INSTITUTE OF APPLIED SCIENCES

THE UNIVERISTY OF THE SOUTH PACIFIC

SEDIMENT TRANSPORT, CURRENTS, AND REEF HABITATS IN THE NAVUA RIVER ESTUARY AND IN-SHORE WATERS: A BASELINE STUDY FOR THE PROPOSED NAVUA RIVER DREDGING PROJECT

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Sediment Transport in the

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1.0 Introduction

Dredging operations typically affect the environment in a number of ways. One of the impacts of dredging is the re-suspension of sediment and its transportation to other areas. At the dredging site, the turbidity of the water would be increased, although temporarily, and there may be some release of nutrients in the water from recent sediment. The sediment plumes transported by the water flow would in turn affect other living organisms by:

- decreasing light penetration and associated photosynthetic activity;
- affecting fish that feed by sight;
- damaging vertebrate and invertebrate gill functions and
- harming fish breeding grounds.

(Comm.Sec., 1993)

In order to appreciate the potential impacts of the proposed dredging operation at the Navua River estuary, the sediment transport processes in the area must be understood. Current studies were conducted using drogues and a current meter.

2.0 Background

Although the Navua River estuary had been dredged once before, no data was collected on water circulation patterns and currents in the subject area. However, a number of studies conducted in the general southeastern coastline of Viti Levu have generated some information which is relevant to the subject of sediment transportation in the Navua River estuary (Shepherd, 1990, Gussmann, *in press*). The current study has attempted to conduct direct measurement of the flow and direction of the estuarine and in-shore currents around the Navua River mouth, although a number of difficulties were encountered.

The Navua River is one of the largest rivers in Viti Levu, with a peak discharge of c. 6000 m^3/s (Harris 1980) and a mean discharge of 45 m^3/s (Harris in Ryland 1981). The Navua River has a drainage area of 1220km^2 (Derrick, 1957), and the delta covers an area of 50km^2 (Shepherd, 1990).

Qualitative assessment based on dominant wind direction (South East Trade Winds), beach shape and geomorphological evidence indicated that a westerly littoral drift had been present in the past, transporting sediment freely towards the west (Shepherd, 1988). The results of the drogue float tracking studies and the current meter study conducted by the Institute of Applied Sciences on October 29, 1999, supported the prevalence of a north-easterly flow over the whole area. Apart from localised, in-shore current patterns that are peculiar to the area, the dominant flow of water in the estuarine and in-shore coastal areas at Navua is the long-shore drift from the north-east towards the south-west.

A number of factors have influenced the localised, in-shore circulation pattern around the Navua River estuary. The presence of the three barrier reefs, particularly the Naitata Reef close to the land, the influence of the Navua River and the sediment load it discharges to the coast, and the effects of the South East Trades all have contributed to the current situation in the area. Over the years, off-shore transport of sediment from the Navua River has been blocked by the Naitata Reef, causing a build-up of silt around the estuary. Under normal weather conditions, tidal currents are not very effective in moving the sediment away from the area (very weak currents detected during the first drogue float studies in July 1999). During the flood tides, the barrier reefs effectively reduce the southerly swells generated by the prevailing winds, so that the low energy zone behind the reefs have seen a gradual build-up of material. However, the longshore drift moves the sediment plume west towards the Beqa passage.

The Wainividio Passage is characterised by strong surges and high energy waves during the turn of the tides, immediately after the low tide (peaks in the current speed, Figs. 5-8). This creates a swirling effect in the Naitonitoni Anchorage. By mid-tide, the currents and speed of the currents normally settles back to the usual north-easterly flow at around 2 – 5 cm/s.

Nearshore sedimentation studies conducted along the coast from Togoru to Takani Pt in Mau showed a general trend of reducing sedimentation rates from west to east. The NSR Environmental Consultants Ltd (1994) which conducted the studies reckoned that this trend probably reflected the influence of the Navua River.

While there is some transport of sediment both westward and to a lesser degree eastward from the Navua River mouth (as deduced from sedimentation studies by Placer Pacific Limited, 1994), the bulk of the sediment load does not move away from the area but accumulates around the river mouth. According to Shepherd (1988), the wave energy is not sufficient to redistribute sediments effectively in any direction, and as a result, the estuarine environment around the Navua River mouth and in the sheltered area behind the Naitata Reef has progressively silted quite rapidly over the years. Extensive submarine sandbars and sandy forelands characterise the area, and the influence of the sediment-loaded Navua River is exacerbating the situation. Under these circumstances, dredging the river mouth is absolutely necessary to reduce flood risk to the delta area. However, dredging is only the short-term solution to the problem. The long-term solution addresses the root cause of the problem in the catchment area of the Navua River.

3.0 Baseline Current studies

Our studies suffered a major setback when the current meter deployed in the river was lost. However, the study was repeated in late October 1999. Surface drogues were used in the river and estuary to determine surface currents. The current meter was deployed from October 26 to October 29 1999. The current meter recorded currents at around 2 m depth, at a single location shown on the map (Fig. 4). The whole study had been hampered by non-availability of current meters, so that it was not possible to conduct simultaneous measurements of currents at different points.

3.1 Surface currents

The drogue used for water current studies consists of a buoy or floatable object attached to a tarpaulin vane which is held down by a piece of iron rod inserted along the lower end of the tarpaulin sheet. Drogues are released in the water and tracked with a hand-held GPS, thus enabling an assessment of the surface currents as the water pushes on the tarpaulin vane. The length of the vane corresponds to the depth of the water column being assessed, and the length of the vane can be varied depending on how deep one wishes to measure the current. In this study, the length of the canvas vane was 1 meter, and this would be adequate for the purpose of the study since much of the area proposed for dredging is relatively shallow. Also, the suspended matter mobilised by the dredging operation would float about in the top meter or so of water.

3.1.1 Drogue Tracking

The first drogue study was conducted on July 12, 1999, commencing at 1100 hrs on an ebbing tide and finishing at 1440 hrs during flood tide. Low tide was at 1148 hrs (0.0m). On the day, the weather was fine and dry with a slight breeze of 3 knots blowing. Four drogues were deployed, but two were not recovered despite intensive search by the team. Fig. 1 shows the location of the surface current study sites, and the tracks of the surface drogues. Table 1 shows the results of the surface drogues tracking.

The second drogue study was conducted on Friday October 29th, 1999, commencing at 1052 hrs on an ebbing tide and finishing at 1303 hrs still on an ebbing tide. Low tide was at 1558 hrs (0.4m). The weather was overcast, rainy, and very windy (see Table 2). In fact, the weather conditions on the day were almost cyclonic. Three drogues were deployed, retrieved, and re-deployed. One drogue could not be found at the end of the study despite 45 minutes of intensive searching. Table 3 shows the results of the surface drogue tracking and Figures 2 and 3 show the tracks of the surface drogues.

3.2 Results of Drogue Tracking Studies

Table 1: Results of Drogue Tracking Studies on July 12, 1999.

Drogue #	Release GPS/time	New GPS/time	Distance/direction moved/time	Speed of surface current (m/s)	Comments
8	18°14.807 S 178°09.250 E at 1110 hrs	18°14.932 178°09.236 at 1220 hrs	230 m south, 70 min 24.5 m west, 70 min	0.05 m/s SW	Ebbing tide, near Prawn farm outlet
10 (mid-river from 8)	18°14.819 S 178°09.228 E at 1112 hrs	18°14.844 178o09.237 at 1222 hrs	46.25 m south, 70 min 15.75 m east, 70 min	0.01 m/s SE	Low tide
10 (re-deployed)	18°15.073 S 178°08.922 E at 1230 hrs	18°15.003 178°08.931 at 1440hrs	129.5 m north, 130 min 15.75 m east, 130 min	0.02 m/s NE	Flood tide
5 (near Waimate Creek mouth)	18°15.544 S 178°09.184 E at 1118 hrs	18°15.656 178°09.270 at 1215	207.2 m south, 57 min 150.0 m east, 57 min	0.07 m/s SE	Ebbing tide.
1	18°15.623 S 178°09.290 E at 1122 hrs	18°15.683 178°09.364 at 1212 hrs	111 m south, 50 min 129.5 m east, 50 min	.0.06 m/s SE	Low tide

Table 2. Weather Conditions during the Deployment of the Drogues

Date	Total Rainfall (mm)	Wind Speed	Wind Direction
July 12th	nil	3 knots (calm)	130 degrees (southeast)
October 29th	42.3 mm (heavy rain)	11-16 knots (windy)	150 degrees (south southeast)

(Source: Fiji Meteorological Service Climate Station Tamanoa & Suva)

Table 3. Results of the Drogue Tracking Study on October 29, 1999.

Drogue #	Release Location GPS/time	New Location GPS/Time	Distance Moved/ Direction/Time	Speed of surface current (m/s)	Comments	New Location GPS/Time	Distance Moved/ Direction/Time	Speed of surface current (m/s)	New Location GPS/Time	Distance Moved/ Direction/Time	Speed of surface current (m/s)
4 (mouth of east tributary)	18°15.217 S 178 °09.171 E at 1052 hrs	18 °15.378 S 178 °09.064 E at 1118 hrs	294.6 m south 189.4 m west in 26 minutes	0.22 m/s SW	Ebbing tide	18 °15.600 S 178 °09.221 E at 1141 hrs	406.3 m south 277.9 m east in 23 minutes	0.36 m/s SE	18 °15.942 S 178 °09.275 E at 1200 hrs (P)	625.9 m south 95.6 m east in 19 minutes	0.56 m/s SE
3 (mid-river)	18 °15.316 S 178 °09.087 E at 1054 hrs	18 °16.128 S 178 °08.867 E at 1133 hrs (P)	1486 m south 389.4 m west in 39 minutes	0.66 m/s SW	Moved quite fast						
2 (west bank of river)	18 °15.340 S 178 °09.079 E at 1056 hrs	18 °15.541 S 178 °09.086 E at 1121 hrs (P)	367.8 m south 12.4 m east in 25 minutes	0.25 m/s SE	Stuck in "vau" on southern bank of Waimate Creek)						
3 (re-deployed)	18 °15.405 S 178 °09.069 E at 1152 hrs	18 °16.031 S 178 °08.910 E at 1217 hrs (P)	1145.6 m south 281.4 west in 25 minutes	0.79 m/s SW							
2 (re-deployed)	18 °15.511 S 178 °09.185 E at 1156 hrs	18 °15.911 S 178 °09.232 E 1224 hrs (P)	732 m south 83.2 m east in 28 minutes	0.44 m/s SE							
4 (re-deployed)	18 °15.342 S 178 °09.036 E at 1210 hrs	18 °15.857 S 178 °09.286 E 1231 hrs (P)	942.5 m south 442.5 m east in 21 minutes	0.83 m/s SE	stuck						
4 (re-deployed)	18 °15.360 S 178 °09.114 E at 1236 hrs	18 °15.538 S 178 °09.257 E at 1305 hrs (P)	325.8 m south 253.1 m east in 29 minutes	0.24 m/s SE	Stuck on east riverbank, point						
2 (re-deployed mid-river	18 °15.381 S 178 °09.076 E at 1237 hrs	Stopped searching after 45 minutes									
3 (re-deployed)	18 °15.445 S 178 °09.062 E at 1239 hrs	18 °15.625 S 178 °09.141 E at 1308 hrs (P)	329.4 m south 139.8 m east in 29 minutes	0.21 m/s SE	Stuck on opposite bank (Vunibau side)						

(P) indicates that the drogues were picked up

Fig 1: Location of sediment tubes (S, B, Rv, Rf) and Drogue tracks (12 July, 1999)

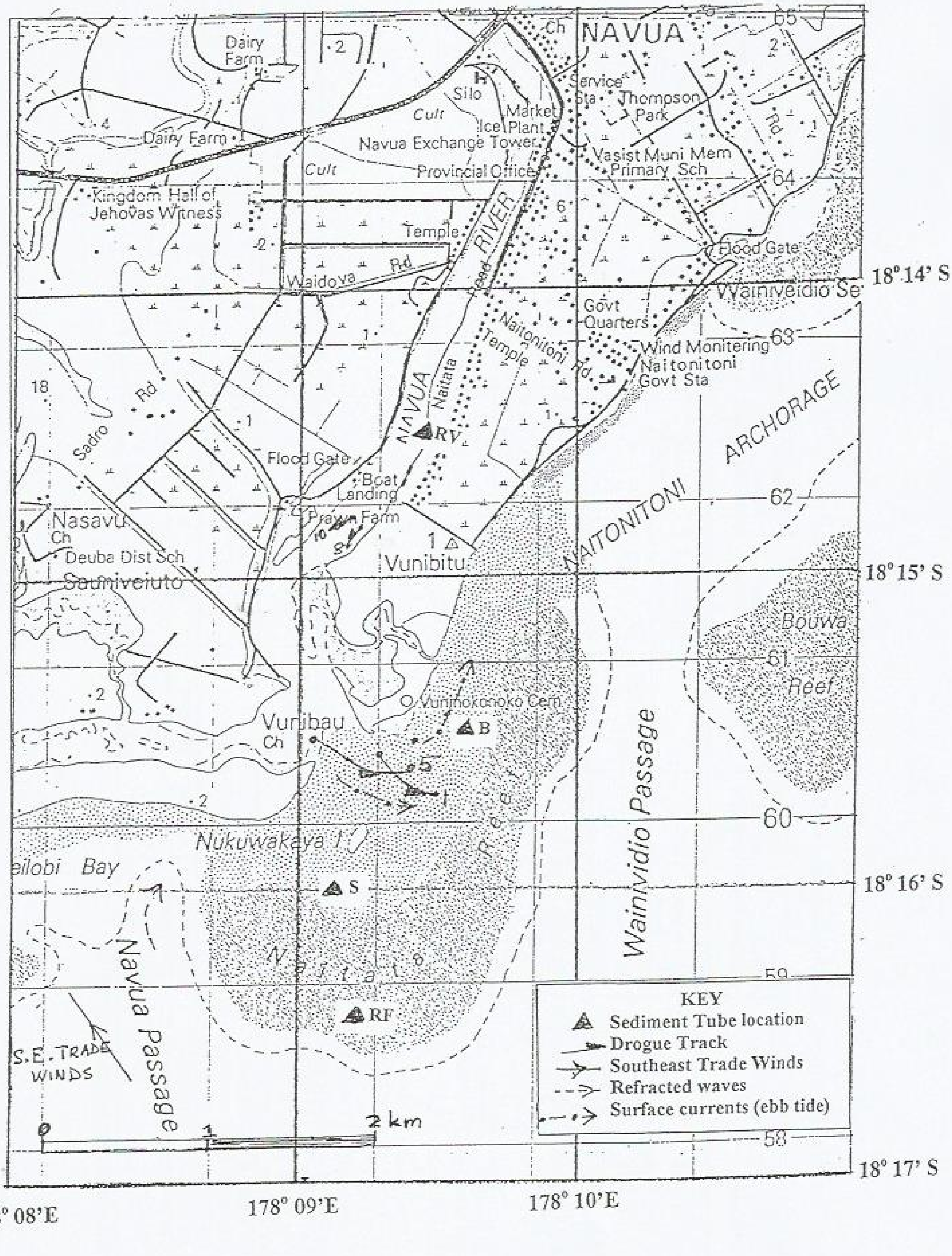


Figure 2. Surface Drogue Tracks in the Navua River Estuary: 1st deployment.

