991, the species composition of this quadrat is conditioned by species tolerant to frequent dilution by runoff.

b) Quadrat 1: July 14, 1992, the assemblage shows, as in quadrat 1, a good growth of the *Acropora* colonies.

c) Quadrat 1: October 14, 1993, the effect on the coral assemblage subject to cyclone Kina and the flood is the mortality of the *Acropora* assemblage. The colonies of *Psammocora contigua* and *Porites* spp. have survived.

d) Quadrat 1: October 8, 1997, the coral assemblage has not been greatly affected by the cyclone and flood. The species are largely massive and resistant to the inshore environment, which is often diluted by freshwater.

cyclone and flood. The species are largely massive and resistant to the inshore

e) Quadrat 2: Established and photographed in December 7, 1991. As with quadrat 1, the sample was dominated by small *Acroporas*. Other coral genera included *Psammocora*, *Montipora*, and *Porites*.

f) Quadrat 2: July 14, 1992, little change is seen in the nature of the sample with the obvious growth of *Acropora*.

URE 4.2.3 (a-h): MALAN CAY: SITE 3

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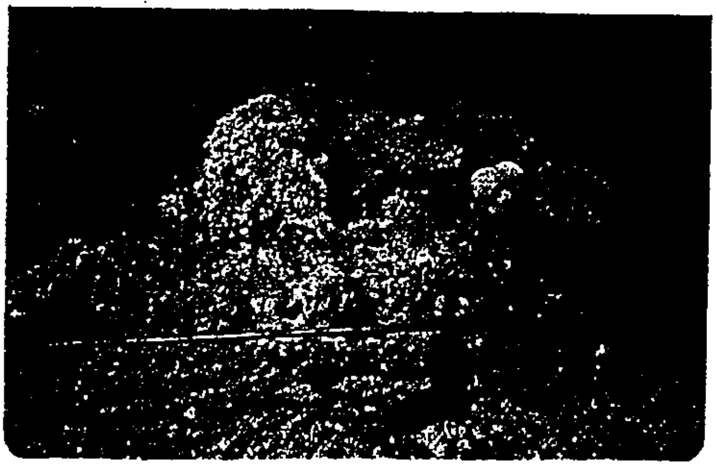
b)



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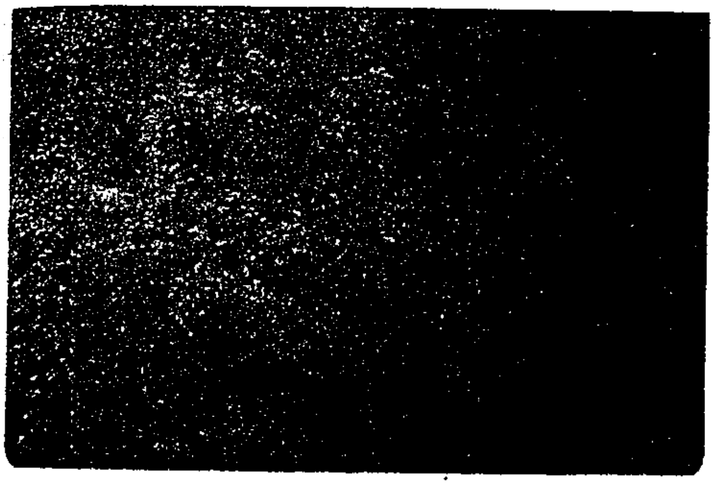

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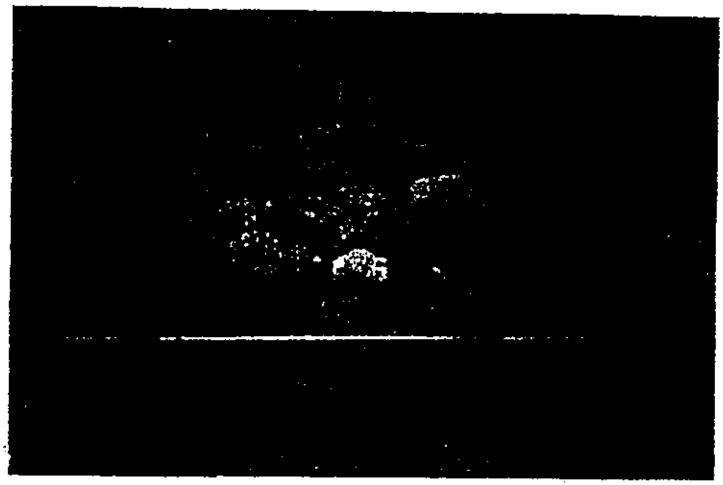
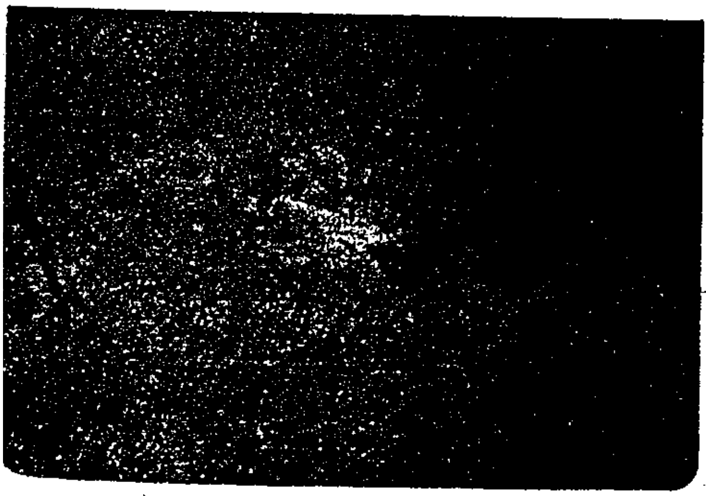
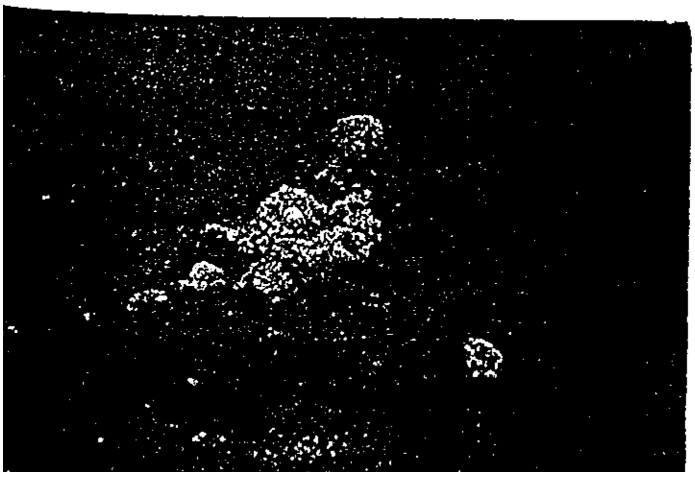


