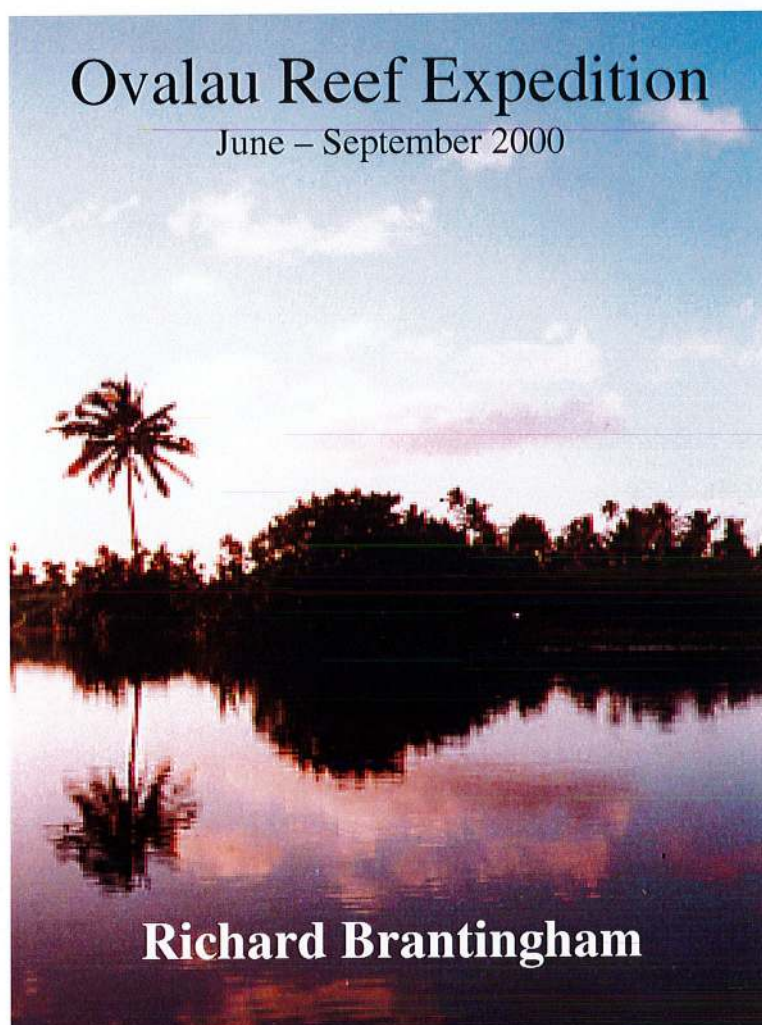


ccc
fig 4

An investigation into relations between marine environmental parameters, suspected to be influenced by the Bureta River and the status of local fringing reef communities, Ovalau Island, Fiji.



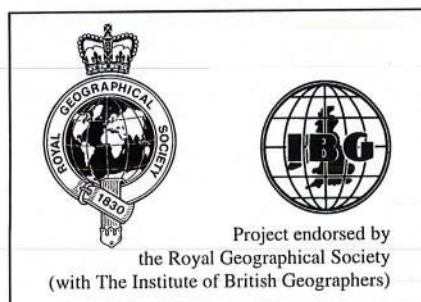
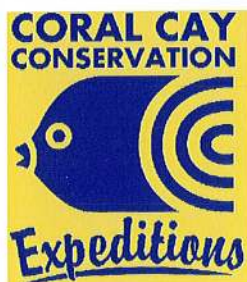
UNIVERSITY OF
CAMBRIDGE



The University
of the
South Pacific



Loughborough
University



Contents:	Page No.
List of Figures.	i
Chapter 1 <u>Introduction.</u>	1
1.1 Background	1
1.2 Fiji	3
1.3 Ovalau	4
1.3 Research Rationale	4
1.4 Aims and Objectives	5
Chapter 2 <u>Literature Rreview</u>	6
2.1 Coral reefs	6
2.2 Salinity	9
2.3 Sediment	10
2.4 Temperature	16
2.5 Algal competition	16
Chapter 3 <u>Team Members.</u>	18
Chapter 4 <u>Expedition Administration and Logistics.</u>	19
3.1 Research material	19
3.2 Maps, charts and aerial photographs	19
3.3 Training and testing	20
3.4 Permission and permits	20
3.5 Fund raising	20
3.6 Insurance	21
3.7 Communication	21
3.8 Field communication	21
3.9 Medical	22
3.10 Emergency evacuation	23
3.11 Specialist equipment	23
3.12 Food	23
3.13 Social impacts	25
3.14 Other activities	27
Chapter 5 <u>Methods.</u>	28
5.1 Survey Procedure	28
5.1.1 Environmental parameters	28
5.1.2 Coral	29
5.1.3 Fish	30
5.2 Classification and Identification	30
5.2.1 Benthic Identification Categories	31
5.2.2 Fish Identification Categories	31
5.3 Data Analysis	33
Chapter 6 <u>Analysis of Environmental Parameters.</u>	34
5.1 Temperature	34
5.2 Salinity	35
5.3 Turbidity	36
Chapter 7 <u>Analysis of Benthic Composition.</u>	37
7.1 Three – metre survey	37
7.1.1 Biotic composition	37
7.1.2 Regression Analysis	40