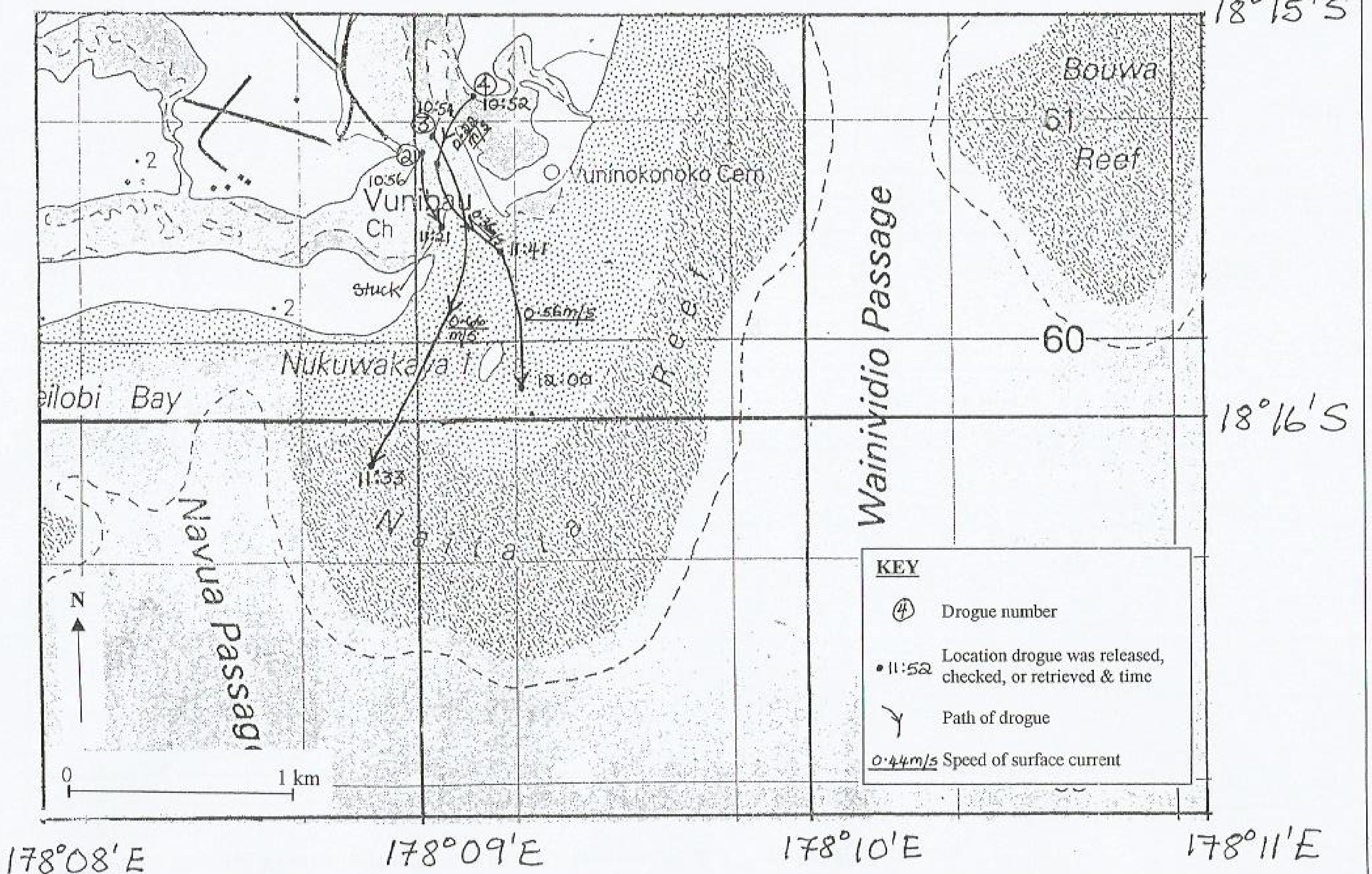
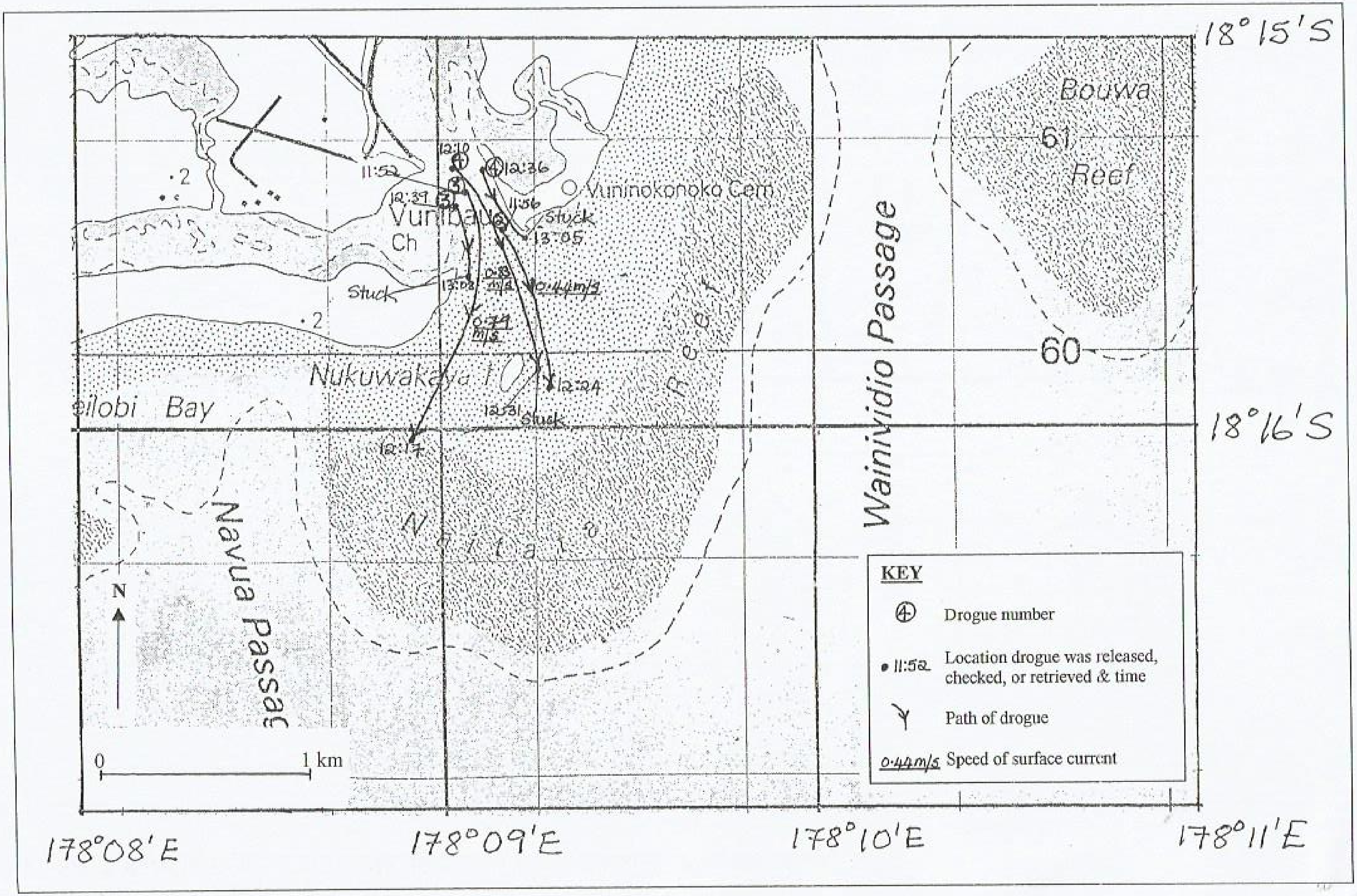


Figure 3. Surface Drogue Tracks in the Navua River Estuary: 2nd & 3rd sets of deployment.



3.3 Discussion of Drogue Study Results

The results of the drogue studies may not fully reflect the flow regime in the Navua River estuary, because of the short period of drogue deployment and the loss of some drogues. However, the study covered the significant section of the tidal cycle: the ebbing or outgoing tide when the movement of the dredge spoil would be determined by the current speed and direction. The results obtained from the current meter deployment (3 days in this case) provided a longer period of current assessment (section 4 below).

The two drogue studies were conducted under very different weather conditions (Table 2). The drogues deployed in the river were controlled by the tidal flow. During the fine, calm conditions on July 12, river flow in mid-river was generally slower (0.01 m/s) than on the sides (0.05 m/s). During the wet, windy conditions on October 29, the flow in the middle of the river was generally faster (0.66 m/s, 0.83 m/s, and 0.79 m/s) than on the sides (0.25m/s, 0.22 m/s, and 0.44m/s).

The drogues were pushed out of the river by the outgoing tide, but in the river mouth the drogues were pushed by coastal in-shore currents. Some of them moved in a south-southwest direction and some in a south and slightly east direction (Figures 1, 2 & 3). The first drogue study on July 12 did not yield conclusive results because of the very weak currents at the estuary (0.06 m/s SE). In contrast, on the wet and windy October day, the currents were much stronger (between 0.44 m/s and 0.83 m/s) and the direction of flow much more conclusive (see Figs 2 & 3).This confirms the dominance of the long-shore drift in the area, transporting sediment towards the south-west. In terms of sediment transport, the current speed and direction as observed on October 29 do represent the typical situation which must be considered in the management of the dredging project.

3.4 Potential Impacts of Dredging on Coral Reefs

The survey of the three reefs in the area found that the reef flats were generally degraded, most probably from years of exposure to freshwater discharge and heavy siltation from the Navua River. The local communities have also contributed to the impoverished state of the reefs through uncontrolled gleaning practices and overexploitation of the marine resources on the reefs. The only live coral assemblages are found on the reef crests.

From the results of the drogue study, it can be reasonably assumed that the reef crests on the three reefs are relatively safe from any impact of the proposed dredging of the Navua River mouth. The dredging operation would not impact on any critical habitat since the immediate area around the project area is predominantly silty from years of exposure to the Navua River discharge. In fact the proposed dredging operation would facilitate the outflow of the river and thus reduce flood risk to the low-lying plains of the Navua River, including the village of Vunibau.

4.0 Sub-surface Current Measurement – current meter

The major setback to the study was the non-availability of current meters to enable simultaneous measurement of the currents in the subject area. The location of the current meter was determined after considering the proposed location of the breakwater. The current meter was thus deployed at a point to the east of the breakwater. The breakwater is being constructed to prevent the in-filling of the dredged canal by material or sediment transported via the long-shore drift. The location of the current meter and the results obtained from the current meter are shown in Fig. 4. The meter was deployed in approximately 2 meters of water, about 750 meters offshore from Vunibitu, which is north east along the coast from the Navua River mouth. The exact location of deployment is 18°15.106 S and 178°09.852 E. It was deployed on Tuesday the 26th of October at 16:27 hours and retrieved on Friday the 29th of October at 14:27 hours, overall a period of nearly 3 days. The current meter recorded the temperature, current speed, and current direction every 20 minutes over this period of about 4 days. The raw data from the current meter is appended at the end of this report.

Weather conditions over the period of study were fairly overcast, very rainy on the last two days, and windy on the last three days. Wind direction (direction that the wind was blowing from) was predominantly south southeast (see Table 1).

Table 4 - Weather Conditions during the Deployment of the Current Meter

Date	Cloud Cover (eighths)	Total Rainfall (mm)	Wind Speed (9am 'spot-on' readings)	Wind Direction
October 26th	8/8	4.0 mm	2 knots	130 degrees
October 27th	4/8	2.7 mm	9 knots	150 degrees
October 28th	4/8	16.8 mm	9 knots	150 degrees
October 29th	8/8	42.3 mm	11-16 knots	150 degrees

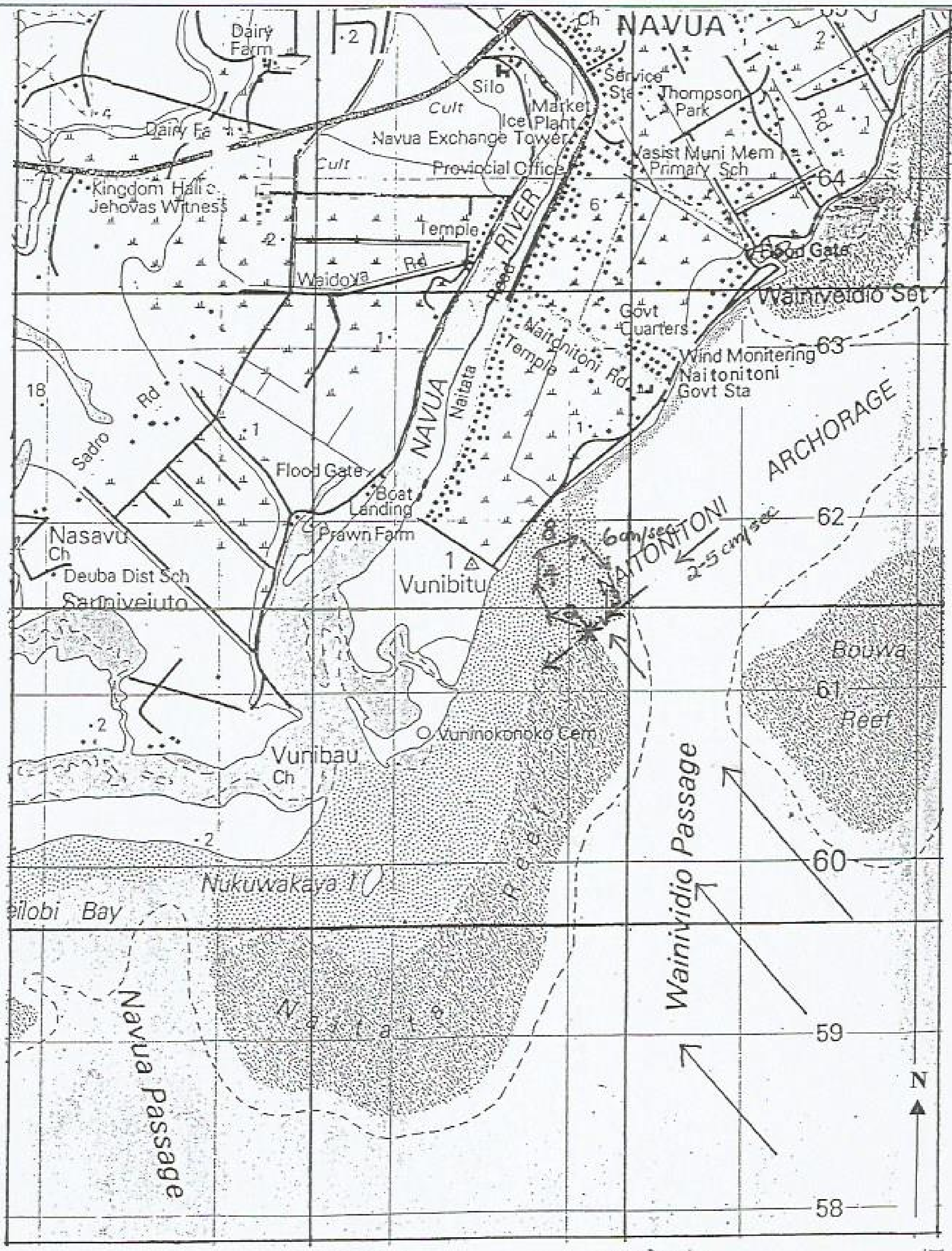
(Source: Fiji Meteorological Service Climate Station Tamanoa (Navua))

4.1 Results from current meter deployment

The variation of current speed and current direction over the 4 days the current meter was deployed are shown in Figures 5 to 8. The currents at the point of deployment show peaks associated with a change in direction immediately after low tide. This is explained by the surge of the water through the Passage. The Wainividio Passage is characterised by strong surges and high energy waves during the turn of the tides, (peaks in the current speed and direction, Figs. 5-8). This creates a swirling effect in the Naitonitoni Anchorage. By mid-tide, after establishment of equilibrium, the currents and speed of the currents normally settles back to the prevalent north-easterly flow at around 2 – 5 cm/s.

The average current speed for Wednesday the 27th October and Thursday 28th October (the two days for which current was measured for the entire 24 hour period) were 4.2562 cm/second and 5.0110 cm/second respectively.