e)

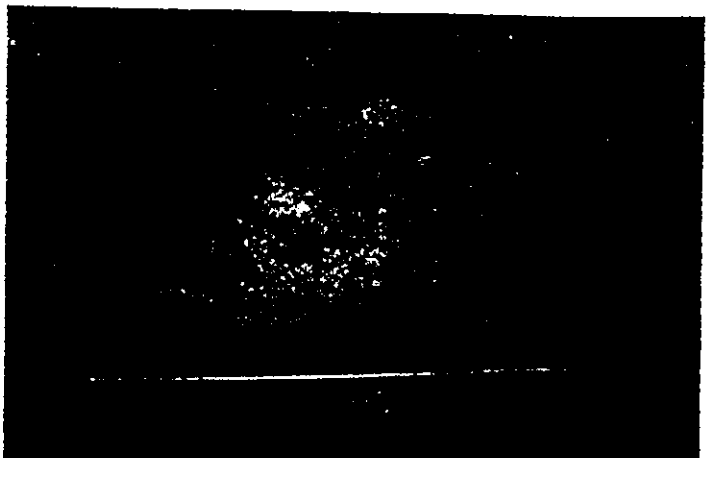


f)

g)



h)



g) Quadrat 2: October 14, 1993, by comparison with the *Acropora* dominated samples at the other sites, this area has shown relatively little change in the coral assemblage due to the dominance of resistance species.
h) Quadrat 2: October 8, 1997, four years later, there is good growth of *Porites* and *Montipora* colonies .The substrate is covered with a close cropped algae. Only one colony of *Acropora* is evident.

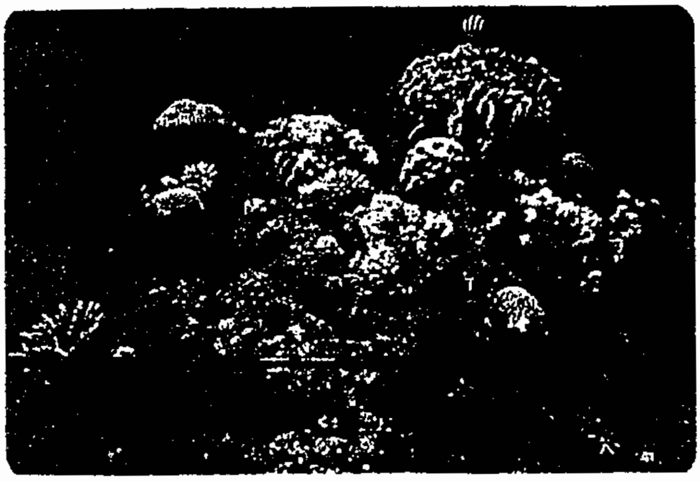
i) Quadrat 3: Established and photographed in December 7, 1991, this quadrat reflects the *Porites* dominated growth as in the previous quadrats, though a large *Pavona* colony and several *Favid* colonies are present.
j) Quadrat 3: July 14, 1992, the coral assemblage is similar to quadrat 1 with general colony growth evident.
k) Quadrat 3: October 14, 1993, as with the other quadrats inshore, the *Acropora* have died. The remainder of the assemblage appears unaffected.
l) Quadrat 3: October 8, 1997, the non-*Acropora* colonies continue to thrive.

Due to its proximity to the mouth of the Nadi River, this site experiences a much greater frequency and relative intensity of flooding than the other sites. As a result, the species composition is dominated by species more tolerant to this environment. These are comprised of *Porites*, *Pavona*, *Leptastrea* and *Psammocora*. The occurrence of *Acropora* is minimal by comparison with the other sites. Unlike the *Acropora* domination of the Alacrity and Yakuilau sites during the baseline survey, there was a near absence of *Acropora* in these quadrat sites. Unique to this site is the conspicuous increase in *Acropora* presence during the first monitoring session seven months after the December 1991 monitoring and represents the result of the spawning of that year. Subsequently, there was removal of all of the *Acropora* colonies after the flooding that affected all sites. It is interesting that the species composition of the quadrat when initially established is the same as that after the major flood. This departure from the norm of the other sites adds credence to the presumption that the inshore site experiences a greater incidence of flooding. Throughout the monitoring, the growth of the non-Acroporan corals was good.