	7.1.3	Abiotic composition	42
7.2		Seven - metre survey	43
	7.2.1	Biotic composition	43
	7.2.2	Abiotic composition	44
7.3		General Discussion	46
	7.3.1	Macroalgae competition	46
	7.3.2	Sediment load	46
	7.3.3	Marine basin morphology	47
Chapter 8		<u>Fish Population Analysis.</u>	50
	8.1	Three metre survey	50
	8.2	Seven metre survey	51
	8.3	General discussion	52
Chapter 9		<u>Conclusions.</u>	53
	9.1	Site Specific Conclusions	53
	9.2	Applications of the Research	54
	9.3	Global Environmental Change and Coral Reefs	55
	9.4	Limitations	55
•		Acknowledgements.	57
•		References.	58
•		Useful Addresses.	61
•		Accounts.	64

List of figures and tables

<u>Figure</u>	<u>Description</u>	<u>Page</u>
1.1	View from eastern ridge of Ovalau Caldera down Bureta valley (S.Philipp)	2
1.2	A) The Fijian Archipelago (Lonely Planet, 2000). B) Ovalau Island.	3
2.1	Darwins theory of subsidence (after Allen and Steene, 1998).	6
2.2	Global distribution of coral reefs ((after WCMC, 2001).	7
2.3	Gross production to respiration ratio (P_G/R) at three different salinities. (after Nystrom et al., 1997).	9
2.4	Dry weight of sediment collected from 25cm ² on live coral tissue and dead coral at Galeta Island and San Blas (from Lasker, 1980).	13
2.5	Growth rates in percent of growth rate at 540 Wm ⁻² (after Strömberg, 1987).	15
4.1	Si and Luké (photograph: Kat Hadfield).	22
4.2	The 'last supper' with the village (photograph: Si Philipp)	23
4.3	Rich and Pede in the village (photograph: Si Philipp)	25
4.4	The Buretan school children and expedition team behind	26
5.1	The south-west coast of Ovalau Island and survey sites.	28
5.2	The classification of coral according to morphology.	32
6.1	Variations in temperature with distance from the Bureta River.	34
6.2	Regression between distance north and temperature.	34
6.3	Variations in salinity with distance from the Bureta River.	35
6.4	Variations in turbidity with distance from the Bureta River.	36
7.1	Variations in biotic categories at 3m.	37
7.2	Biotic composition of 3m reef transect	37
7.3	Shannon diversity index (H') for biotic categories at 3 metres.	38
7.4	Relations between coral abundance and distance north.	29
7.5	Relations between coral abundance and distance south.	29
7.6	Relations between coral diversity and distance north.	29
7.7	Relations between coral diversity and distance south.	29
7.8	Biotic Categories as a percentage of total biotic cover.	30
7.9	Coral abundance north against temperature (°C).	31
7.10	Coral abundance south against turbidity (FTU).	31
7.11	Coral diversity north against salinity (PSU).	32
7.12	Coral diversity south against salinity (PSU).	32
7.13	Abiotic composition of mean transect at 3 metres.	32
7.14	Relations between abiotic cover and distance north.	33

7.15	Relations between abiotic cover - and distance south.	33
7.16	Biotic composition of reef at 7 metres.	33
7.17	Relations between coral abundance and distance north at 7 metres.	34
7.18	Relations between coral abundance and distance south at 7 metres.	34
7.19	Abiotic composition of reef at 7 metres.	34
7.20	Relations between abiotic cover and distance north at 7 metres.	35
7.21	Relations between abiotic cover and distance south at 7 metres.	35
7.22	Dominant reef profiles observed in study area.	36
7.23	The constriction created by the islands and reefs.	38
7.24	The suspected discharge path eastwards from Waidau Creek.	39
7.25	The suspected discharge path northeastwards from Bureta River.	39
8.1	Variations in mean fish composition at 3m.	40
8.2	Variations in mean fish composition.	41

<u>Tables</u>	<u>Description</u>	<u>Page</u>
7.1	Correlations between biotic category abundance and distance.	38
7.2	Model Summaries of stepwise regression analysis between the coral and fish population characteristics and environmental variables	41
8.1	Comparison of mean Goby (Gobiidae) abundance per survey direction.	51

Chapter 1 Introduction

1.1 Background

During the last decade, there has been increasing concern about the state of reef communities throughout the world, culminating with the International Year Of The Reef in 1997 and International Year Of The Ocean in 1998.