Figure 4. The Navua Estuary Showing the Location of the Current Meter as well as Sub-surface Current Direction and Speed



KEY

✳	Location of current meter
1 cm/sec	General current direction & speed during an outgoing tide
2 cm/sec	General current pattern & speed during an incoming tide
↖	Dominant wind direction

Figure 5. Sub-surface Current Speed and Direction at Navua 26th October, 1999

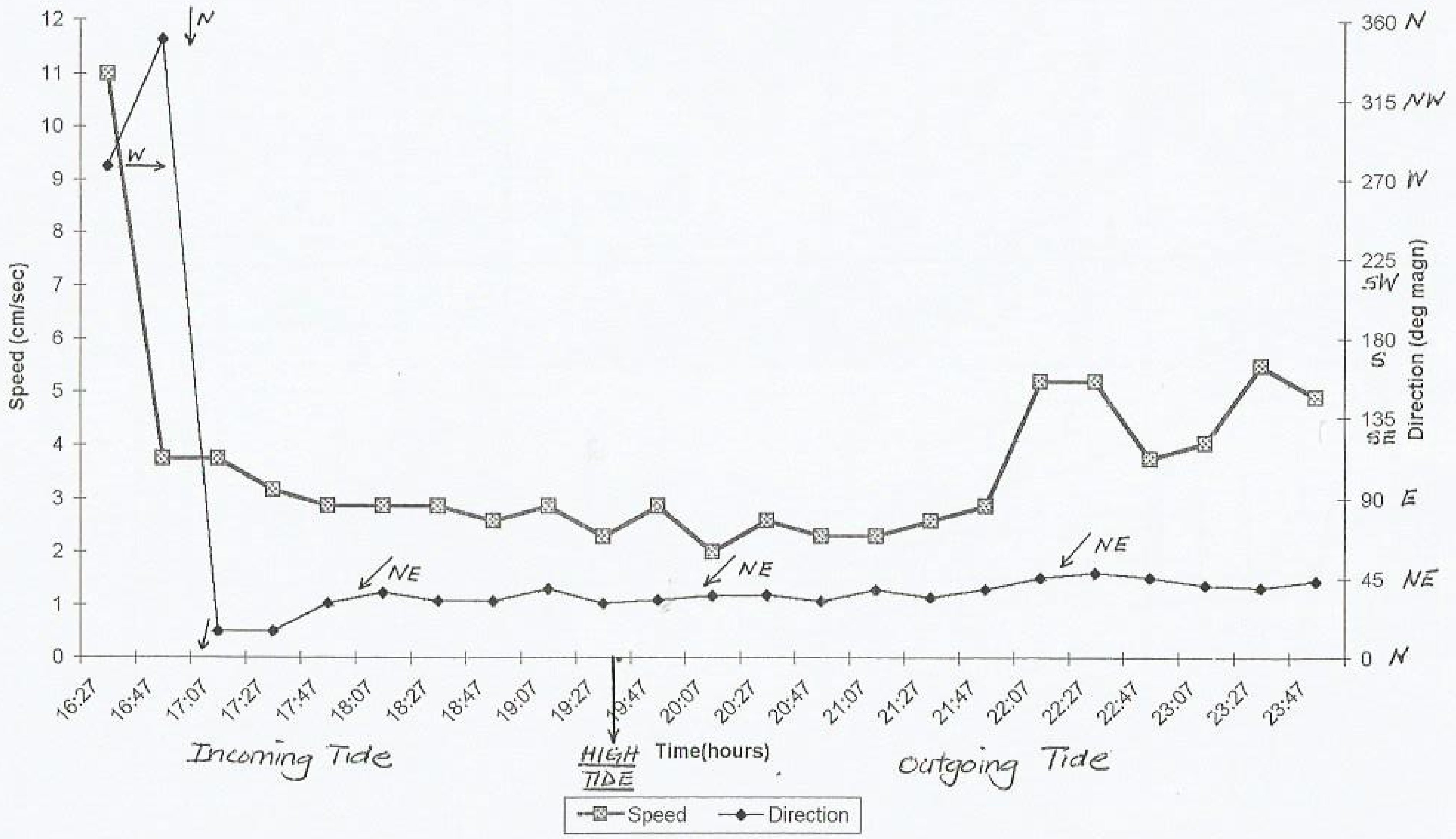


Figure 6. Sub-surface Current Speed and Direction at Navua 27th October, 1999

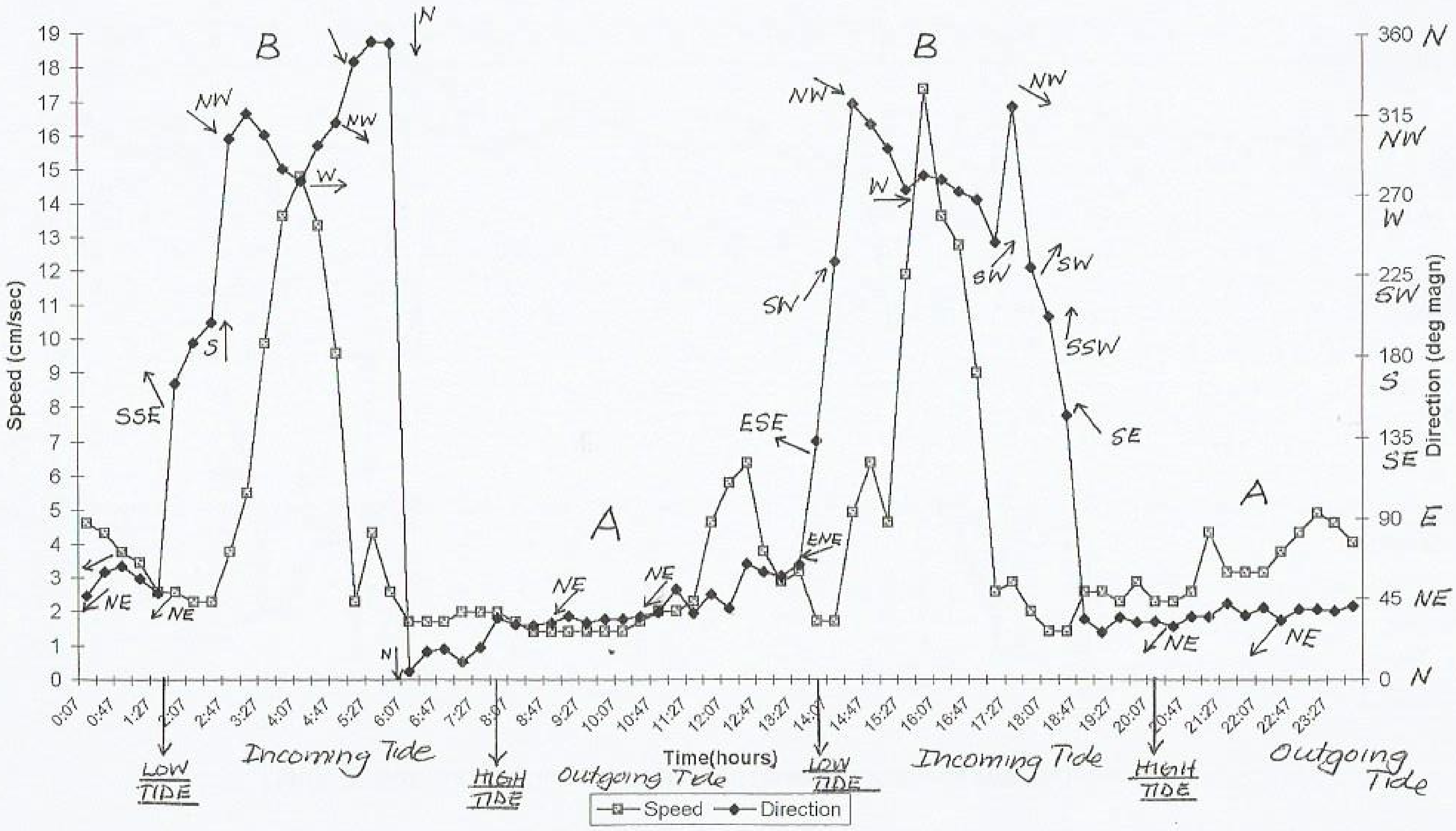


Figure 7. Sub-surface Current Speed and Direction at Navua 28th October, 1999

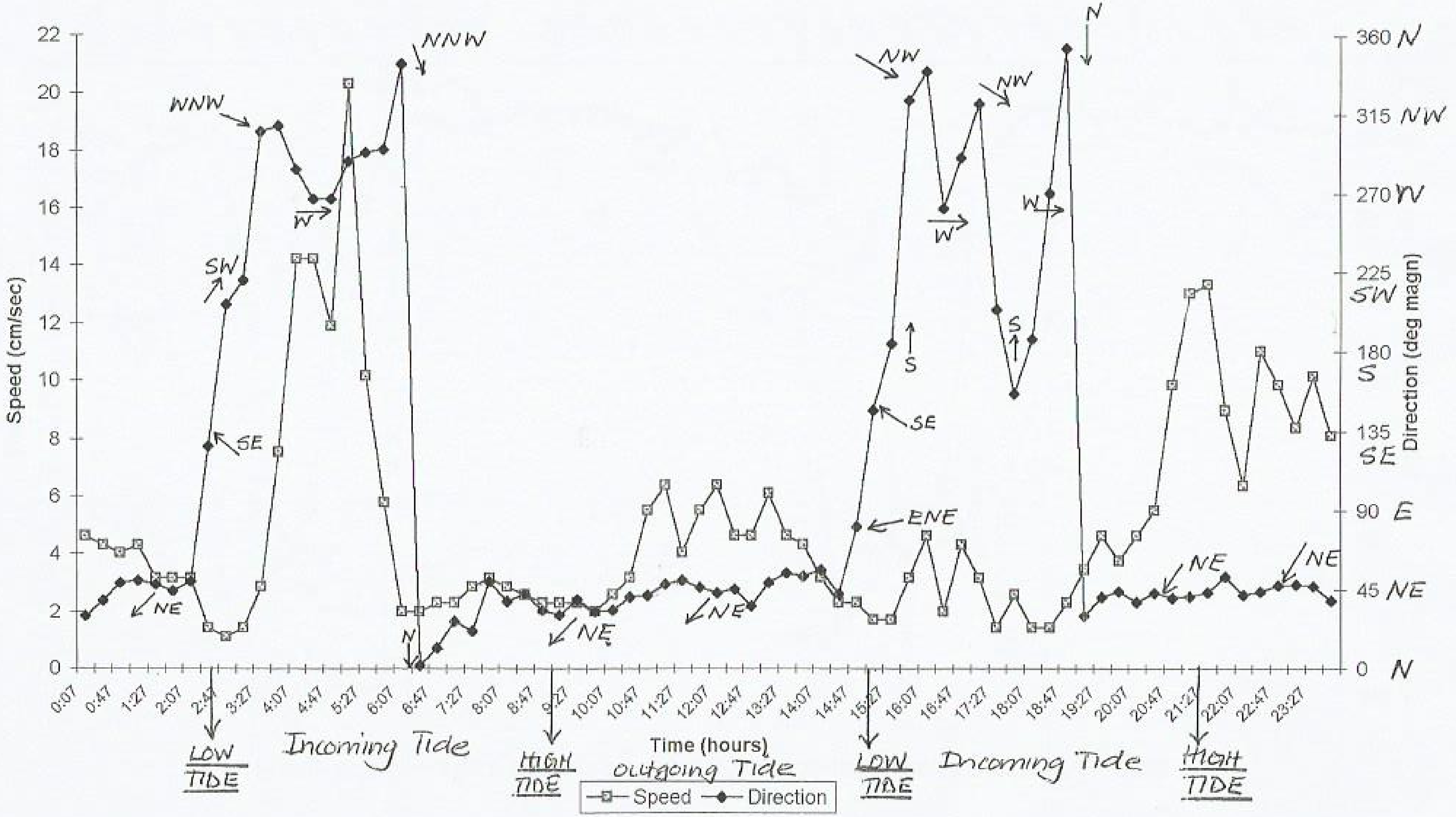
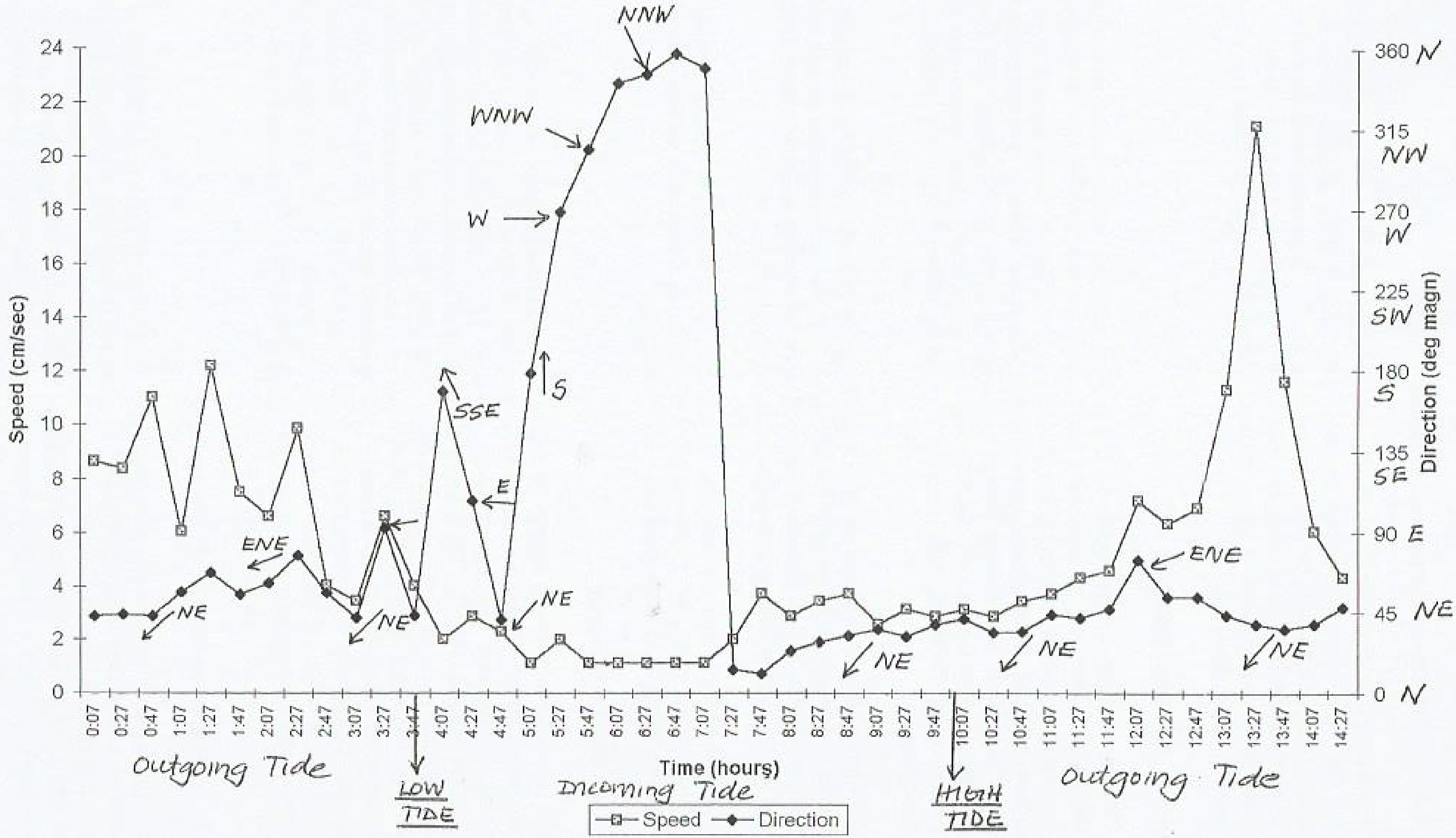


Figure 8. Sub-surface Current Speed and Direction at Navua 29th October, 1999



4.2 Discussion of current meter results

From the plots of current speed and current direction against time it appears that there are two main subsurface current regimes in the area of study (Figures 4 -8). These current regimes are largely controlled by the general Westerly littoral drift present along the coast (Sheppard 1998) as well as the tidal regime and to a limited extent by wind direction and speed. A clear relationship between current direction and current speed was also observed.