URE 4.2.4 (i-l): MALAN CAY:,SITE 3

i)

j)

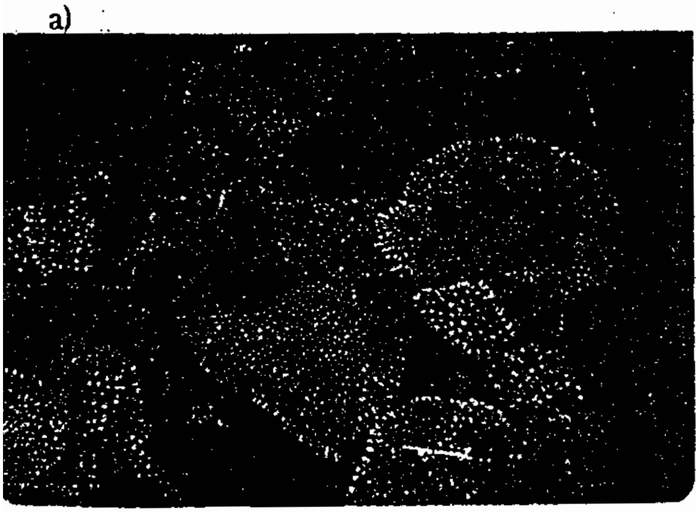


k)

l)

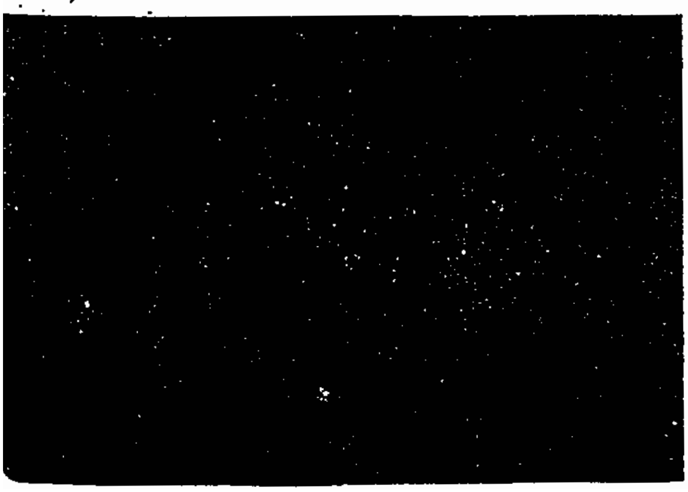
-d): YAKUILAU REEF: SITE 4

a)



b)

c)



d)

4.2.4 Yakuilau Reef : Site 4

(Figure 4 2.4 a-d)

a) Quadrat 1: Established and photographed in December 7, 1991. This quadrat shows expansive coral growth with some of the largest colonies evident though still representing the six-year age since the 1985 cyclone. After cyclone Kina this site is the most rapid to be re-established (see plate d).

b) Quadrat 1: July 14, 1992, extensive tabulate coral growth exists.

c) Quadrat 1: October 14, 1993, the coral assemblage has suffered nearly total mortality with cyclone Kina and the flood. The colony skeletons, still in place, reflect the sturdy nature of a wave washed environment.

d) Quadrat 1: October 8, 1997, unlike the Alacrity Cay assemblages , this site is re-establishing itself quickly. It hosts a variety of Acroporas with a good coral cover.

4.3 Foreshore Area: Seagrass Beds and Infauna

The seagrass beds were extensively represented on the seaward side of the north arm of the Nadi River delta prior to the reclamation. *Lingula* colonies were well represented adjacent to the flats margining the entrance to the river.

During the period of reclamation and the marina development transported fill and dredged spoil created the bund area enclosing the harbour. A breakwater was constructed along the southern side of the channel. The harbour basin, estuary mouth and channel seaward

During this construction, the seagrass beds to the south of the channel were smothered by silt (Appendix B photographs A & B,). The grasses to the north or up current of the channel remained undisturbed.

The present monitoring has revealed the re-establishment of seagrasses, in the area previously inundated with fine sediment and spoil (Appendix B photographs C & D).

4.3.1 Seagrass beds and monitoring site environments

(Figure 4.3.1)

a) Nadi River estuary and marina sites during the construction phase in 1993. Sediment plume covers a wide area of the Nadi Bay smothering the seagrass beds.

b) Denarau Island Resort marina. Re-established seagrass beds appear as dark patches to the left of the breakwater. Seagrass beds that remained unaffected during the construction can be seen to the right of the channel.

c) *Syringodium isoetifolium* (left) shows well-established turf and *Halophila ovalis* (on slope) grows down the slope.

d) Robust growth of *Syringodium*

e) Inshore site of Malan Cay showing well established *Porites lutea.* Ephemeral genus *Acropora* is represented by small colonies of a one to two years old.

f) *Acropora* colonies cover the Yakuilau bommie reef top.

g) Encrusting colonies of *Montipora sp.* Co-monopolise with the *Acropora on* the bommie reef top.

h) Two and three year old colonies of *Acropora* are slowly restoring the site to the level of luxuriance observed prior to the 1993 February flood

4.4 Foreshore survey

The foreshore transect study conducted at low tide on Wednesday 8th October showed the first growth of very young *Syringodium* at about 70 meters from the high water mark (HWM), (Table 4.4). This species is usually the first to colonise intertidal sandy shore areas. Further out at about 100 meters from the HWM, the zone of *Syringodium* thickens mixed with the first growth of *Halophila*. In addition to the increase in the abundance of seagrass from the shore, associated seagrass communities such as beach-de-mer and gastropods were also more numerous than had previously been recorded (Table 4.4.1).