Coral reefs are the most diverse of aquatic ecosystems. The earliest forms of coral are thought to have existed 400 million years ago, although, the present forms represent a development episode of approximately 5000 years (Allen and Steene, 1998). The primary skeletal structure of precipitated carbonates is also habitat to a variety of other life, including sponges, soft corals (see section 2.1), fish, starfish, ascidians (filtering invertebrates approximately 2mm long), urchins (algal feeding spiny organisms with a similar biological composition to starfish), algae, snails and slugs. This great ecological diversity and extensive history should remain the prime rationale for the study and conservation of reefs systems.

There are, however, other justifications. Geologically, reef structures contain a wealth of information about Quaternary sea-level change (for example; records from the Huon Peninsula, Papua New Guinea), atmospheric and oceanic composition, and the geographical extent of climate zones. There are of course economic perspectives to reef conservation. Firstly, reefs support an increasing amount of fisheries and therefore are a considerable source of protein for a large population (English *et al*, 1998). Secondly, Barrier and Fringing reef systems (see section 2.1) provide shelter for many coastlines, but their effectiveness as a defence is dependent on the continued growth of the primary reef structure. In a region such as the South Pacific where tropical cyclones are common and the majority of urban settlements are coastal, further degradation of coral reefs may have long term adverse effects. Thirdly, reef organisms such as sponges and soft corals secrete chemicals, which are the focus of current medical research. Finally, many countries are highly dependent on revenue related to reef tourism. For example, the Great

Barrier Reef Marine Park receives over one million visitors a year participating in a variety of activities (Steene and Allen, 1998).

Thus to ensure the continued viability of reef systems, one must better understand the agents and mechanisms of degradation so as to plan to counter or contain them. The major sources of reef degradation include: - infestations of the species *Acanthaster Planci* (crown of thorn starfish) which preys on living coral; bleaching (the loss of colour and death of coral) linked to zooanthellae expulsion due to excessive heat (see section 1.2.1); anthropogenic pollution and eutrophication; destructive fishing and boating practices, such as dynamite and cyanide fishing, and anchor damage; and fluvial sedimentation.

Natural sedimentation has always been a dominant influence on the development of reefs. The major concern presently is increases in fluvial sediment load attributed to changes in land-use practices and urbanisation. Deforestation produces large amounts of loose soil available for colluvial and fluvial transport. The subsequent land-use, in many cases agriculture, may exacerbate the problem where bad management leads to intensive farming, down slope ploughing and inappropriate crop types such as banana or pineapple.



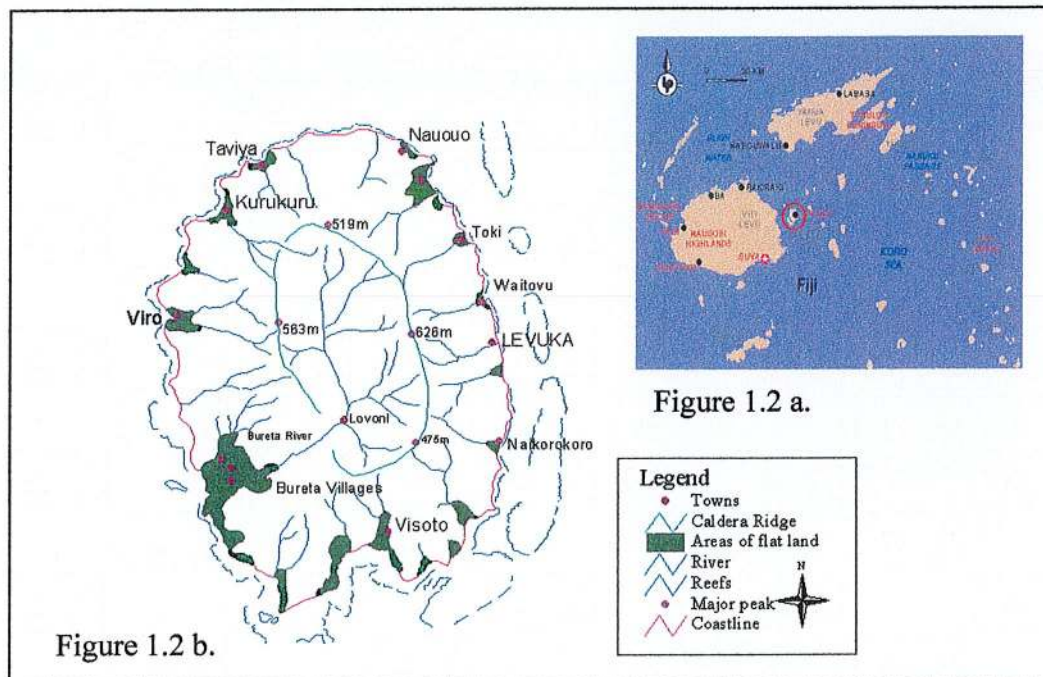
Figure 1.1 View from Eastern ridge of Ovalau Caldera down the Bureta valley.