4.2.1 Ebb tide regime

The outgoing tide-current regime (A Figure 6) is generally stable. During an ebb tide the general north-east to south-west drift which prevails through the Navua-Suva Lagoon (Gussmann In Press) dominates. Current speed is stable around 2 to 5 cm/second. This is the general current pattern during an outgoing tide but varies in some situations. This current pattern is disrupted during the incoming tide when seawater rushing towards the land through the Wainividio Passage, meets with the general south westerly drift causing a swirling effect within the Naitonitoni Anchorage.

On the final day of deployment (29 October), heavy rain and strong winds caused a dramatic increase in the Navua River discharge. This was detected in the change from the usual current pattern associated with ebb tides. The current speed was much faster than the usual during the outgoing tide in the afternoon (Figure 8).

Comparing the surface and sub-surface currents during ebb tides, the average sub-surface current speeds (4 -5 cm/second) were relatively slower than surface currents obtained during the drogue study (20 – 80 cm/second).

4.2.2 Flood tide regime

The incoming tide-current regime (B Figure 6) is a dynamic pattern. Soon after low tide occurs, current direction changes: from northeast direction to southeast, then from the south, then west, then the northwest, the north before stabilizing at the northeast direction, around mid-tide. The current direction goes through a 360 degree change, thus causing a swirling effect in the area. Following the direction change in the currents, there is a short time lag after which current speed increases dramatically from around 2–5 cm/second to around 15–20 cm/second. This is due to the insurge of seawater through the Wainividio Passage at the turn of the tide (low tide). The current speed then stabilizes at the lower range of 2–5 cm/second. Again this is the general current pattern during an incoming tide, but variation may occur from time to time.

4.3 Mitigative effects of the Breakwater

Locating the breakwater in the designated area would help to alleviate the build up of sediment around the Navua River mouth by directing the sediment transported by the general north-east to south-west drift outwards through the Wainividio Passage during ebb tide. Dredge spoil within the Navua River estuary will still be transported out in a southwesterly direction through the Navua Passage due to this westerly littoral drift.

5.0 Sedimentation Rates in the Navua River and Nearshore coastal waters

5.1 Introduction and Background

Dredging of the Navua River estuary would mobilise sediment and increase the suspended matter concentration in the water. The Navua River presently transports quite a lot of sediment into the coastal waters, having passed through water logged highlands, forestry plantations, deforested areas and intensively-cultivated areas. In order to assess the impact of the dredging on the water quality, it is necessary to establish the background sedimentation rates for the river and nearshore waters, particularly near the reefs.

Sedimentation rates can be highly variable depending on proximity to source of sediment including rivers and dredged areas, water circulation and flow direction, and the mineralogy of the sediments. Sediment causes stress to the coral reef ecosystems. Various studies have found that sedimentation rates of <2 to 10 $mg/cm^2/day$ are often associated with unaffected reefs, rates of 10-50 $mg/cm^2/day$ are associated with moderate to severe sedimentation stress, and for severe to catastrophically affected reefs, the sedimentation rates are >50 $mg/cm^2/day$ (Brown, 1997). Along the southeastern coast of Viti Levu, in an area between Togoru Passage and Mau Passage, the sedimentation rates observed by the NSR Environmental Consultants Ltd ranged from 0.3 $mg/cm^2/day$ to 9.8 $mg/cm^2/day$, in a decreasing trend from west to east.

5.2 Methodology

To establish sedimentation rates prior to dredging, four sediment tubes were deployed in the area. The sediment tubes are constructed from PVC with a length of 400 mm and diameter of 13.5 cm. The tubes are fixed on steel pickets in such a way as to ensure its complete submergence at all times. The open end of the tubes have a baffle structure which aids in the retention of sediment deposited within the tubes. Sediment contained within the tubes is therefore a measure of the maximum rate of deposition, as resuspension and further transport of the sediment will not occur after deposition in the tubes.

The tubes were deployed on June 4 1999, and retrieved on July 12 1999. At the Institute of Applied Science laboratory, the sediment samples were decanted onto 0.45 micron filters, and dried to constant weight. The sedimentation rates were calculated as $mg/cm^2/day$.

The location of the sediment tubes are shown in Fig.1. Table 5 shows the results obtained from sedimentation studies.

5.3 Results and Discussion of Sedimentation Studies

Table 5. Results from Sedimentation Studies

Sediment Tube location (Lab I.D.)	**No. days deployed**	**Weight of sediment (g)**	**Sedimentation Rate ($mg/cm^2/day$)**	**Comments**
Sandbank (S) (99/1096) S 18°16.03 E 178°09.19	38 days	59	12.3	Most western site, nearshore waters
River (Rv) (99/1097) S 18°14.66 E 178°09.46	38 days	1,045	217.0	In the river, some heavy rain during deployment
Beacon (B) (99/1098) S 18°15.48 E 178°09.62	38 days	294	61.0	Most eastern of the tubes, nearshore waters behind Naitata reef
Naitata Reef (Rf) (99/1099) S 18°16.38 E 178°09.18	38 days	12	2.5	Close to reef crest, west of river estuary.

The high disparity between the sedimentation rate for the river ($217 mg/cm^2/day$) and the site closest to the river mouth (beacon, $61\ mg/cm^2/day$) indicated that sediment deposition was occurring at a relatively fast rate at the river mouth and in the slower flowing sections of the river including the creeks (Waimate creek) near the river mouth. The factors causing such a phenomenon have been discussed already.

The impact of the high energy waves passing through the Wainividio Passage during flood tides may be responsible for the high sedimentation rate for the beacon site. The other two sites have lower sedimentation rates as a resultant of their distances away from the source of sediment - the Navua River.

The general westerly littoral drift does transport sediment plumes towards the Beqa lagoon and adjoining lagoons, as reported by other researchers.

6.0 Conclusions

The sediment transport pattern in the area proposed for dredging at the Navua River mouth appears to be characterised by a prevalence of a north-east to south-west drift along the coast. The drogue results and the current meter data also confirm this. However, the reef passages provide variation when the flood tides generate high energy waves which continually cause a re-suspension of sediment and its transport away from the area. The net process appears to be one of sediment deposition at the mouth of the Navua River, as a consequence of a combination of factors: the high sediment loading in the Navua River discharge, the close proximity of the Naitata Reef to the land, the low energy zone behind the reefs and the long-shore drift.

Constructing a breakwater at the designated location would help prevent in-filling of the dredged channel. Dredging would provide a short-term solution to the flood risk, but addressing land-use activities in the catchment area may be the long-term solution to the problem.

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APPENDIX

CURRENT METER DATA – NAVUA RIVER ESTUARY

26/10/99 – 29/10/99

Date	Time	Current Speed (cm/sec)	Direction (deg magn)
26/10/99	16:27	10.9804	277.15
26/10/99	16:47	3.7145	348.9
26/10/99	17:07	3.7154	14.65
26/10/99	17:27	3.1342	14.65
26/10/99	17:47	2.8436	30.4
26/10/99	18:07	2.8436	36.35
26/10/99	18:27	2.8436	31.8
26/10/99	18:47	2.553	32.15
26/10/99	19:07	2.8436	38.8
26/10/99	19:27	2.2624	30.4
26/10/99	19:47	2.8436	32.5
26/10/99	20:07	1.9718	34.6
26/10/99	20:27	2.553	34.95
26/10/99	20:47	2.2624	31.45
26/10/99	21:07	2.2624	37.75
26/10/99	21:27	2.553	33.9
26/10/99	21:47	2.8436	38.45
26/10/99	22:07	5.1684	45.1
26/10/99	22:27	5.1684	47.55
26/10/99	22:47	3.7154	45.1
26/10/99	23:07	4.006	40.55
26/10/99	23:27	5.459	39.15
26/10/99	23:47	4.8778	43
27/10/99	0:07	4.5872	46.5
27/10/99	0:27	4.2966	59.45
27/10/99	0:47	3.7154	62.6
27/10/99	1:07	3.4248	55.95
27/10/99	1:27	2.553	47.55
27/10/99	1:47	2.553	164.1
27/10/99	2:07	2.2624	186.85
27/10/99	2:27	2.2624	198.05
27/10/99	2:47	3.7154	301.3
27/10/99	3:07	5.459	315.65
27/10/99	3:27	9.818	303.75
27/10/99	3:47	13.5958	284.15
27/10/99	4:07	14.7582	277.5
27/10/99	4:27	13.3052	297.45
27/10/99	4:47	9.5274	310.4
27/10/99	5:07	2.2624	344.35
27/10/99	5:27	4.2966	355.2
27/10/99	5:47	2.553	354.5
27/10/99	6:07	1.6812	4.15
27/10/99	6:27	1.6812	15.35
27/10/99	6:47	1.6812	16.4
27/10/99	7:07	1.9718	9.75
27/10/99	7:27	1.9718	17.45
27/10/99	7:47	1.9718	33.9

Date	Time	Current Speed (cm/sec)	Direction (deg magn)
27/10/99	8:07	1.6812	30.05
27/10/99	8:27	1.3906	29.7
27/10/99	8:47	1.3906	31.1
27/10/99	9:07	1.3906	34.95
27/10/99	9:27	1.3906	31.1
27/10/99	9:47	1.3906	33.2
27/10/99	10:07	1.3906	32.85
27/10/99	10:27	1.6812	34.25
27/10/99	10:47	1.9718	36.7
27/10/99	11:07	1.9718	49.65
27/10/99	11:27	2.2624	36.35
27/10/99	11:47	4.5872	46.85
27/10/99	12:07	5.7496	38.8
27/10/99	12:27	6.3308	63.65
27/10/99	12:47	3.7154	59.1
27/10/99	13:07	2.8436	57
27/10/99	13:27	3.1342	63.3
27/10/99	13:47	1.6812	132.6
27/10/99	14:07	1.6812	232
27/10/99	14:27	4.8778	320.9
27/10/99	14:47	6.3308	309.7
27/10/99	15:07	4.5872	295.7
27/10/99	15:27	11.8522	272.25
27/10/99	15:47	17.3736	280.65
27/10/99	16:07	13.5958	278.2
27/10/99	16:27	12.724	271.55
27/10/99	16:47	8.9462	267
27/10/99	17:07	2.553	242.85
27/10/99	17:27	2.8436	319.5
27/10/99	17:47	1.9718	228.85
27/10/99	18:07	1.3906	201.55
27/10/99	18:27	1.3906	146.6
27/10/99	18:47	2.553	33.2
27/10/99	19:07	2.553	25.85
27/10/99	19:27	2.2624	33.9
27/10/99	19:47	2.8436	31.1
27/10/99	20:07	2.2624	31.45
27/10/99	20:27	2.2624	29
27/10/99	20:47	2.553	34.6
27/10/99	21:07	4.2966	34.6
27/10/99	21:27	3.1342	41.95
27/10/99	21:47	3.1342	35.3
27/10/99	22:07	3.1342	39.5
27/10/99	22:27	3.7154	32.5
27/10/99	22:47	4.2966	38.45
27/10/99	23:07	4.8778	38.45
27/10/99	23:27	4.5872	37.4
27/10/99	23:47	4.006	40.2

Date	Time	Current Speed (cm/sec)	Direction (deg magn)
28/10/99	0:07	4.5872	29.7
28/10/99	0:27	4.2966	38.45
28/10/99	0:47	4.006	48.6
28/10/99	1:07	4.2966	50
28/10/99	1:27	3.1342	47.55
28/10/99	1:47	3.1342	44.05
28/10/99	2:07	3.1342	49.3
28/10/99	2:27	1.3906	126.3
28/10/99	2:47	1.1	206.45
28/10/99	3:07	1.3906	220.1
28/10/99	3:27	2.8436	304.8
28/10/99	3:47	7.4932	307.95
28/10/99	4:07	14.177	283.45
28/10/99	4:27	14.177	266.65
28/10/99	4:47	11.8522	266.3
28/10/99	5:07	20.2796	288
28/10/99	5:27	10.1086	292.9
28/10/99	5:47	5.7496	295
28/10/99	6:07	1.9718	343.65
28/10/99	6:27	1.9718	1.35
28/10/99	6:47	2.2624	11.5
28/10/99	7:07	2.2624	26.55
28/10/99	7:27	2.8436	21.3
28/10/99	7:47	3.1342	49.65
28/10/99	8:07	2.8436	38.1
28/10/99	8:27	2.553	42.3
28/10/99	8:47	2.2624	33.2
28/10/99	9:07	2.2624	30.4
28/10/99	9:27	2.2624	38.8
28/10/99	9:47	1.9718	32.15
28/10/99	10:07	2.553	33.2
28/10/99	10:27	3.1342	40.2
28/10/99	10:47	5.459	41.25
28/10/99	11:07	6.3308	47.9
28/10/99	11:27	4.006	50
28/10/99	11:47	5.459	45.8
28/10/99	12:07	6.3308	42.65
28/10/99	12:27	4.5872	44.75
28/10/99	12:47	4.5872	35.3
28/10/99	13:07	6.0402	48.6
28/10/99	13:27	4.5872	54.2
28/10/99	13:47	4.2966	52.45
28/10/99	14:07	3.1342	55.95
28/10/99	14:27	2.2624	42.3
28/10/99	14:47	2.2624	80.1
28/10/99	15:07	1.6812	146.25
28/10/99	15:27	1.6812	184.05
28/10/99	15:47	3.1342	322.65

Date	Time	Current Speed (cm/sec)	Direction (deg magn)
28/10/99	16:07	4.5872	339.45
28/10/99	16:27	1.9718	261.4
28/10/99	16:47	4.2966	290.45
28/10/99	17:07	3.1342	320.9
28/10/99	17:27	1.3906	203.65
28/10/99	17:47	2.553	155.35
28/10/99	18:07	1.3906	186.85
28/10/99	18:27	1.3906	270.15
28/10/99	18:47	2.2624	352.75
28/10/99	19:07	3.4248	29.7
28/10/99	19:27	4.5872	40.55
28/10/99	19:47	3.7154	43.35
28/10/99	20:07	4.5872	37.75
28/10/99	20:27	5.459	42.65
28/10/99	20:47	9.818	39.85
28/10/99	21:07	13.0146	40.9
28/10/99	21:27	13.3052	43
28/10/99	21:47	8.9462	52.1
28/10/99	22:07	6.3308	41.95
28/10/99	22:27	10.9804	43.7
28/10/99	22:47	9.818	47.2
28/10/99	23:07	8.365	47.9
28/10/99	23:27	10.1086	46.85
28/10/99	23:47	8.0744	38.45
29/10/99	0:07	8.6556	43
29/10/99	0:27	8.365	43.7
29/10/99	0:47	10.9804	43
29/10/99	1:07	6.0402	56.65
29/10/99	1:27	12.1428	67.15
29/10/99	1:47	7.4932	55.25
29/10/99	2:07	6.6214	61.55
29/10/99	2:27	9.818	76.95
29/10/99	2:47	4.006	55.95
29/10/99	3:07	3.4248	41.95
29/10/99	3:27	6.6214	92.35
29/10/99	3:47	4.006	43.35
29/10/99	4:07	1.9718	167.95
29/10/99	4:27	2.8436	107.75
29/10/99	4:47	2.2624	40.9
29/10/99	5:07	1.1	177.75
29/10/99	5:27	1.9718	268.4
29/10/99	5:47	1.1	303.4
29/10/99	6:07	1.1	340.5
29/10/99	6:27	1.1	345.4
29/10/99	6:47	1.1	356.95
29/10/99	7:07	1.1	348.55
29/10/99	7:27	1.9718	12.55

Date	Time	Current Speed (cm/sec)	Direction (deg magn)
29/10/99	7:47	3.7154	10.45
29/10/99	8:07	2.8436	23.05
29/10/99	8:27	3.4248	28.3
29/10/99	8:47	3.7154	31.8
29/10/99	9:07	2.553	35.3
29/10/99	9:27	3.1342	31.45
29/10/99	9:47	2.8436	38.45
29/10/99	10:07	3.1342	41.25
29/10/99	10:27	2.8436	33.55
29/10/99	10:47	3.4248	34.25
29/10/99	11:07	3.7154	43.7
29/10/99	11:27	4.2966	41.95
29/10/99	11:47	4.5872	46.85
29/10/99	12:07	7.2026	74.5
29/10/99	12:27	6.3308	53.5
29/10/99	12:47	6.912	53.85
29/10/99	13:07	11.271	43.35
29/10/99	13:27	21.1514	38.45
29/10/99	13:47	11.5616	35.65
29/10/99	14:07	6.0402	38.45
29/10/99	14:27	4.2966	47.9

Survey of the Coral Reef Habitats in the Proximity of the Navua River Estuary

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Survey of the Coral Reef Habitats in the Proximity of the Navua River Estuary

Introduction

Dredging of rivers and estuaries may have considerable impacts on coral reefs because of the transport of suspended sediment by currents and its deposition in other areas including coral reefs. The impacts result from an increase in suspended sediment in the water column reducing light penetration and increasing turbidity, the smothering of benthic communities as a result of the deposition of sediment, or changes in wave pattern and coastal currents (Zamali and Lee 1991).