4.5 Sediment Analysis

The particle size analysis describes the percentage of sediment sizes present in the samples (Table 4.5.1). The first column is the sample identification number relative to site. Second, third and fourth columns describe the percentages of sand, silt and clay in the sample with the corresponding particle size diameter range. The fifth and sixth columns are the percentages of finer sand fractions. The last four columns relate to the amplified ranges of the particle sizes shown in columns 1-4.

Samples obtained from Q8, Q15 and Q16, and show an average content of 95.81% medium sized sand, 2-5% silt and < 3% clay. The dark grey colour indicates that it is from a terrigenous source. The mangrove sample showed a very high percentage of organic matter. It was also noted that the mangrove samples (MM1A and MM1B), had an unusually high percentage of fine sand composition which was similar to the samples obtained from the beach.

Table 4.4.1: Foreshore Survey 1997

08/10/97
Denarau
Site 1.: Transect 1

GPS: 17°45'.943" S
177°28'068"E

Quadrat No.	Distance (m) below high water mark	Comments
1	0	• fine black sand (90%) • dead debris *Anadara* sp. - kaikoso shells (25%) • flora and fauna dead
2	5	• fine black sand at the surface (90%) • coarse sand varying between 20cm-50cm in depth • pebbles of various sizes (10%) • dead shells (10%)
3	10	• coarse sand (100%) • auger sample: top 5cm coarse sand, below soft mud (clay/black mud) • absence of flora or fauna
4	20	• ripples of sand and exposed • sand/silt mixture (100%) • auger sample: all sand/silt (more silt under) • absence of flora or fauna
5	30	• same as quadrat 4
6	40	• same as quadrat 5
7	50	• same as quadrat 6 • auger sample: below 20cm more silt than sand, no life • absence of flora or fauna
8	60	• ripples of sand and silt • absence of flora
9	70	• first sign of seagrass: *Syringodium isoetifolium* (<1%) • 4 worm casts
10	80	• auger sample: more silt than sand • 11 worm casts • crabs *Uca sp.*
11	90	• juvenile seagrass beds: *Syringodium isoetifolium* (<1%) • 10 worm casts
12	100	• auger sample: silt/sand mixture (<10%) • ~~dense seagrass: *Syringodium isoetifolium* (90%)~~
13	110	• same as quadrat 12
14	120	• brown filamentous algae and seagrass: *Syringodium isoetifolium*
15	130	• brown filamentous algae • dense seagrass *Syringodium isoetifolium* (>20%)
16	140	• seagrasses: *Syringodium isoetifolium* (30%), *Halophila ovalis* (<0.1%) • juvenile cowries (10 per m^2) • brown algae (10%)
17	150	• very thick seagrass cover : 80%, • brown algae(5%) • juvenile beche-de-mar (1) • worms and gastropods. • increasing faunal diversity

Table 4.5.1 Particle Size Analysis Results

Sample Id No.	Distance Below high water mark (m)	sand 2mm - 0.05mm	silt 0.05mm 0.002mm	clay - < 0.002mm	0.25 0.1	0.1 - 0.05	2 - 0.2	0.2 - 0.02	0.02 0.002	< 0.002
Q 8 a	60	96.0	0	-	5.4	90.6	1	98.5	-	<2
Q8 b	60	97.0	0	-	3.4	93.4	0.4	94.4	-	-
Q16 a	140	97.0	2	1	4	92.0	0.8	98		
Q16 b	140	94.8	5	-	6.3	94.0 -		96.8	2.5	
Q17 a	150	96.4	2	<3	5.9	90.5	0.5	98.6	-	<3
Q17 b	150	97.4	2	<1	4.9	92.5	0.1	98.9	-	<1
MM1a		95.9	0.4	3	2.4	93.5	0.5	95.9	0.6	3
MM1b		91.0	1.5	<1	7.0	85.0	0.5	90.9	1.5	<1

5.0 DISCUSSION

5.1 Changes in Water Quality from 1993 to 1997

For most of the water physio-chemical parameters including temperature, pH, salinity, conductivity and dissolved oxygen, no unusual values or variation were observed during monitoring period from September/October 1993 to October 1997. These parameters have not been affected by the dredging operation of 1993 (Appendix A Table 2). The current status of these parameters conform to acceptable levels as prescribed in various guidelines as well as the Fiji Draft Sustainable Development Bill (1996).

Dissolved oxygen values indicated oxygen-saturation for the whole bay and this has not changed since 1993. The aquatic life-forms would not have been deprived of their oxygen supply throughout the monitoring period.