The study of interactions between fluvial sedimentation and coral in a natural or semi-natural environment provides a useful comparator to other areas and for future projects. Ovalau Island presents a suitable location in which to carry out such a study. It is relatively small (102km²) with a stable mixture of high-biomass primary and secondary forest as well as savannah grasslands. Due to the topography, agriculture is limited to mainly subsistence farming, although there are some small 'commercial' plantations. The largest urban developments are on the Eastern coast; Bureta is the largest village on the Western coast with a population of approximately 400 inhabitants.

1.2 Fiji

(figure 1.2a)

Fiji is an archipelago comprising 844 high islands, cays and islets of which 106 are inhabited. The islands have a mild and mostly stable tropical maritime climate throughout the year. With South-Easterly Trade Winds, the larger islands are subject to relief rainfall,



Figures 1.2

a) *The Fijian Archipelago* (Lonely Planet, 2000).
b) *Ovalau Island* (R. Brantingham).

whereas the smaller islands tend to have dry and sunny microclimates. In general, temperatures range between 25 and 30°C with humidity often reaching 90%; average sea temperatures are between 25 and 28°C (Jones and Pinheiro, 1997).

1.3 Ovalau (figure 1.2b)

Ovalau Island lies in the Lomaiviti group at the centre of the Fijian archipelago. It is the remnant of the Lovoni volcano and erosion of the caldera has produced a radial drainage pattern. The only breach of the Lovoni caldera is the forth order Bureta River which deposits sediment in the mangrove lined Buretan lowlands and estuary. Agriculture is restricted by the topography and is therefore largely subsistence with a number of small commercial plantations on the Western and central lowlands, near to Buresala and Lovoni, respectively.

The south-eastern and eastern coasts are relatively exposed and have well developed barrier reef systems due to the large influx of nutrients and low sedimentation caused by prevailing South Easterly wind. The west coast has comparatively more Mangrove growth, which may reflect better conditions and higher fluvial sedimentation (Nunn, 1999) or less coastal clearing and development. The sea to the west and south-west is confined by Moturiki, Yanuca Lailai and Yanuca Levu Islands, thought to be remnant volcanic plugs (Nunn, 1999). Connecting these islands is an extensive reef system interrupted by a single channel cleared for navigation at high tide. It seems reasonable, therefore, to speculate that this natural barrier restricts the tidal and wind driven movement of water between the Koro Sea and the channel dividing Moturiki and Ovalau Islands, and *vice versa*.

1.4 Research Rationale

Although only a limited number of South Pacific Islands support fluvial systems, research of this type is particularly lacking in a region where reefs are so ecologically valuable and economically significant. Specifically assessing the relationship between fluvial input and coral reef health will provide a platform from which more focused research can be

applied. It is also intended that research of this nature will not only increase reef conservation awareness, but offer an example to which other studies in the South Pacific and other regions of the world can refer and be compared.

1.5 Aims and Objectives

To evaluate the nature and extent of relations between salinity, temperature and turbidity, suspected to be governed by fluvial input, and the state of fringing coral reef communities adjacent to the Bureta River.

To fulfil this aim four objectives were set. To investigate and discuss relations between:

- i. distances along the coast north and south of the Bureta River and salinity, temperature and turbidity.
- ii. distances north and south of the river and abundances and diversities of the benthos (coral morphologies and abiotic categories).
- iii. distances north and south of the river and abundances and diversities of ten reef fish families.
- iv. salinity, temperature and turbidity and the abundances and diversities of coral morphologies and fish families.

The dependencies between reef structure complexities and the abundances and diversities of fish being supported by the reef will also be discussed. Furthermore, characteristics of the local marine and terrestrial environments will be discussed in relation to the results.

Chapter 2 Literature Review

This section will introduce the key components of reef systems and consider the important abiotic and biotic influences on coral reefs recognised in the present literature.

2.1 Coral Reefs

Sir Charles Darwin was one of the first to propose a method of coral reef origin and classification in his Theory of Subsidence, 1858. Although others have been proposed, Darwin's has been recognised worldwide and is summarised in figure 2.1.

There are an estimated 500 species of scleractinian (reef building and hard) corals in the Indo-Pacific region. Figure 2.2 shows the global distribution of reefs and emphasizes the influence of sea temperature in controlling this distribution. Reef growth stops at a depth of approximately 50m, however, the most active growth occurs between 0 and 20m (Davies, 1980).