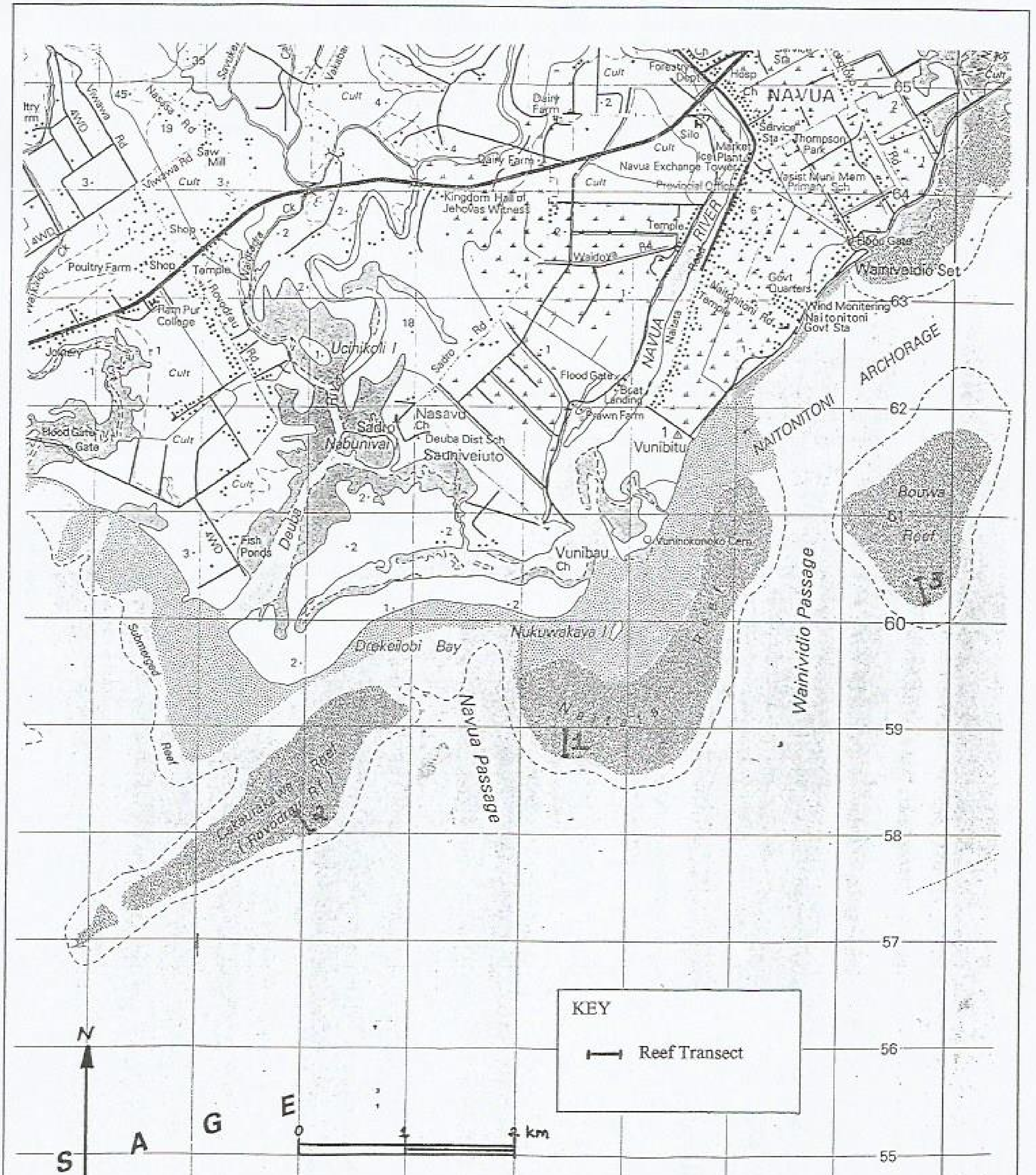
A study was carried out to examine the reef habitats that were most likely to be affected by the dredging project to be carried out at the mouth of the Navua River. Three nearshore reefs were surveyed; Naitata which is directly opposite the Navua River mouth, Cakaurakawa which is situated westward from the river mouth and Bouwa which is eastward from the river mouth (Figure 1).

Method

Reconnaissance surveys were initially done to assess which reefs to be surveyed. Line transects and reef walks at low tide were carried out on each reef in order to obtain information to assess the diversity of species, cover abundance, and substrate type of the reef habitats. Photographs were also taken. Line Intercept Transects (LIT) were carried out as detailed in the Survey Manual for Tropical Marine Resources (English *et al.* 1994). This method has also been used to survey the marine benthos on reefs surrounding the Denarau Island Resort by Tamata *et al.* (1998) and the Labasa River by Sinclair Knight Merz (1999).

On each reef, five line transects (each 20 meters long) were employed, originating at the reef crest (windward side of the reef) and moving towards the leeward side of the reef (see Figure 1 for the approximate location of each transect). The first 20 meter transect started at the reef crest, however, the second 20 meter transect started a further 10 meters from where the first ended, in order to cover a wider range of reef zones. The transects were conducted at low tide on the 16th of June and the 12th of July, 1999. Qualitative information was obtained during reef walks and from photographs of corals within a square meter frame. The dominant species present on the reefs were identified according to Veron (1986) and Allen & Steene (1994).

Figure 1. The Navua River and Surrounding Reefs
(Source: Government of Fiji 1993)



Data Analysis

The line transect data was processed using the Australian Institute of Marine Science Reef Monitoring Data Entry System (ARMDES). Within this system, data for each transect is compiled in a sample table and a data table. The information is presented as a relative percent cover of the four main benthic forms along the transect; hard coral, algae, abiotic, and other categories and is shown as a pie graph. The hard corals are divided into Acropora and non-Acropora groups and the algae are divided into macro-, coralline-, and turf-algae. The percent cover for each group is presented as a bar graph.

The percent cover of each individual group within each category was calculated manually. In addition, comparisons between the five (20 meter) transects studied on a particular reef were done using spreadsheet analysis, in order to observe the zonation pattern.

Results

All three of the reefs are completely exposed at low tide. In addition, at low tide, the channel between Naitata Reef flat and the coastline is extremely shallow and extensive sandbars are exposed. In general, for all three reefs, the cover abundance of live coral and diversity of life is high only near the reef crest (windward side the reef). Further towards the leeward side of the reefs, on the reef flats, the benthos grades to macro-algae, rubble, and sand. All three transects indicated that the reef habitats are algae dominated with more than 60% of each transect composing of algae. The second highest percent cover abundance on all three reef transects was abiotic substrate such as sand, rubble, and dead coral that made up 18 to 27% of each transect. Hard coral made up less than 5% of each transect and was found on the outer edge of the reef. The 'other' category, which included marine organisms such as zoanthids and holothurians, also made up only a small portion of the reef transects (Figures 2,3,4). The hard corals were largely *Acropora* species and the algae were predominantly macro-algae (*Sargassum echinocarpum* var. *vitiensis*) and the encrusting coralline red algae, *Lithothamnion* sp.. A very small number of marine fauna were observed.

Figure 2. Percent cover of main benthic forms for the Naitata Reef transect

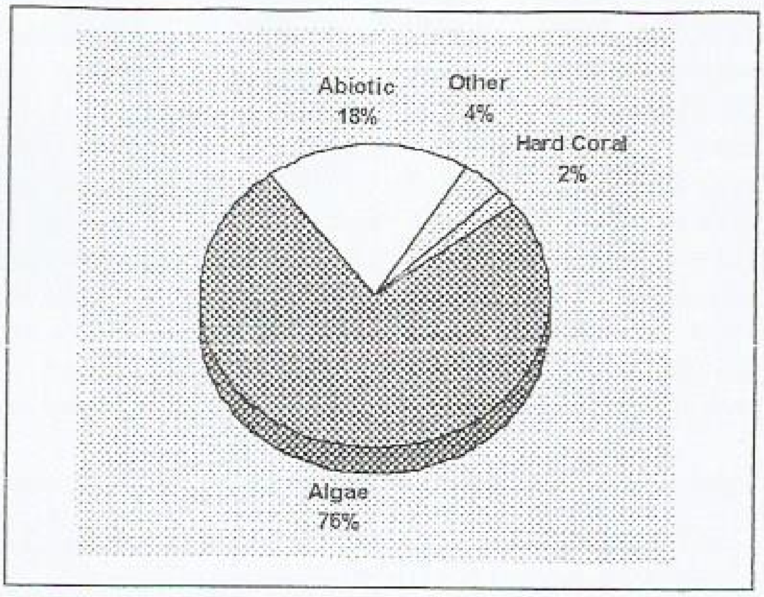


Figure 3. Percent cover of main benthic forms for the Cakaurakawa Reef transect

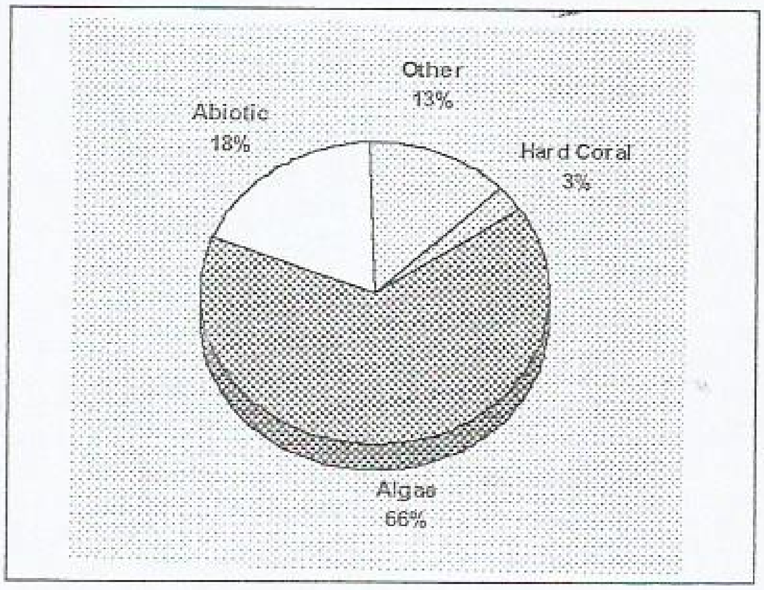
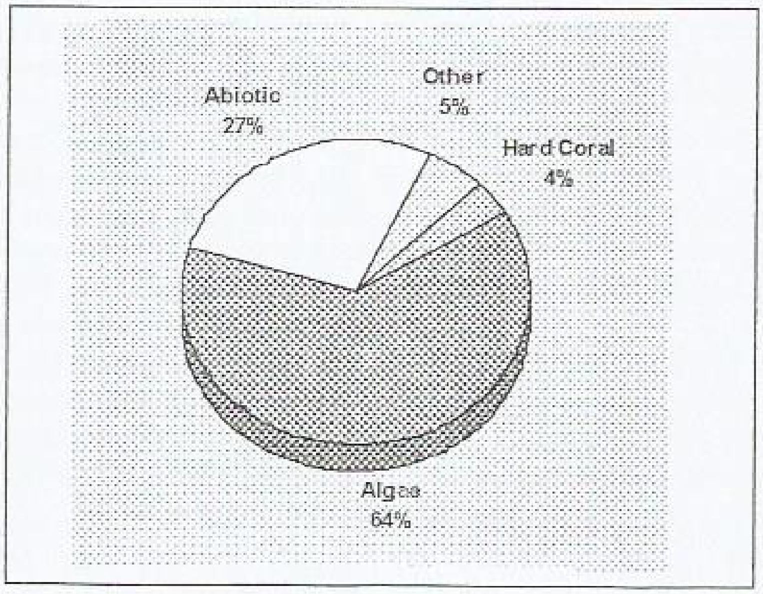


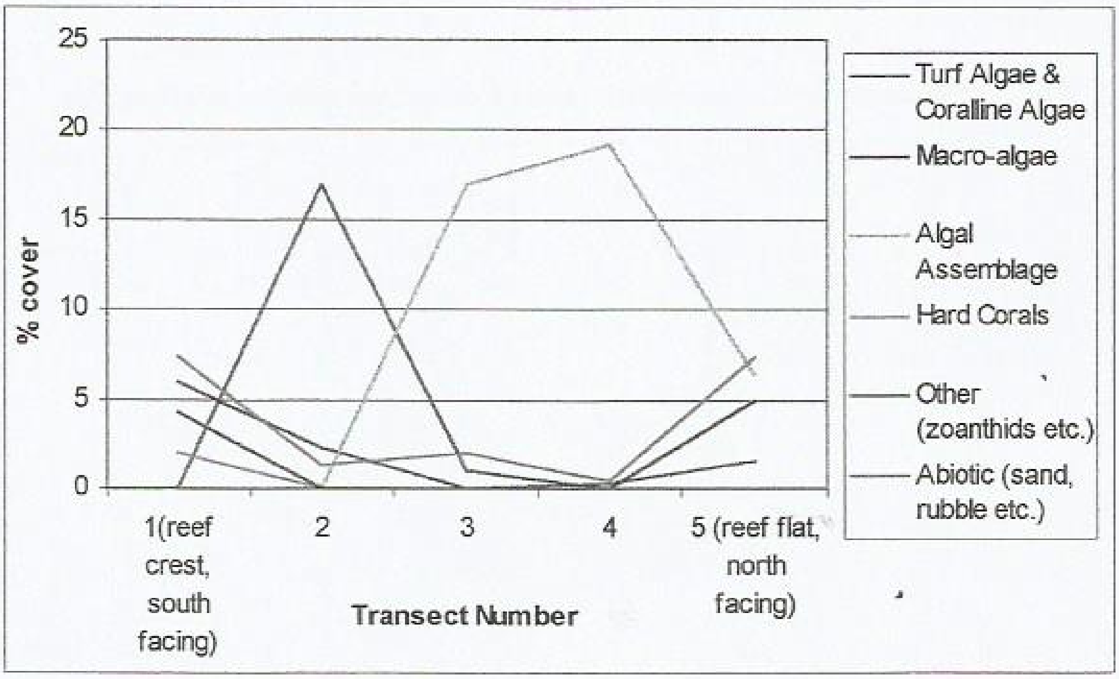
Figure 4. Percent cover of main benthic forms for the Bouwa Reef transect



Reef 1- Naitata

Algae was the dominant cover on this reef and was predominantly *Sargassum echinocarpum* var. *vitiensis* (a macro-algae) or *Sargassum* coated by a red filamentous algae (Appendix Figure 1). The hard corals present were predominantly branching *Acropora* species (Appendix Figure 2 & Figure 10a). The substrate was largely rubble or dead coral with algae (Appendix Figure 3). The zonation pattern showed that near the reef crest turf algae, corralline algae, hard corals, and zoanthids were abundant and the substrate was largely dead coral with algae. Further towards the leeward side of the reef, macro-algae and a combination of macro-algae and coralline algae began to dominate whilst the abundance of hard corals, turf algae and zoanthids declined. Even further towards the leeward portion of the reef, abiotic factors such as rubble dominated as well as some macro-algae (Figure 5 & Appendix Figure 10g).