The clarity of the water is one parameter that has changed over the years since 1993. The 1993 clarity values ranged from 1.7 meters (within the plume field from dredging, close to the seagrass zone) to 5 meters (close to Alacrity Cay,). This time, clarity of the water in Nadi Bay has deteriorated with values ranging from 1.0 meter close to Alacrity Cay, to 2.15 meters at about 200 offshore from the Sheraton Hotel. Observations by tourists and Sheraton Hotel Management of turbid waters in the near-shore area are clear evidence that sediment levels appears to be increasing rather than return to pre-dredging conditions.

This observation has significant implications on the objective of the whole monitoring programme, which wasto assess the effects of dredging. The dredging for and marina and navigation channel was completed in early 1994 and marina operations have grown since commissioning in May 1994. Despite this, the clarity of the water has not improved, in fact it has deteriorated since the last monitoring which coincided with the actual dredging (see Appendix B photos A & B). This observation indicates that other factors are contributing to the increasing turbidity in the water. The various boating activities including the popular Shotover Jet Operations need to be seriously assessed in the light of these findings. However, natural sediment loading from the Nadi River is just as significant as the effects of operation of the marina and associated activities.

In line with decreasing water clarity, the total suspended solids (TSS) concentrations showed significant increases at all stations, since the 1993 monitoring. The range of TSS in 1993 was 5.2 - 54.8 mg/L. This time the range has increased to 28.0 - 223 mg/L (Appendix A Table 1). The station close to Alacrity cay (station 1) appears to be the most affected of all the stations, i.e. clarity for the site had decreased from 5 m in 1993 to 1.5 m in 1997 and TSS had increased from 29.6 mg/L in 1993 to 223 mg/L in 1997. Alacrity cay is directly in the path of discharge from the Nadi River. Outgoing tide laden with sediment would.pass directly over and close to the Alacrity cay. As well as this, the general direction of the current being in a westerly direction would bring in sediment from various developments up the coast. The observed turbid waters close to the hotels is due to a combination of these factors. Photograph E in Appendix B clearly shows the sediment plume spreading out from the estuary and drifting around the breakwater towards the west. The photos also show the plume around the Alacrity cay.

Levels of nutrients are low enough to be of no concern. The only high value obtained was 237.8 ug NO3/L, near the Sheraton Hotel. Nevertheless, these are within the usual range expected for open oceans (30 - 300 ug/L).

5.2 *Changes Observed in the Coral Reef Sites during the Monitoring Periods*

The results of the present monitoring is the culmination of observations of four reef sites and one inshore habitat over a total period of 5 years 10 months. The monitoring periods were unequal comprising periods of 7 months after establishment with two subsequent sessions of 15 months and 4 years.

During these periods changes in the nature of the sites were correlated with the development of the marina and with climatic events that occurred during that time. A similar luxuriance of *Acropora* was observed during the baseline assessment and the first monitoring session. Subsequent to that, Cyclone Kina followed by record flooding a month later, caused near total mortality among the *Acropora* greatly affecting the composition of the Alacrity and Yakuilau sites. The Malan Cay site, being located closer inshore and comprised of an assemblage that is resistant to the inshore effects of flooding and siltation, was less affected in terms of coral mortality.

Subsequent to the flood, colonisation occurred on the offshore sites of the Alacrity Cays. By contrast, the Yakuilau Reef bommie has shown remarkable recolonisation by *Acropora* and *Montipora* species. The inshore site, of Malan Cay, has shown some *Acropora* recolonisation but generally the species composition has remained unchanged with the quadrat species suffering little mortality among the more inshore-tolerant species. These colonies have exhibited good growth over the last three years.

5.3 Changes in the Seagrass beds

The Seagrasses dominated the sand flat area adjacent to the marina prior to construction. The spoil from the dredging and bund construction subsequently buried these (Appendix B photographs A & B). Though the grasses were not present after the first two monitoring periods of 1992 and 1993, they have become re-established. The seagrass beds appear as dark patches to the left of the breakwater in photograph C. Appendix B. Photograph D is a close-up view of the sand flat at low tide. Comparison of pre- and post-construction photographs allows an estimate of 50% of the habitat that was formerly available has been lost due to the dredging of the channel and breakwater construction. An estimate of the degree of re-establishment is 30% within the comparable area now available for regeneration. Presently, they host three species with re-colonisation approaching the pre-marina development.

An increasing presence of graziers including juvenile cowries and brachiopods was noted in the zone of seagrasses. The present situation illustrates a "young foreshore" with juveniles dominating the populations of each species, whether it be seagrass or fauna. Provided no major disruption or disturbances occurs in the area, the foreshore and seagrass bed should return to pre-dredging status of 1991, with distinct zonation of the sea grass communities and associated fauna (Lovell *et al.* 1991).

5.4 *Environmental Influences*

5.4.1 Flooding

Dilution of the seawater, reduction in light and the transport of sediment are all effects of flooding. Chronic and periodic effects condition the nature of the coral communities in proximity to the river mouths. Squires (1962) described the effect of the Rewa River, Fiji on the coral communities of varying distances from the river mouth. Wholesale coral death has been attributed to flooding elsewhere. Death by flooding occurred on the Queensland coast in 1918 (Hedley 1925) and during major flooding at the mouth of the Brisbane River (Slack-Smith 1959; Lovell, 1975, 1989). Flooding in Jamaica (Goodbody 1961) and on the reefs in Tahiti (Crossland, 1928), and Samoa (Mayor, 1924a) caused mortality.