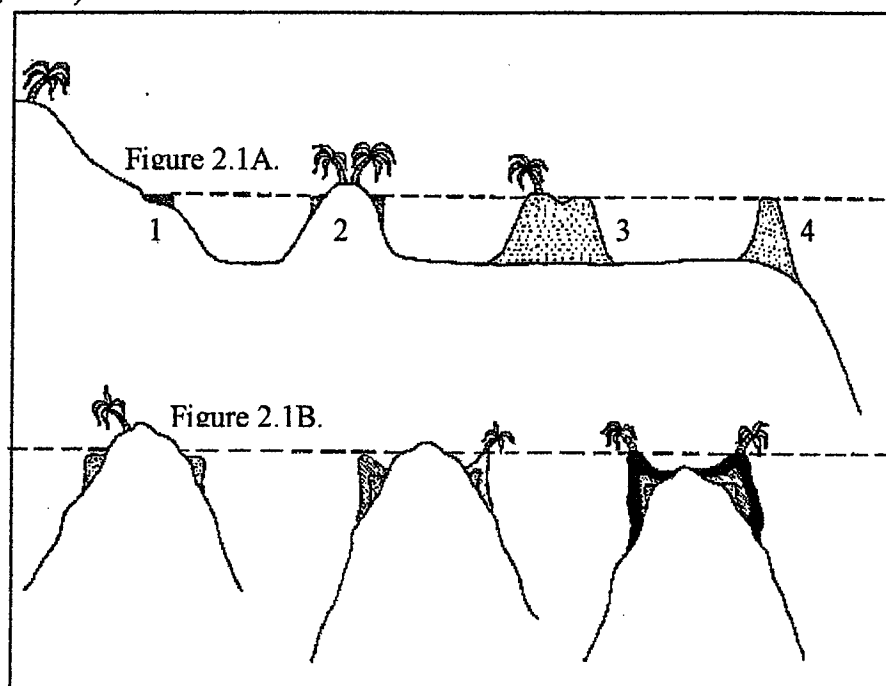


Figure 2.1.A Types of reefs on continental shelves: 1) coastal fringing reefs, 2) continental island fringing reef, 3) platform reef with coral cay, and 4) barrier reef.

Figure 2.1.B Successive layers of living coral reef grow around the fringe of volcanic islands as they gradually sink, resulting in the formation of an atoll.

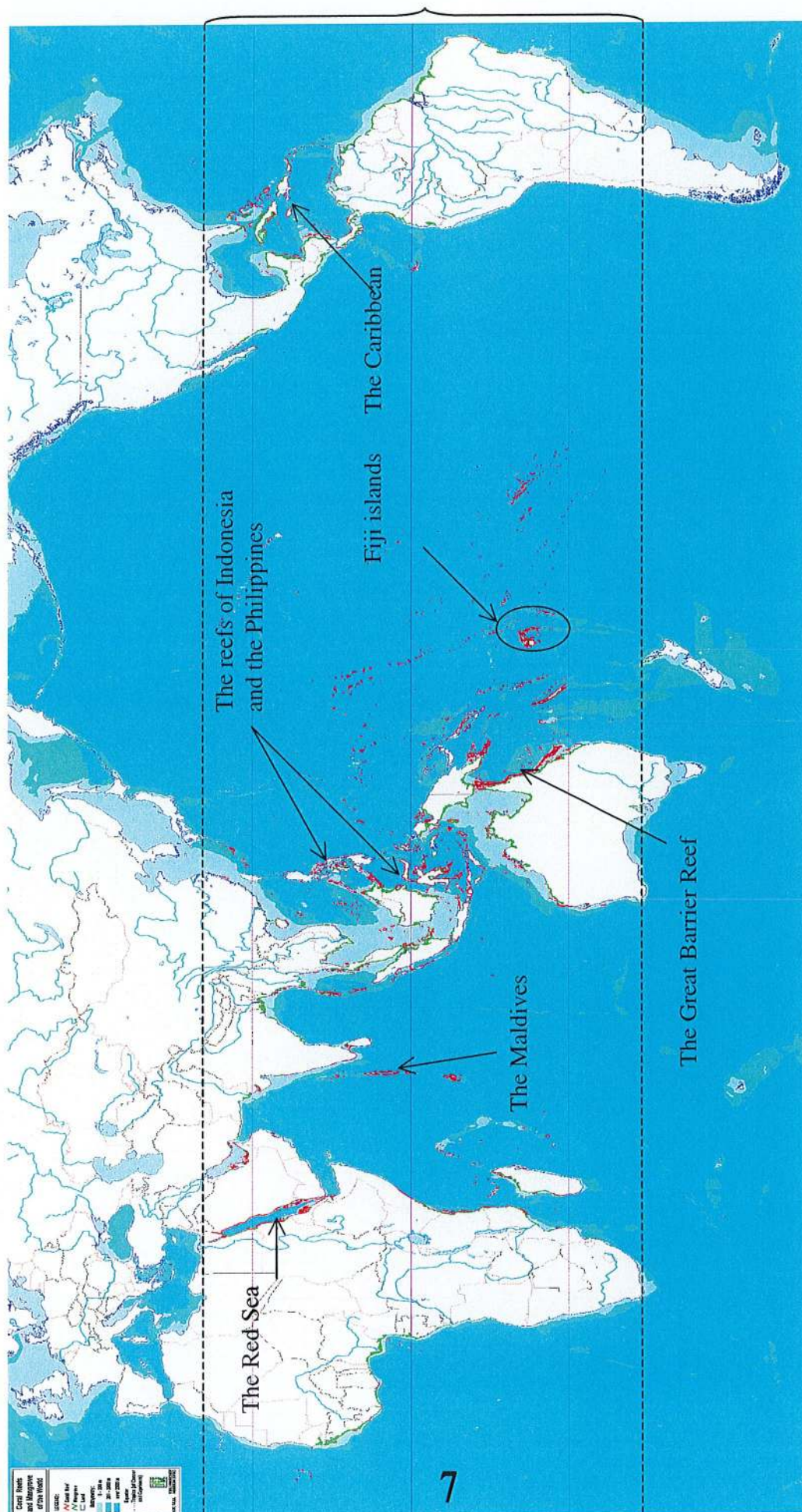


Figure 2.2 Global coral reef distribution and key areas of reef development.