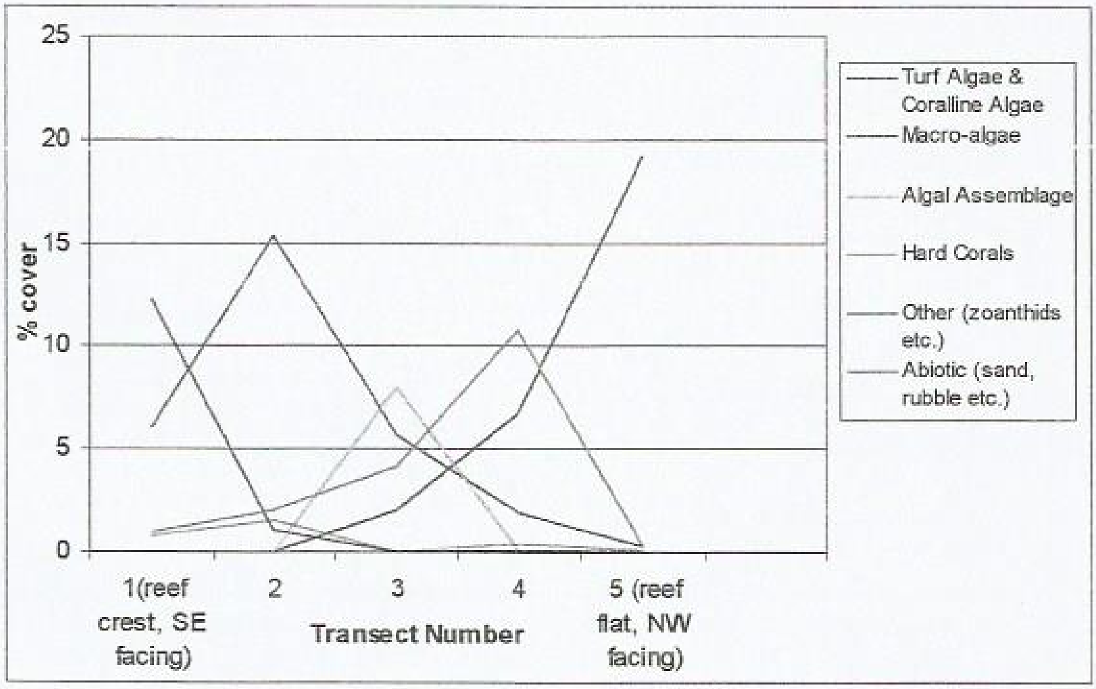
Figure 5. Percentage cover abundance of each category across Naitata Reef



Reef 2 – Cakaurakawa

Algae was again the dominant cover on this reef and was predominantly red encrusting coralline algae as well as *Sargassum* (a macro-algae) (Appendix Figure 4). There was a slightly higher cover abundance of hard corals on this reef as compared to Naitata and the majority of the hard corals observed were non-*Acropora* species (Appendix Figure 5). One of the identifiable species was the submassive *Porites* and *Montipora* (Appendix Figure 11d). Near the reef crest extensive carpets of zoanthids (*Palythoa*) were observed. The substrate was largely rubble or sand (Appendix Figure 6). Marine fauna observed along the transect included a holothurian, *Holothuria atra*, and an anemone. The zonation pattern across the reef indicated that near the reef crest zoanthids were dominant as well as turf algae and coralline algae. Hard corals were also more dominant within the first two transects. Towards the leeward side of the reef, macro-algae started to become dominant as well as a combination of coralline algae and macro-algae (Appendix Figure 11e). Abiotic factors such as rubble and sand were also dominant. Within the last transect macro-algae was almost completely the dominant cover (Figure 6 & Appendix Figure 11h)).

Figure 6. Percentage cover abundance of each category across Cakaurakawa Reef



Reef 3 – Bouwa

Algae, particularly macro-algae such as *Turbinaria* and *Sargassum* and a mixture of macro-algae and coralline algae, was the dominant cover on this reef (Appendix Figure 7). This reef had the highest cover abundance of hard corals making up 5% of the transect. The hard corals included *Acropora* (Appendix Figure 12c), *Montipora, Goniastrea* Appendix Figure 12d), *Echinopora, Pocillopora* (Appendix Figure 12e), *Tubipora musica,* and *Porites* (Appendix Figure 8). Apart from the massive colonies, these corals were all found towards the reef crest or drop off. Zoanthids (*Palythoa*) (Figure 12h) and the soft corals *Plathora* and *Lobophyta* were also present near the reef crest. Holothurians present on the transect were *Bohadschia argus* (Appendix Figure 12l), *Holothuria altra,* and *Stichopus chloronotus*. One vasua (*Tridacna squamosa*) (Appendix Figure 12i), one trochus (*Trochus niloticus*) and a few sea urchins (*Tripneustes gratilla*) were also observed on the reef. Large areas of *Halimeda opuntia* and *H. macroloba* were also observed on the leeward side of the reef. The abiotic cover abundance was higher than that of the other two reefs and consisted largely of dead coral with algae near the reef crest and sand and rubble throughout the rest of the reef (Appendix Figure 9). The zonation pattern showed that near the reef crest turf algae and coralline algae were dominant together with zoanthids and hard corals. Towards the middle of the transect, macro-algae was beginning to dominate as well as a combination of macro-algae and coralline algae. Abiotic factors such as sand and rubble were also dominant in the middle of the transect. Towards the last transect macro-algae was largely dominant (Figure 7).

Figure 7. Percentage cover abundance of each category across Bouwa Reef

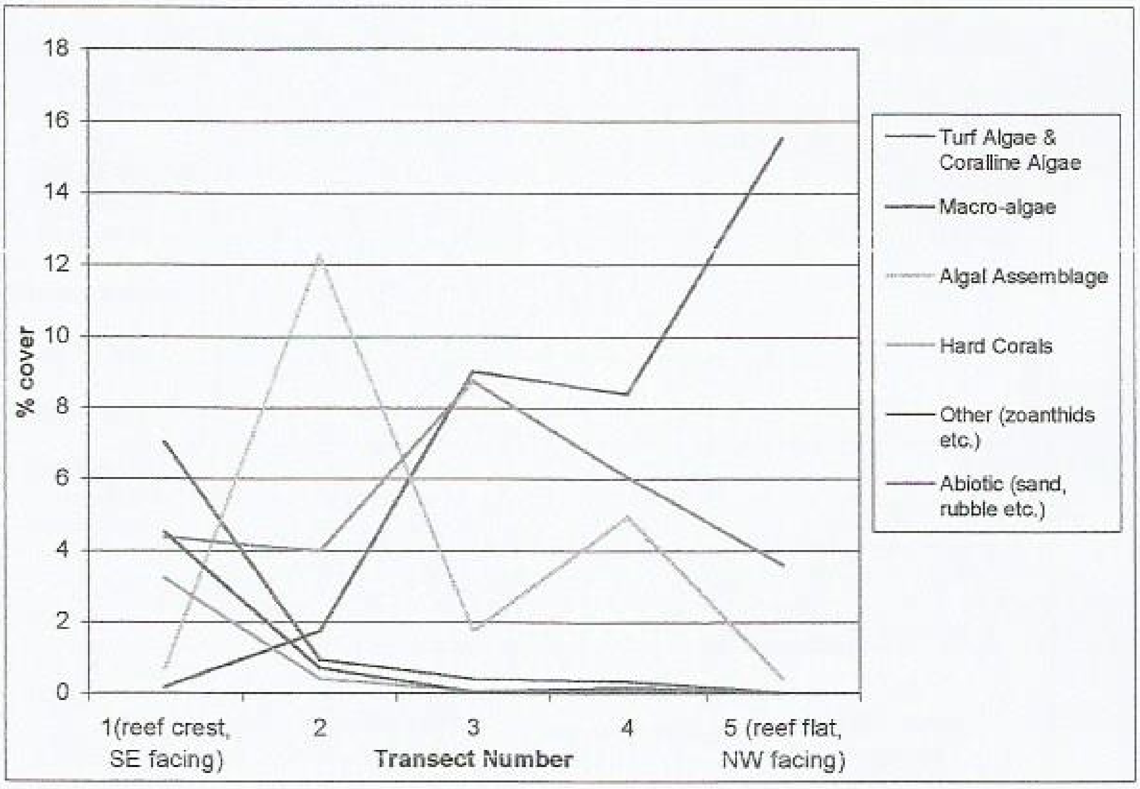


Table 1. Percentage cover abundance of each individual group along each reef transect

Group	Reef 1 - Naitata	Reef 2 – Cakaurakawa	Reef 3 – Bouwa
ALGAE			
Turf Algae	6.22	1.96	3.69
Coralline Algae	3.87	27.45	5.02
Macro-algae	22.86	28.02	34.86
Algal Assemblage	42.39	8.2	20.0
HARD CORALS			
Acropora Branching	1.69	0.33	2.09
Acropora Submassive	0	0.05	0
Coral Encrusting	0.1	0.2	0.38
Coral Branching	0.21	1.06	0.34
Coral Massive	0	0.33	0.66
Coral Submassive	0	0.76	0.18
Coral Foliose	0	0	0.11
OTHER			
Zoanthids	4.08	13.17	4.97
Other (marine fauna)	0.12	0.16	0.21
Soft Coral	0	0	0.24
ABIOTIC FACTORS			
Rubble	6.22	8.91	10.81
Sand	4.68	6.81	10.09
Dead Coral with Algae	7.39	2.59	6.15
Dead Coral	0.07	0	0.2
Rock	0.1	0	0

Discussion

Overall all three reefs in close proximity to the Navua River mouth are largely dominated by algae and abiotic factors such as rubble and sand, except for a small area near the reef crest or windward portion of the reef. This is due to the impact of freshwater and suspended sediments on the leeward areas of all three reefs. Near the reef crest a number of hard corals can be found as well as zoanthids and softcorals. Rubble, dead coral, sand, and macro-algae dominated the leeward side of the reefs. Macro-algae present included *Sargassum, Turbinaria,* and *Padina*. Seagrass was also present on the leeward sides of the reefs. Brittle stars (*Ophiocoma scolopendria*), the starfish *Linckia laevigata*, and an unidentified eel were also fairly common in the tidal pools. Apart from these species the abundance of marine organisms of importance as food species to the surrounding villagers was virtually non-existent.

The proposed dredging activity up the Navua River is not likely to have significant impacts on the reefs surrounding the river mouth because the state of the reefs are already fairly degraded. The diversity of life and abundance of corals is fairly low apart from a small section of the reefs near the reef crest or drop off. Although the reef transect only covered a small portion of the reef habitat near the reef crest, a rapid change in the composition of reef biota from that of hard corals and coralline algae to abiotic substrate and macro-algae was observed.

This type of coral reef habitat is expected because these coral reefs are subjected to suspended sediment and freshwater brought down by the Navua River. As a result, reefs close to river mouths often have low species diversity, low coral cover, and branching forms often dominate (Holthus 1991). Hard corals are virtually absent due to periodic flooding of freshwater and chronic siltation over time, conditions which corals are intolerant to. The increase in coral diversity with distance from a river mouth is well known. The coral reefs around the mouth of the Rewa River are good examples (Squires 1962 In Lovell 1998). Macro-algae and abiotic substrate dominate the reef areas facing the river mouth. The sediment-laden water most probably contains elevated nutrient levels in which macro-algae, in particular *Sargassum*, proliferate outcompeting corals for coverage of reef substrate (Holthus 1991). Cyclones in the past are most likely to have also caused damage to these reefs.

Reef type and location also influences the sedimentation regime on a reef. Fringing and inshore reefs around high islands are the most influenced by terrestrial sediments. Other factors that affect the sedimentation regime include position on a reef. The inshore portions of the reef flats generally accumulate sediments while the outer edges are subject to sediment transport by the waves and currents. Sediment size is also important as very fine sediments remain in suspension for long time periods and are easily transported. Sediment rate and persistency also directly influence the structure of reefs as well as the hydrodynamic conditions that play a role in how far the sediments are carried out. Freshwater inputs also affect sediment transport and deposition especially during flood events (Holthus 1991).

A second factor which influences the coral reef community impacted on by sedimentation is the susceptibility of corals to sedimentation. Colony shape affects sediment retention with branching and foliose colonies accumulating the least sediment and plate-like colonies accumulating the most (Holthus 1991).

Long-term coverage of coral colonies by sediments results in the death of the corals by smothering. In addition the reduction of the available solar radiation, which is required for photosynthesis, by suspended sediments reduces coral growth. The increase in suspended sediment also impacts on plankton in coral reef waters which in turn affects the coral, other filter feeding invertebrates, and planktivorous fish that depend on this food source (Holthus 1991).

In terms of sediment movement within the lagoon, the location of Naitata Reef directly opposite the river mouth presents a situation of confined circulation of water which probably results in the deposition of most suspended sediment on the leeward reef flat of Naitata Reef and inside the lagoon. This is supported by Gussman (In Press). Alternatively, some suspended sediment may be transported along the shore, as longshore drift, in a northeasterly direction. Due to this, most suspended sediments are not likely to impact on the reef crest portions of the reefs near the Navua River mouth.

The only concern would be if the dredging activity would cause an impact on the reef areas near the reef crest either through the resuspension of sediments and the altering of currents at the Navua River mouth or due to an increase in the volume of freshwater coming down the river. Some precautions that could be taken in order that the dredging does not have any additional impacts on these coral reefs are: i) the use of sedimentation control techniques and; ii) the monitoring of the sediment rate during dredging operations (Holthus 1991).