Storm damage and flooding are intermittent, though the latter may be aggravated by human activity. The influences of cyclones involving storm damage and flooding are events that are part of the environment in which coral reefs develop. This may reflect degrees of development or stages of growth since destructive alteration of the community by the last storm or flood.

The mechanical effects of extreme wave action, the reduction in salinity, increased turbidity, the alteration in the reef morphology and current structure give rise to alteration of the reef communities and, at times, wholesale death. These community changes involve the reduction of monopolising species, the dispersal of coral fragments, which develop into new colonies, new substrate becoming available for settlement. As part of the system within which coral reefs have evolved, cyclones have many beneficial effects on the reef's growth and development. They can also precipitate degradation when environmental conditions have generally declined through chronic pollution or increased sedimentation.

5.4.2 Sedimentation

The silt that floods convey may remain persistent and periodically re-suspended. It may be deposited shoreward or move to depth, but it may be continually re-suspended. It becomes chronic when there is a change in the watershed through agricultural practices, which allows continued entry into the marine environment. Anecdotal information of a more luxuriant reef inshore may reflect the cumulative effect of agriculture and general development over the last 40 or 50 years. The slow accumulation of sediments may have similar effects to flooding in terms of local death. The Vuda Point fringing reef, extending from the Vuda River along the margin of North Nadi Bay, is an example where the nature of a fringing reef changed over time due to a pronounced build up of sediment (Lovell, 1995).

Siltation directly affects species diversity and the degree of living cover. Bull (1982) in comparing two bays on Magnetic Island, North Queensland, found a marked reduction in the number of species in the site most affected by siltation. Roy and Smith (1971) found a 50% lower coverage in turbid areas of the Fanning Island lagoon. Porter (1972a,b) attributed diversity reduction in back shelf regions of Caribbean reefs to sedimentation. Loya (1972) concluded that heavy sedimentation might be a very significant factor in determining Scleractinian community structure. He attributed a reduction in species abundance and percentage cover in areas on Eilat Reefs, Red Sea to this agent. He points out that the few massive species found in this zone have probably evolved cleaning mechanisms. Marshall and Orr (1931), in studying the effects of sedimentation at Low Isles, Queensland, found the predominant bay genera to be those most tolerant to siltation.

Deposited sediment may limit the establishment of sessile organisms such as coral. Motoda (1940) explained the paucity of reef corals in certain areas in Palau as due to unfavourable substrates. Kissling (1965) found substrate to be the prime factor in regulating coral distributions in the shallow water environment at Spanish Harbour.

Understanding the mechanisms by which sediment affects coral is helpful. Firstly, most corals are attached to reefal material and cannot move to improve their circumstance. Attachment itself relies on a suitable substrate. Silt covered surfaces are not suitable and the larval stage cannot settle. Feeding is interfered with and the continuous need for cleaning becomes an energy consumptive requirement that depletes the energy budget. Cloudy water prevents the penetration of light, depriving the coral's symbiotic algae, the zooxanthellae, of their energy source. Their contribution to the corals nutritional requirement and skeletal construction are reduced. The skeletal design of the colony is often unsuited to the increase in siltation with its growth form resulting in silt capture and smothering (Holthus, 1991).

5.4.3 Crown-of-thorns starfish

The crown-of-thorns starfish, *Acanthaster planci* (bula or vulawalu in Fijian) is a natural inhabitant of coral reefs. Their occurrence was first recorded in Fiji in 1965 and there have been several episodes of elevated numbers since that time. (Lovell, 1994a,b). In the case of Ovalau Island, the initial stages of a crown-of-thorns outbreak affected only the barrier reefs (Lovell, 1997). Subsequently, large individuals were observed on the inshore reefs probably through migration from barrier reef areas. Recent reports of elevated numbers at sites throughout Fiji indicate that this is not an isolated occurrence.

On the western side of Viti Levu, large numbers of crown-of-thorns have occurred in the last few years and at present exist in elevated numbers throughout the Mamanucas. In Nadi Bay reefs their occurrence is low and conforms to their general absence on inshore reefs. Unlike the Ovalau situation, the distances for migration from the offshore islands are substantial.

5.4.4 Longer Term Benthic Fluctuations in Nadi Bay

What is apparent during this monitoring program is the variable nature of the composition of the coral reefs in Nadi Bay. In 1991, there was a luxuriance of *Acropora,* which represented most of the benthic cover in the sample quadrats. The fast growing *Acropora* tends to monopolise available substrate through overgrowing the encrusting and massive colonies. These latter, slower growing colonies become dominant when environmental conditions eliminate the *Acropora* through flooding or wave action.

This monitoring program has observed a portion of such a cycle. The *Acropora* had become well established at the more offshore sites and suffered complete mortality due to the flood. They are now are becoming re-established. The Yakuilau reef bommie top presently hosts the degree of luxuriance that was apparent in the baseline assessment. The Alacrity Cays remain substantially degraded with young *Acropora* colonies present and more numerous during this years settlement. Malan Cay has a similar *Acropora* occurrence but hosts the most diverse non-*Acroporan* dominated assemblage.