Coral colonies are composed of polyps; small fleshy sacks with a central mouth surrounded by a ring of tentacles. Polyps are connected by living tissue, which allows mutual use of nutrients and energy throughout the colony. They secrete a calcareous substance, which provides protection, structure and reef mass which in turn will provide substrate for following coral generations. The expulsion of polyps due to a substance or environmental intolerance is usually considered as a 'coral stress'. Hermatypic corals are dependent on a symbiotic relationship between polyps and zooanthellae; brown, single celled algae that live within the polyp tissue. Zooanthellae produce carbon rich organic compounds through photosynthesis, which can account for up to 98% of coral nutrient requirements. Ahermatypic corals do not have zooanthellae, but capture prey with stinging tentacles.

Soft corals rely on a similar system to that of ahermatypic corals whereby polyps feed on plankton but have a non-solid calcareous base. The soft structure is a fleshy stem reinforced by microscopic calcareous particles. Sponges rely on a simple body structure of many internal canals through which water is passed. There are an estimated 10,000 species worldwide. They filter feed on micro-organisms and bacteria through a combination of special feeding cells and a vacuum formed through cilia (small hairs) movement. Some sponges rely on a similar symbiotic relationship to that in hermatypic corals, whereby algal cells produces photosynthesates used by the sponge for energy (Allen and Steene, 1998).

Examples of these morphological classifications are illustrated in figure 5.2.

Macroalgae is the term used to describe a primary producer group of large seaweeds in the marine environment. They are found from the high intertidal zone to depths of more than 200m and attach themselves to most substratum (rock, coral, rubble or other algae). Most live in the photic zone, as they are photosynthetic. Macroalgae are also an important source of food for herbivorous fishes and invertebrates (South, 2001: personal communication).

Reefs support between 500 and 700 species of fish in the Caribbean and Pacific, and over 3000 in the waters of Indonesia and the Philippines (Goldman and Talbot, 1976; Roberts and Ormond, 1987). Chabanet *et al.* (1997) found fish species richness and diversity to be correlated with coral architectural complexity, diversity, abundance and size of colony. Surveys prior to this found similar results (Luckhurst and Luckhurst, 1978; Talbot *et al.*, 1978; Gladfelter *et al.*, 1980; Carpenter *et al.*, 1981; Sano *et al.*, 1984, 1987; Hixon and Beets, 1989; Grigg, 1993; Galzin *et al.*, 1994). Barbault (1992) demonstrated that a highly complex reef environment is the key to providing a variety of habitats capable of supporting many species (Chabanet, 1997).

2.2 Salinity

The lower and upper salinity tolerance limits for corals are c.26‰ and c.40‰, respectively, with optimum conditions lying between c.34‰ and c.36‰ (Kinsman, 1964; Davies, 1980). Nystrom *et al.* (1997) investigated the effects of breaching these limits with species of *Pocillopora damicornis* and *Porites lutea* by calculating their P_G/R ratio (gross production to respiration ratio as an estimate for the autotrophic capabilities of a community or organism, McCloskey *et al.*, 1978) at different salinities. Nystrom's findings are summarised in Fig 2.3.

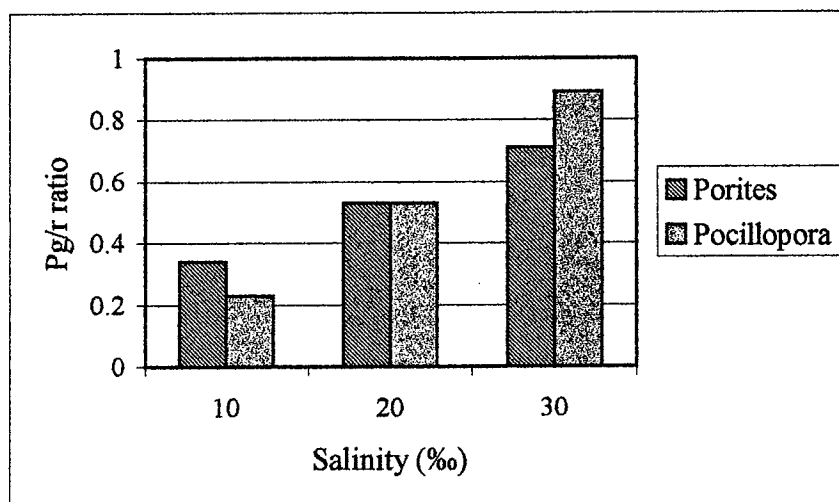


Figure 2.3 Gross production to respiration ratio (P_G/R) at three different salinities (after Nystrom *et al.*, 1997).