Appendix

Figure 1. Percentage cover abundance of algal types over the Naitata Reef transect

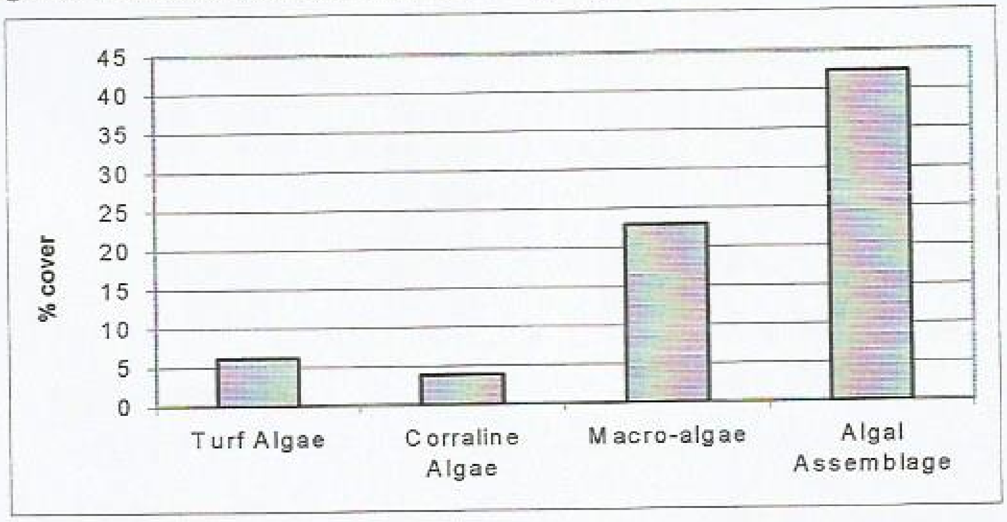


Figure 2. Percentage cover abundance of hard corals over the Naitata Reef transect

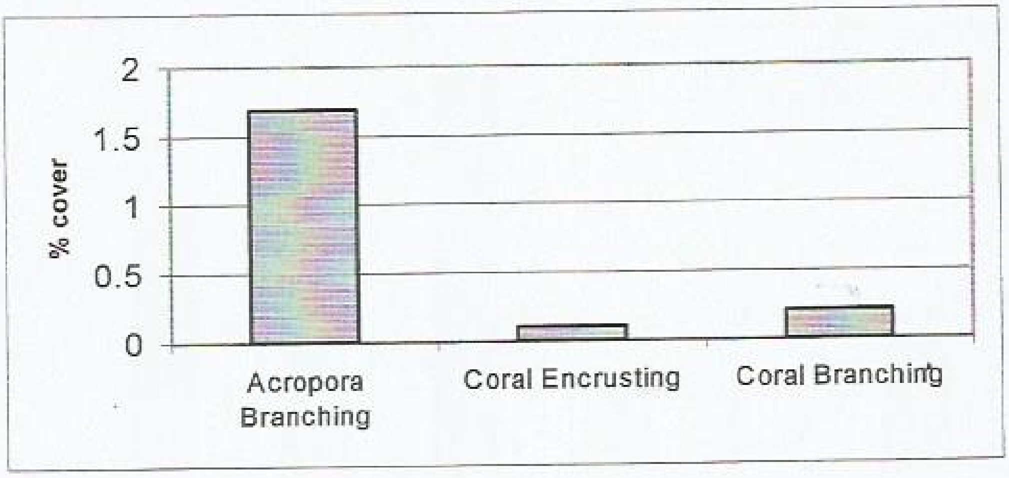


Figure 3. Percentage cover abundance of abiotic substrate types over the Naitata Reef transect

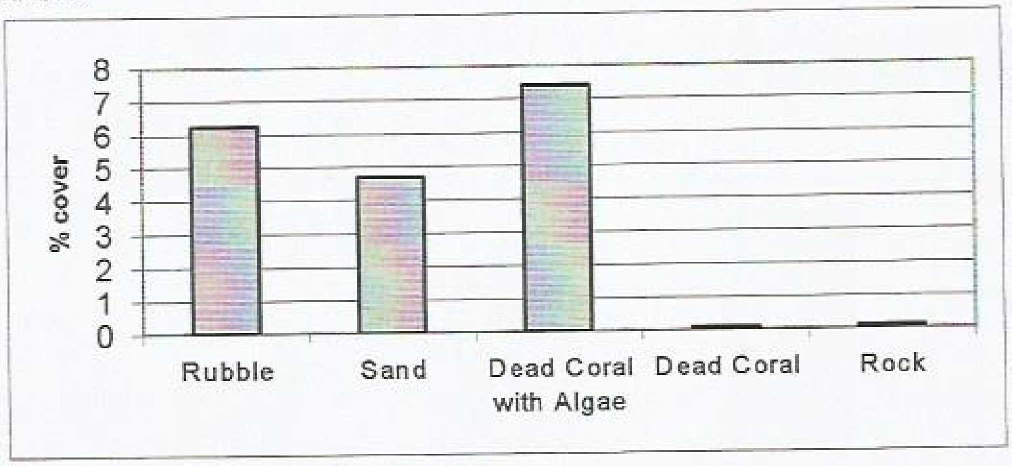


Figure 4. Percentage cover abundance of algal types over the Cakaurakawa Reef transect

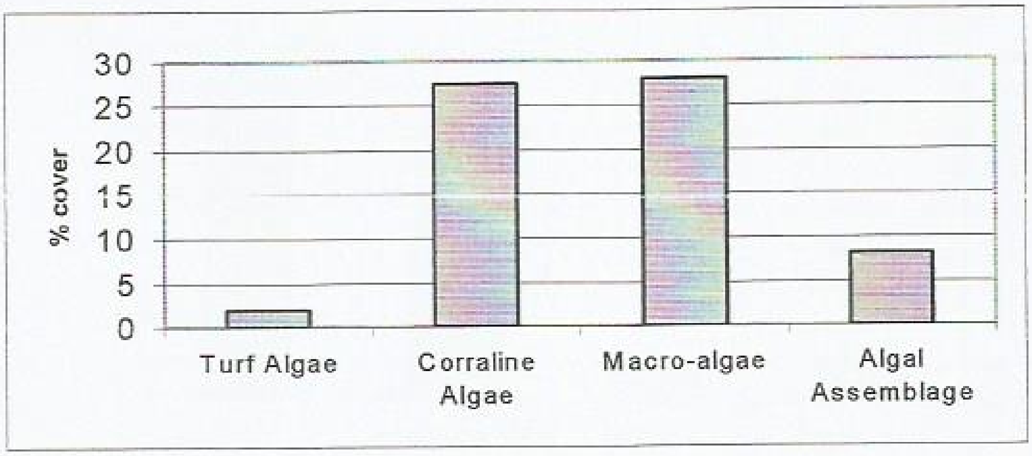


Figure 5. Percentage cover abundance of hard coral types over the Cakaurakawa Reef transect

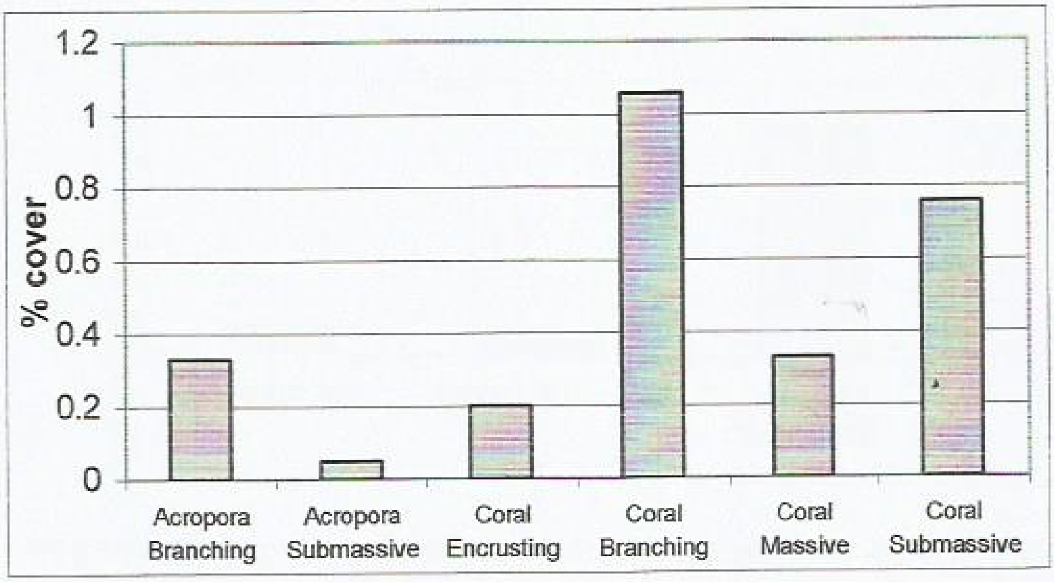


Figure 6. Percentage cover abundance of abiotic substrate types over the Cakaurakawa Reef transect

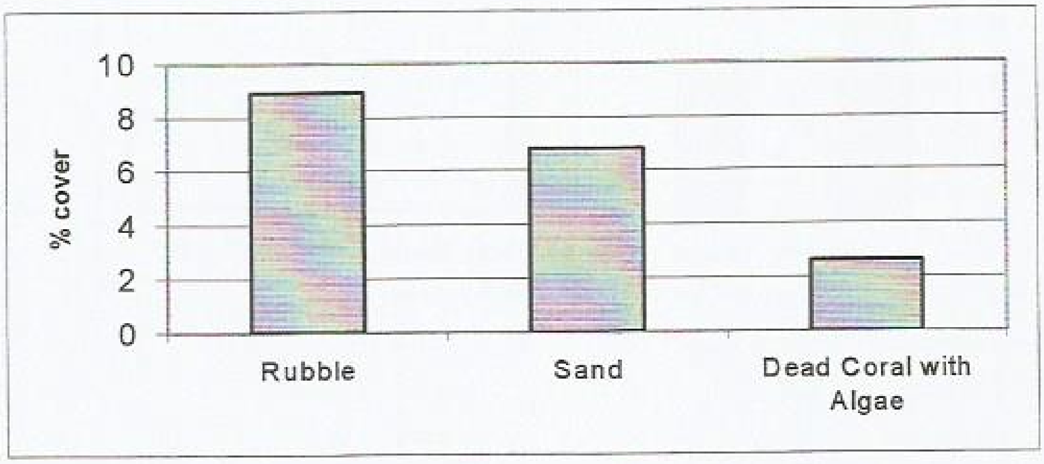


Figure 7. Percentage cover abundance of algal types over the Bouwa Reef transect

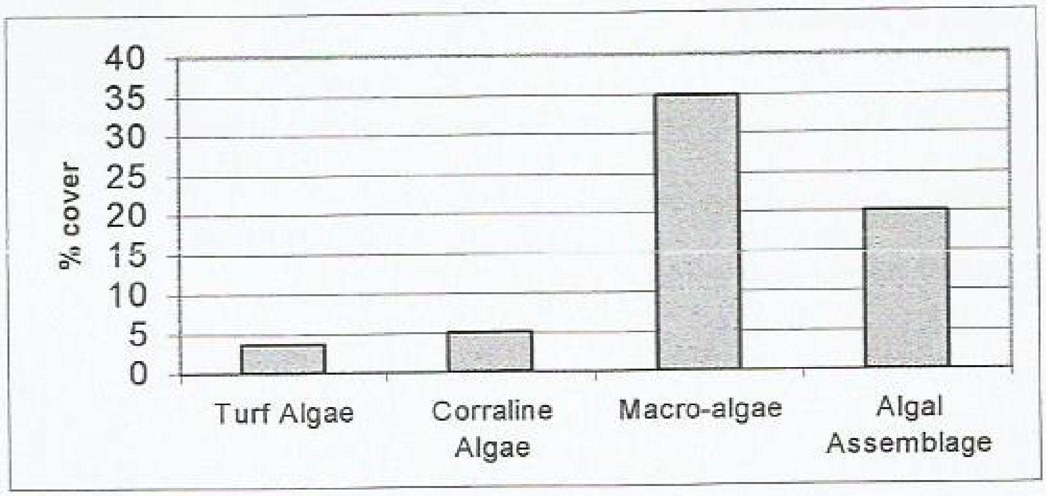


Figure 8. Percentage cover abundance of hard coral types over the Bouwa Reef transect

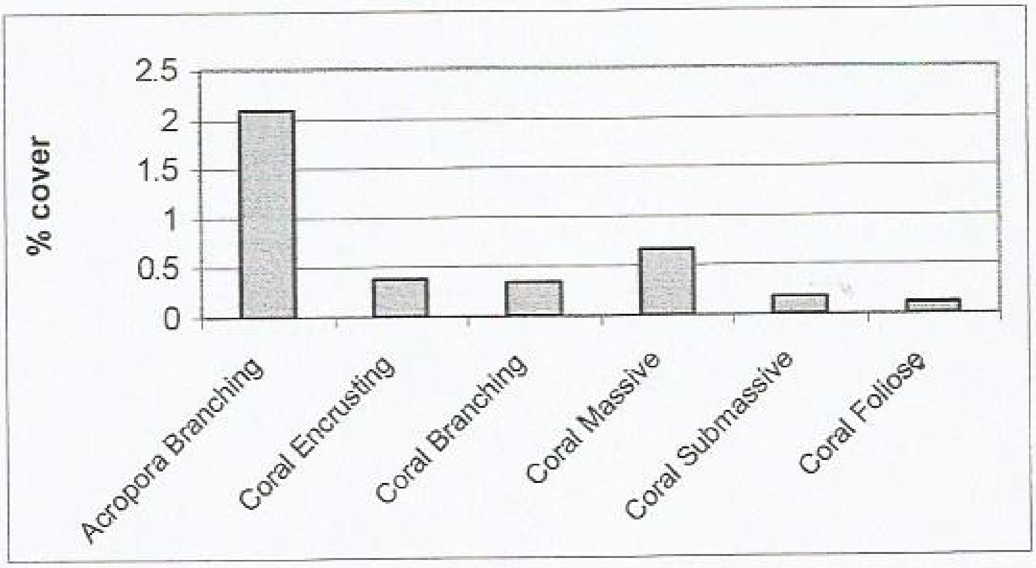


Figure 9. Percentage cover abundance of abiotic substrate types over the Bouwa Reef transect

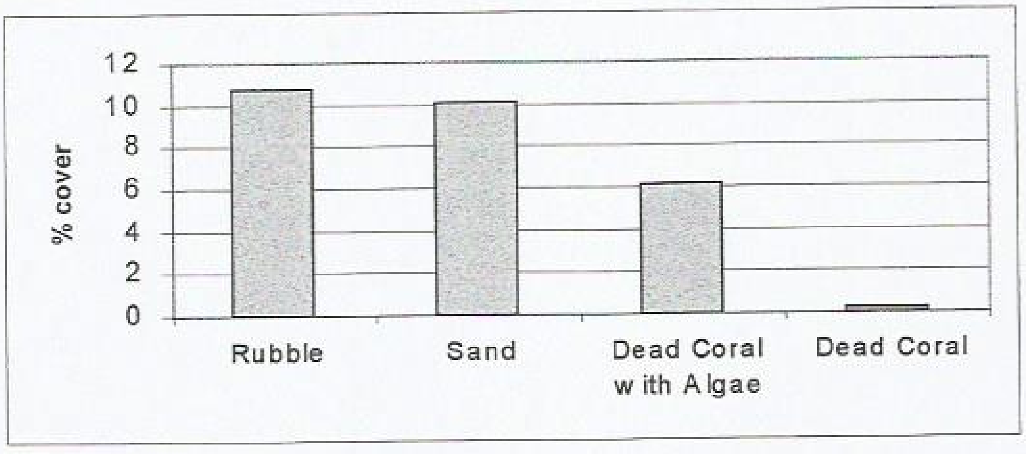


Figure 10 (a-h) Habitats and zonation patterns on Reef 1 – Naitata Reef.

a) The reef crest area, consisting largely of *Acropora* colonies.
b) A colony of *Pocillopora*.
c) The colony of *Goniastrea*.
d) Dead *Acropora* coral and rubble behind the zone of live corals.
e) Brittle stars, *Ophiocoma scolopendria*, feeding amongst the *Sargassum* (macro-algae).
f) The macro-algae *Sargassum* on a sandy substrate.
g) The back-reef area which is predominantly macro-algae and rubble.
h) A general photo of Naitata Reef.