It appears from the prevalence of the *Acropora*, that the genus is becoming more numerous. Given a period of benign conditions where there is an absence of cyclones and flooding, the *Acropora* would re-establish in the luxuriance that was seen in 1991. It is interesting that the period of re-establishment for Yakuilau reef has been less than six years, the Alacrity Cays are still depauperate with respect to their *Acropora* compliment. The.Malan Cay is similar to the 1991 situation though the growth of the non-*Acropora* coral is evident.

5.4.5 Sediment Particle Size

According to the textural triangle used to describe sediment particle characteristics, (Jorgensen and Johnson 1989), samples taken from quadrat 8 (75m), quadrat 16 (140m) and quadrat 17 (150m) are classified as being entirely of sand. Material obtained in the 2mm sieve was particle debris and consisted of dead seagrass and shells weighing less than a gram. Sieving of the beach samples found that sediment material was also being collected at particle sizes of 0.0063mm and below. Particle material of this size is classified as silt (Jorgensen and Johnson 1989) and was also present in suspension. These results indicate the presence of silt at depths of 10cm to 20cm in areas where these samples were obtained.

The mangrove sample had a very high percentage of organic matter, which needed prolonged hydrogen peroxide treatment. Furthermore the mangrove sample also consisted of an unusual high percentage of sand, which was similar to the percentages found in the beach samples. A possible explanation for this result may have been due to the constraints of the method used to determine particular size. Although this method was able to determine percentage values for sand using peaks on the calculation curve, because silt values produced a straight line based on a single value, the percentage value for silt could not be calculated. Therefore despite silt being present in the sample, the percentage of silt could not be determined using this method.

Determining particle size was difficult because of the limited number of resources that were available in terms of literature, technical assistance and the amount of time needed to understand the procedures necessary for this analysis. A similar project being conducted at the Institute of Applied Sciences by a post-graduate student (Alifereti Tawake) proved to be of great assistance as a guideline during this analysis.

A further problem encountered during the analysis was obtaining comparable data, as research on local mangrove soils in Fiji appears to be fairly limited. The most relevant data that could be obtained was a particle analysis study done on the Ba riverbed load (Feresi 1994). The method used by Feresi (1994) obtained percentages for sand, clay and silt, however because of problems previously encountered in this study, meant that the results from these two studies could not be compared in a comprehensive manner.

6:0 CONCLUSIONS

The general conclusions drawn from analysing data and observations gathered over the six year period from establishment of monitoring sites to the final monitoring conducted in October 1997 may be summarised as follows:

1. unless disturbed by extreme events such as flooding and cyclones, coral reefs tend to stabilise into characteristic coral assemblages, depending on the conditions of the environment, in the case of Denarau, the inshore reefs such as Malan cay were dominated by those species tolerant to high sediment levels and flooding. The *Porites* dominated while *Acropora* was hardly present.
2. the off-shore sites including Alacrity cay and Yakuilau Island were dominated by *Acropora* species;
3. natural events such as cyclone Kina and the subsequent flood of February 1993 destroyed as much as 90 % of the coral assemblages in all of the sites, but the major damage was done to the offshore reefs;
4. dredging and reclamation caused massive destruction to the seagrass beds and dramatically increased sediment levels in the immediate environ, however, the impacts are temporary;
5. four years after the dredging, the seagrass is re-establishing on the sand flats;
6. Alacrity cay is not re-establishing its coral assemblages as quickly as Yakuilau and the increased sediment in the area close to the estuary could be responsible for this delay;
7. the clarity of the water continues to deteriorate, despite the fact that dredging had stopped in early 1994.

In conclusion, other factors apart from dredging are contributing to the decreasing water clarity in Nadi bay waters.

7.0 RECOMMENDATIONS

The status of Alacrity cay is under threat from effects of continual sediment loading. This site which once provided an excellent snorkelling site must be monitored very carefully, and effort must be made to return this site to pre-development conditions.

The monitoring has clearly shown that waters in the Nadi bay around the Denarau Resort are becoming more and more turbid. This is creating discomfort to the tourists and hotel management alike. More detailed assessment of the actual sediment loading and possible reasons for the increased turbidity must be conducted to ensure that mitigative measures are put in place to improve this important aspect of the environment.

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9.0 APPENDICES

9.1 WATER QUALITY

9.2 PHOTOGRAPHS

9.3 WENTWORTH GRADE SCALE

APPENDIX A

Table 1: Water Quality Results for 1997

Site No.	Site Description	Temp (^0C)	Salinity (ppt)		pH	Diss.Ox (ppm)	Clarity (m)	Total susp. solids (mg/L)	Total Diss. solids (mg/L)	Nitrate ($\mu g NO_3$/L)	Orthophosphate ($\mu g PO_4$/L)	Faecal coliform (/100ml)	Hydro carbons (mg/L)
1	Alacrity cav	25.3	27.4		8.15	7.69	1.50	223	41.627	<34	33.5	0	4
2	Yaku Is	25.1	27.3	42.5	8.17	7.73	2.00	28.0	41,520	<34	27.1	2	6
	Sheraton	23.7	27.6	42.5	8.16	7.76	2.15	68.0	30.299	237.80	37.5	0	4
4	Seagrass beds	25.2	7.70	42.7	8.12	7.20	1.75	32.0	35,254	<34	38.7	0	7
5	Marina	25.3	27.4	42.9	8.09	7.40	1.00	N/A	N/A	N/A	N/A	N/A	4