The results highlight that certain species are more stenohaline and therefore less tolerant to low salinities, in this case *Pocillopora*. If these types of differences exist between all coral species; salinity tolerance can be considered as an important factor in the structuring of reefs (Nystrom *et al.*, 1997).

Using eggs of the coral *Acropora digitifera*, Richmond (1992) found that a 10% dilution of control seawater (34‰) resulted in a 41% decrease in fertilization rate. Further, a 20% dilution caused an 81% reduction. Coral eggs are lipid rich and therefore float on the surface until fertilization. Subsequent embryos will remain positively buoyant for days (Richmond, 1992). In coastal environments with large freshwater inputs, haloclines will not only limit depths of establishing corals (Squires, 1962), but directly effect coral spawning patterns.

2.3 Sediment

Fluvial and marine sediments affect the health and distribution of coral reefs in three ways: - by direct sedimentation; via water column turbidity; and by limiting settlement and recruitment in the earliest stages of coral development.

Direct sedimentation is a significant control on coral reef communities. It can either cause smothering and burial resulting in insufficient light, nutrients and food, or larger particles may abrade and damage coral tissue (Randall and Birkeland, 1978; Hubbard, 1986; Hubbard *et al.*, 1987; van Katwijk *et al.*, 1993). Hubbard (1986) found sediment transport systems to be a large influence on the pattern of reef distribution. Studying the Salt River submerged canyon on St. Croix Island, U.S. Virgin Islands (U.S.V.I.), lower sediment transport rates on the west wall and at Cane Bay (5km west) both had significantly greater reef growth. Hubbard (1987) while studying three reefs on St. Johns Island, U.S.V.I. found there to be a gradual reduction in coral growth over the last 100 years and periods of reduced growth both of which he associated with intense cultivation on the island. In Fouha and Yling Bays, Guam, Randall and Birkeland (1978) related decreases

the percentage of living coral from less than 2% to over 12%. Similarly, van Katwijk *et al.* (1993) found a correlation of 0.68 (Pearson) between 'sediment' (defined as: *non-organic, non-calcerous fraction of bottom sediments*) and coral stress; and a correlation of 0.81 (Pearson) between terrigenous sediment (defined as: *a mixture of 'sediment' and non-calcerous suspended matter*) and coral stress. Comparable examples can be found in Squires (1962), Maragos (1972) and Dodge (1974). These studies have proved very useful in recognising trends in reef development. However, it is necessary to analyse the causes at an organism level in order to explain these distributions.

The factors enabling coral to survive in condition of high sediment deposition can be divided into active and passive sediment rejection mechanisms; active rejection requiring the coral to exert energy in order to remove sediment, while passive not requiring any energy. The use of these mechanisms is the tolerance of the species to sediment, which is largely a function of the characteristics of the individual species (Rogers 1990). In particular, *Montastrea cavernosa*, *Montipora verilli*, *Pocillopora damicornis* and *Porites lutea* are recognised as four of the most sediment tolerant species (Randall and Birkeland, 1978; Lasker, 1980; Rogers, 1990). A comprehensive study into the impacts of anthropogenic sedimentation (associated with gold mining) of *Porites lutea* on Misimi Island, Papua New Guinea, found there to be no change in average growth characteristics with considerable increases in sedimentation. Live coral colonies in the 'severe impact zone' survived and sustained growth in average sedimentation rates of $156 \text{ mg.cm}^{-2}.\text{d}^{-1}$ over a three-year period compared with $0.8 (\pm \text{S.D.: } 0.4) \text{ mg.cm}^{-2}.\text{d}^{-1}$ in natural conditions preceding the period of mining.

'It appears that colonies of massive Porites can cope with and are not markedly affected by prolonged and very high sedimentation, providing they are not entirely buried.' (Barnes and Lough, 1999)

In those species with low tolerance to sedimentation, experimental application of sediments to living coral tissue by Rogers (1983) and Peters and Pilson (1985) showed cellular damage and zooxanthellae expulsion to be the primary detrimental effects,

followed by death after complete burial (Babcock and Davies, 1991). Similarly, Richardson (1998) cites Bruckner *et al.* (1997) as finding a pattern between the abundance of corals with black band disease (the first recognised coral disease to kill tissue) and high levels of terrestrial runoff.

The detailed characteristics of sediment tolerant corals have been well studied (Hubbard and Pocock, 1972; Bak and Elgershuizen, 1976; Lasker, 1980; Rogers, 1983; and Stafford-Smith and Ormond, 1992). Stafford-Smith and Ormond (1992) found that passive sediment loss is strongly influenced by tissue and skeletal morphology, colony orientation and water movement. For example, on Lizard Island, Queensland, Australia, exposed reefs (ocean facing) were associated with encrusting forms, while the central lagoon (typified by low water movement and generally higher sediment deposition) was dominated by branching and foliose morphologies (figure 5.2). Lasker (1980), studying *Montastrea cavernosa* found that passive influences occur at the time of initial sediment impact.