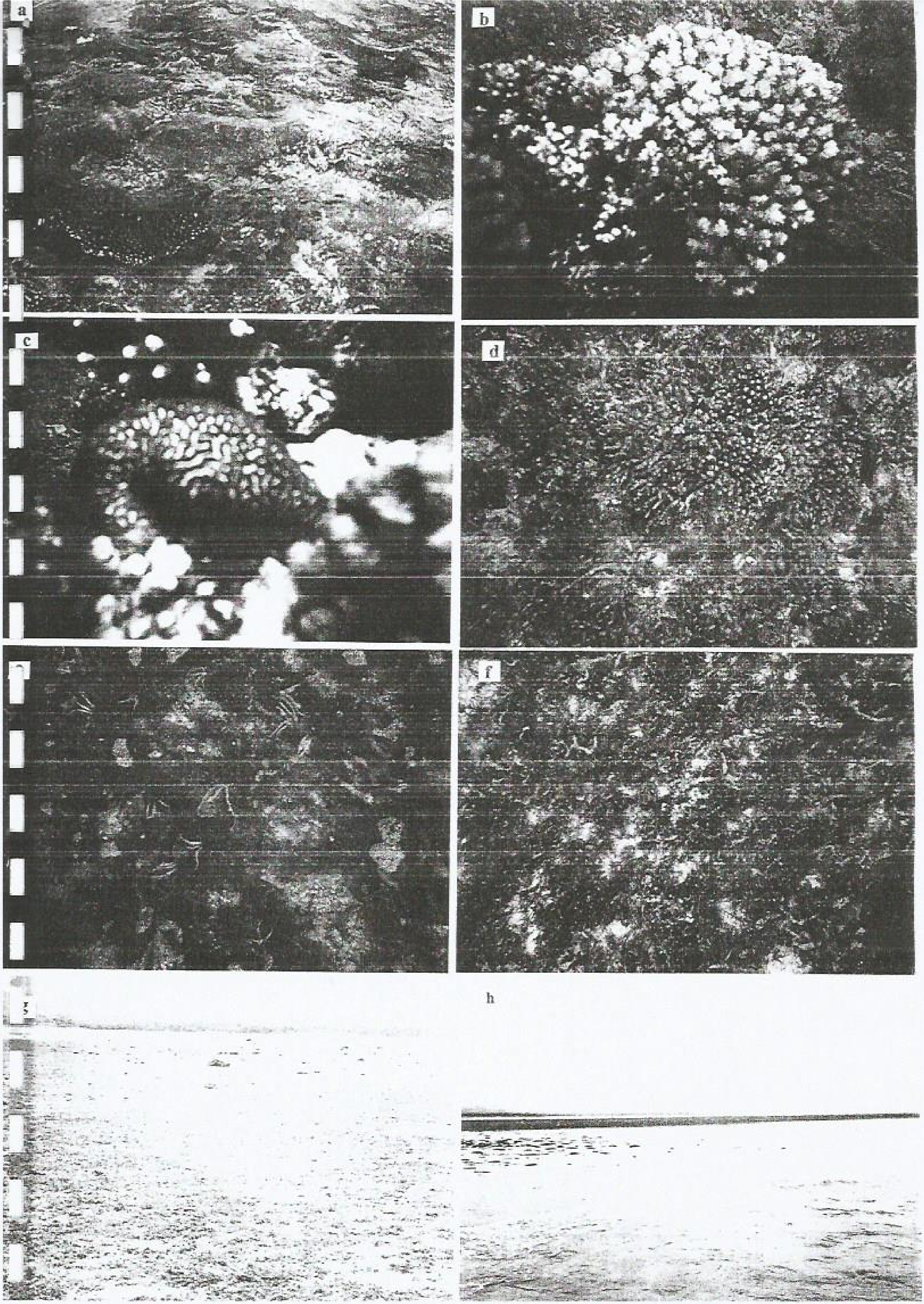

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Figure 11 (a-h) Habitats and zonation pattern on Reef 2 – Cakaurakawa Reef.

a) The reef crest of live corals showing digitate *Acropora* species. This zone is often exposed during low tide.
b) The zone of live corals showing (i) in the middle left of the photo a giant clam, *Tridacna squamosa* , (ii) in the top right corner the starfish *Linckia laveigata,* (iii) zoanthids, *Palythoa*, and (iv) the encrusting coral *Montipora*.
c) A colony of *Acropora* digitate.
d) The green encrusting coral *Montipora* and a small Venus shell (white) *Periglypta* spp..
e) A general view of the second zone on the reef consisting of rubble, dead coral and brown macro-algae.
f) A close-up of the dead coral and macro-algae zone.
g) A general view of the back-reef area dominated by macro-algae and rocks that act as a micro-habitat for reef organisms.
h) A close-up of the macro-algae zone showing *Sargassum* (the brached macro-algae) and *Padina* (the foliose macro-algae).

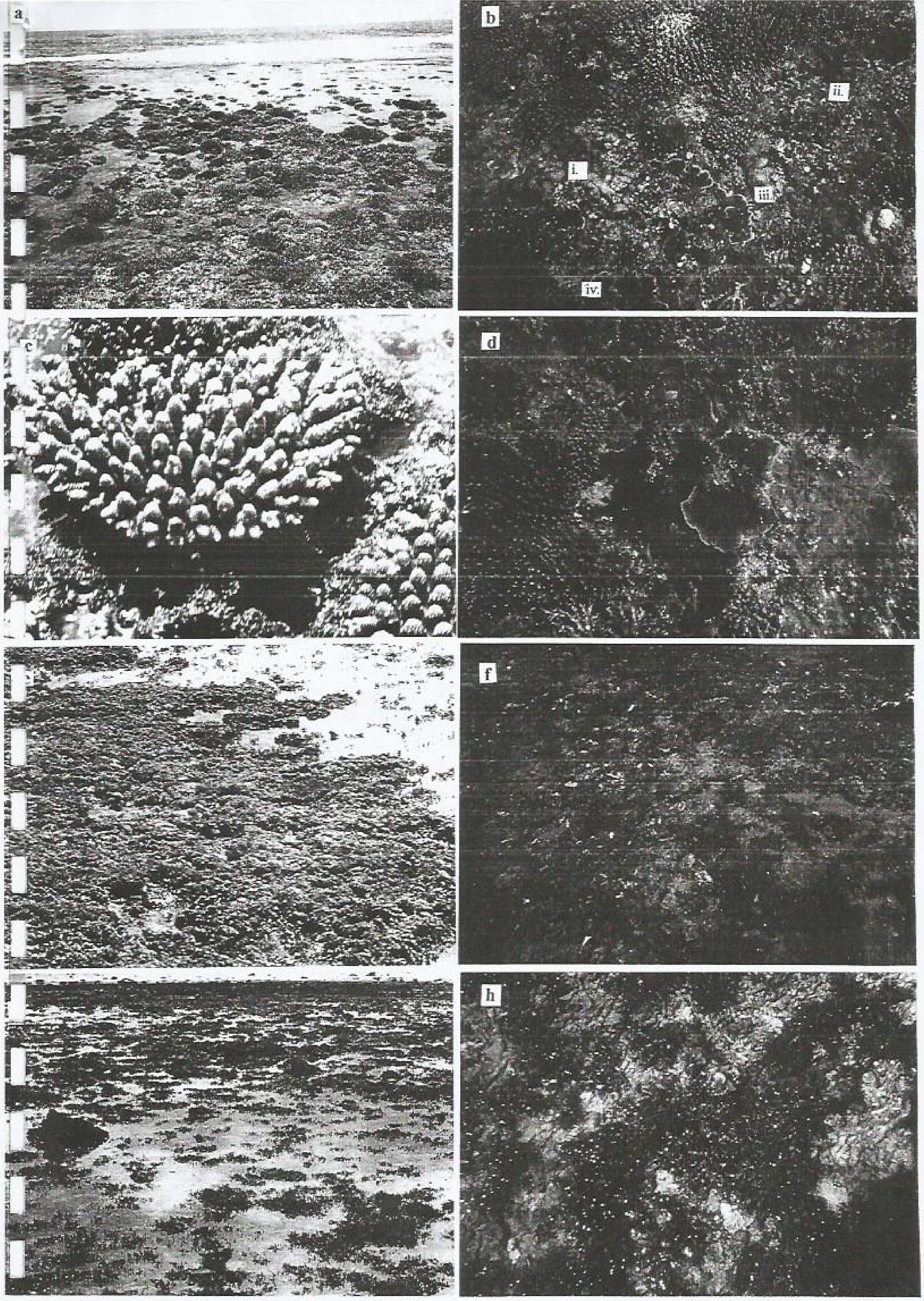
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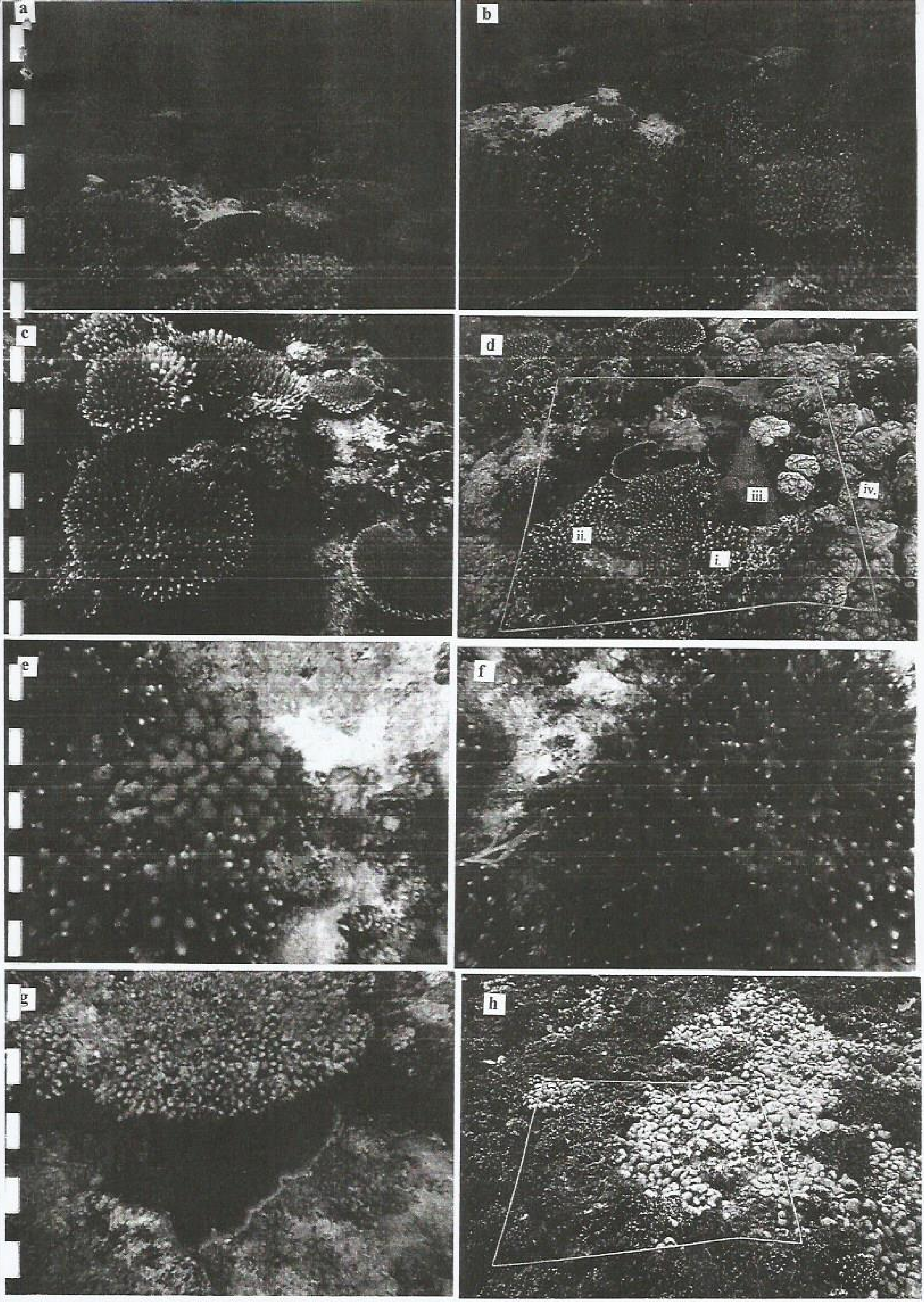
Figure 12 (a-n) Habitats and zonation patterns on Reef 3 – Bouwa Reef

a) Extensive coral cover near the reef crest. The genus *Acropora* dominates in a variety of growth forms (branching, digitate, plate, and corymbose) and reef fish are also present.
b) Different morphological forms of the genus *Acropora*.
c) Corymbose *Acropora* colonies.
d) A variety of corals including (i) *Acropora*, (ii) *Pocillopora* (pink), (iii) *Goniastrea* (green) and (iv) a type of soft coral, *Lobophyta*.
e) *Pocillopora* coral (pink) and digitate *Acropora* species.
f) A distinct species of branching *Acropora*.
g) A type of encrusting coral.
h) The zone near the reef crest showing the extensive carpets of zoanthids *Palythoa*.
i) A giant clam (*Tridacna squamosa*) amongst live coral and rubble.
j) The soft coral *Lobophyta* (in white in the middle right of photo).
k) A view of the middle reef section where the macro-algae *Sargassum* dominates.
l) A holothurian, *Bohadschia argus*, amongst the macro-algae.
m) A view of the Navua River mouth from the ocean side.
n) A view of the Navua River mouth looking towards the reefs.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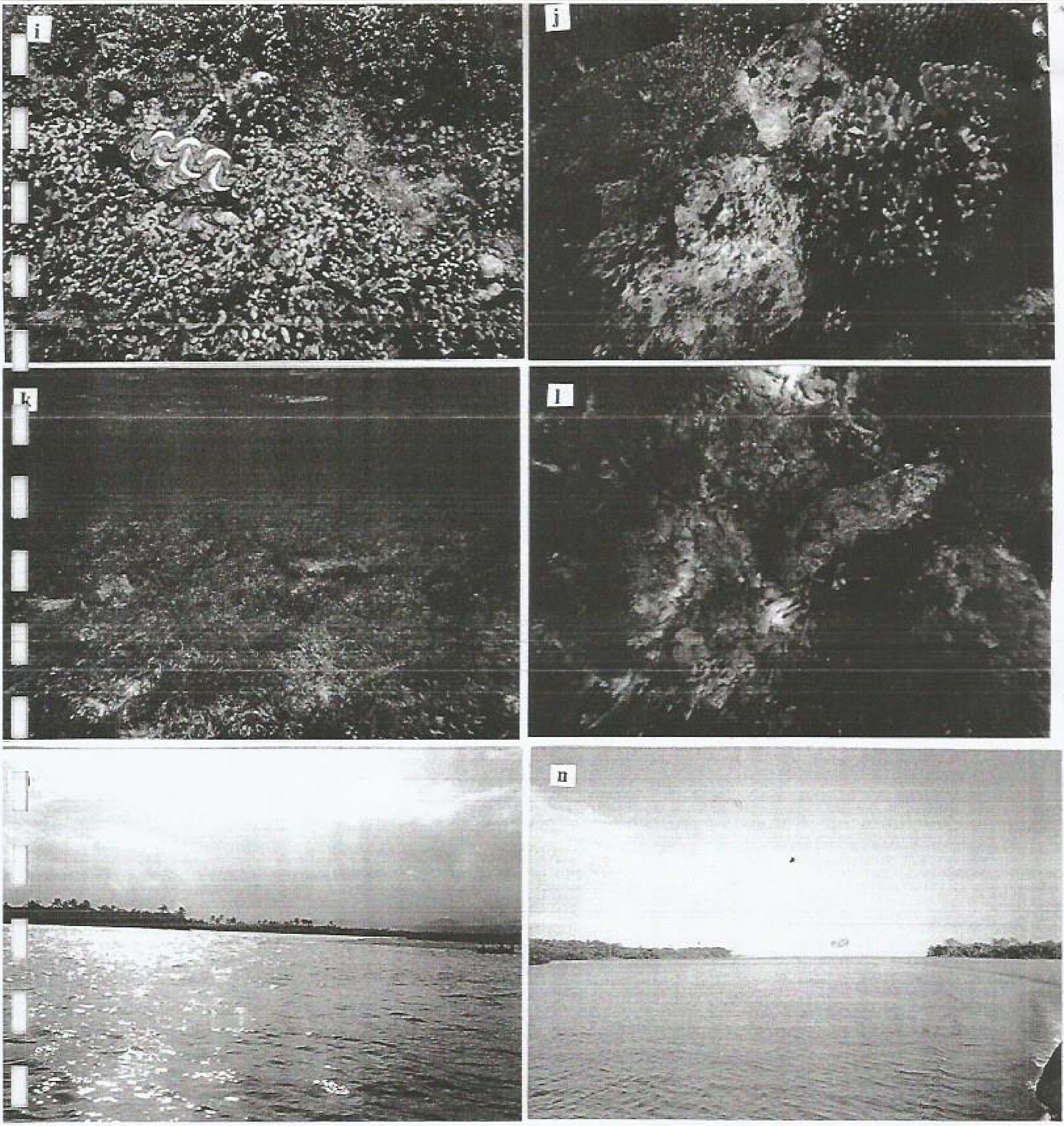
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