TABLE 2 :COMPARISON OF WATER QUALITY FOR OCTOBER 1993 AND OCTOBER 1997

Station No.	Location	Water Clarity 1993 (m)	Water Clarity 1997 (m)	Total susp. solids 1993 (mg/L)	Total susp. solids 1997 (mg/L)
1(93) = 1(97)	Alacrity Cay	5.00	1.50	29.6	223
4 (93) = 2 (97)	Yaku-i-lau Is	2.50	2.00	10.0	28
6 (93) = 4 (97)	Seagrass beds	1.70	1.80	28.8	32

9.2 APPENDIX B : PHOTOGRAPHS

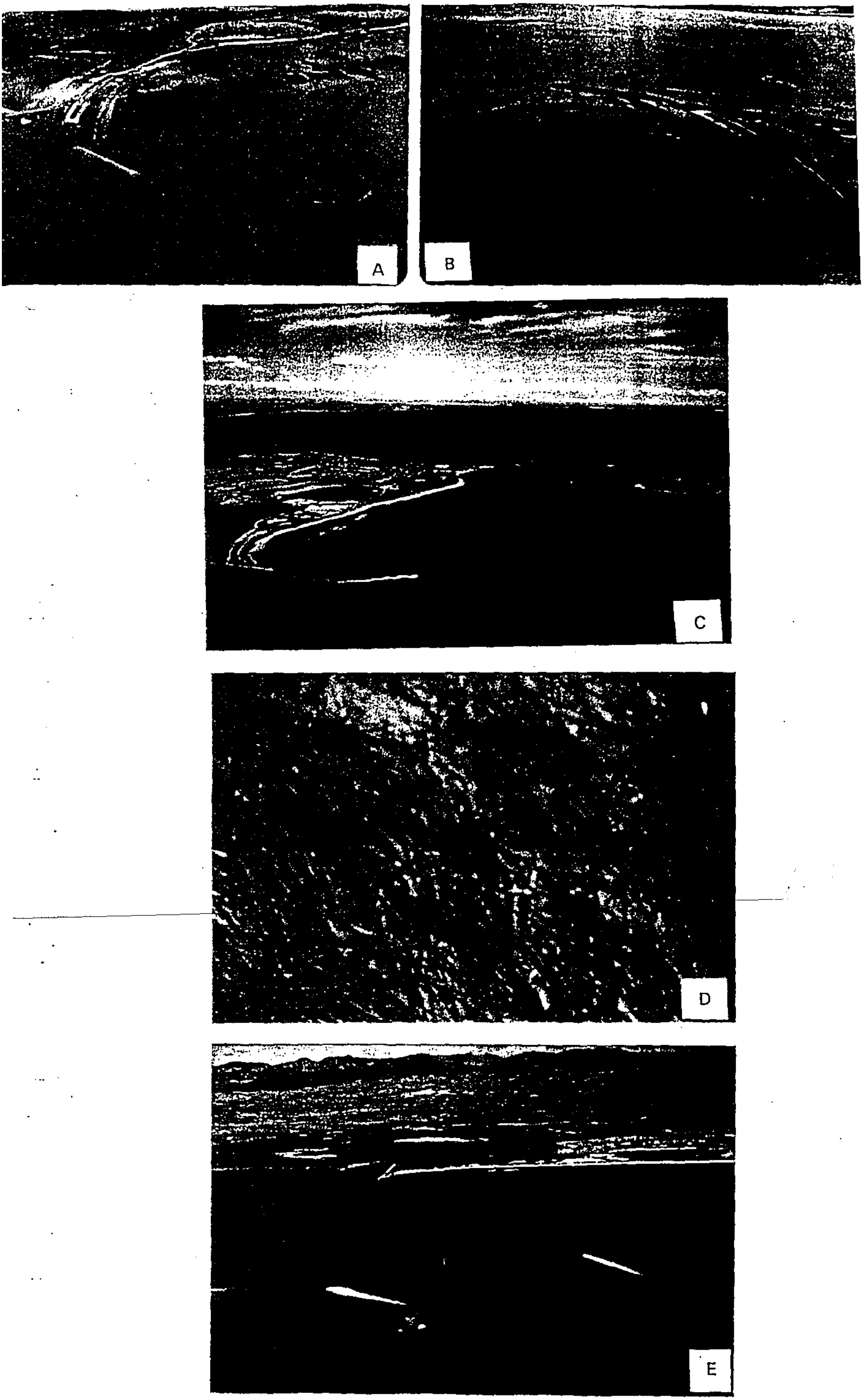
A: DURING DREDGING AND LAND-FILLING OPERATIONS - OCTOBER 1993. SEAGRASS BEDS SMOTHERED BY SILT

B: OCTOBER 1993 - DYKES UNABLE TO CONTAIN DREDGE SPOIL WHICH HAS SPILLED ON TO THE FORESHORE SMOTHERING THE SEAGRASS BEDS

C: OCTOBER 1997 - SEAGRASS BEDS RE-ESTABLISHING ON SAND FLATS TO THE LEFT OF BREAKWATER

D: CLOSE-UP VIEW OF THE YOUNG SYRINGODIUM ON THE SAND FLATS

E: THE BAY IN OCTOBER 1997 - SEDIMENT PLUME CLEARLY SPREADING FROM THE ESTUARY AND OUT IN WESTERLY DIRECTION.


A
B
C
D
E