In the same study, Lasker (1980) proved the significance of active sediment rejection mechanisms. Figure 2.4 shows the dry weight of sediments collected from equal areas on living coral tissue and corallum (already dead coral). In both study sites, dead coral collected considerably more sediment. The study goes on to show that active sediment rejection mechanisms are independent of sediment type. These claims are based on the analysis of one coral *Montastrea cavernosa*, while Stafford-Smith and Ormond (1992) in a study of 42 Australian coral species recognised that if passive influences such as colony morphology are sufficient, active rejection become obsolete (for example *Acropora Hyacinthus*).

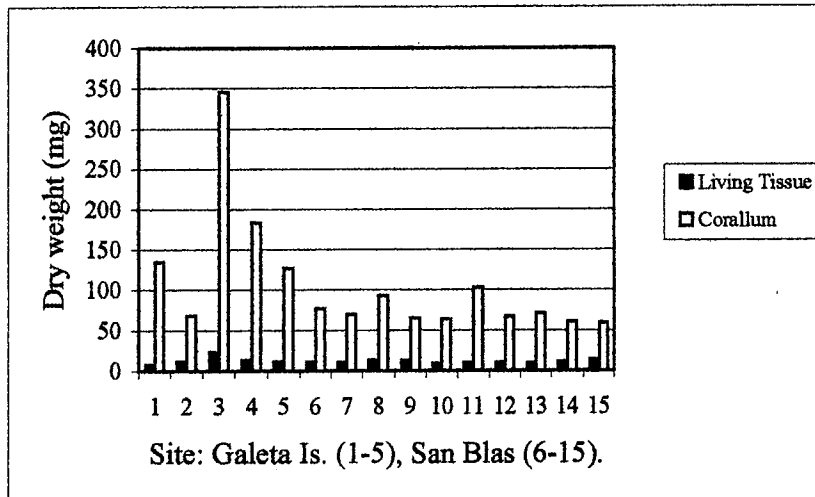


Figure 2.4 Dry weight of sediment collected from 25cm² on live coral tissue and dead coral (corallum) at 5 sites on Galeta Island and 10 sites at San Blas (from Lasker, 1980).

In the species analysed, ingestion, cilia movement (the flexing of small hairs to create a moving surface), mucus agglutination (the coalescing of sediment particles by secreted mucus), tissue expansion/ pulsing and tentacle action were the dominant mechanisms by which sediment was rejected. Furthermore, most mechanisms were found to be more efficient at rejecting specific grain sizes and dominant mechanisms could be identified in certain species (Stafford-Smith and Ormond, 1992). Information at this 'micro' scale is an important consideration in the local and regional distribution of coral species.

Marine suspended sediments are associated with either fluvial discharge or the re-suspension of sediments previously deposited in the marine environment (Strömberg, 1987; Rogers, 1990; Adjeroud, 1997; Larcombe and Woolfe, 1999). Both forms influence the distribution of coral species by increasing the turbidity of the water column and therefore reducing irradiance. Van Katwijk *et al.* (1993) found a Pearson's correlation coefficient of 0.76 between suspended sediments (defined as: 'non calcareous suspended matter content of seawater') and coral stress.

Fluvial sediment plumes are largely a function of the size, topography, geology, soil condition, land-use, and rainfall volume and intensity of the terrestrial basin (Hubbard, 1987; Rogers, 1990). Larcombe *et al.* (1995) and Rogers (1990) found normal suspended

sediment concentrations (SSC) on fringing reefs to lie between $\approx 5 \text{ mg.l}^{-1}$ and 10 mg.l^{-1} , while concentrations above coral reefs associated with fluvial runoff have been recorded from between 10 mg.l^{-1} and in excess of 200 mg.l^{-1} (van Katwijk *et al.*, 1993; Miller and Cruise, 1995; Kleypas, 1996).

Sediment in re-suspension, however, is strongly influenced by the depositional processes operating within the marine basin (Rogers, 1990; van Katwijk *et al.*, 1993; Larcombe and Woolfe, 1999). Concentrations are also a function of currents created by tidal action, prevailing winds, swell and tropical cyclones. For example, in the Great Barrier Reef Lagoon, swell waves are found to be the most influential process for entrainment and suspension while uni-directional currents caused by prevailing winds and tides will generate relatively little turbidity (Larcombe, 1995; Larcombe and Woolfe, 1999).

The relative contribution to water column turbidity of re-suspension in comparison to fluvial input is significant and exemplified by two areas of the Great Barrier Reef Lagoon. The Barron River, Queensland, Australia recently produced a plume, confined to the upper 2m of the water column and with a SSC of between 3 and 10 mg.l^{-1} . The plume extended 45km along the coast and 10km directly offshore. It would therefore contain less than 9000 tonnes of suspended sediment. In an area, such as Cleveland Bay, Queensland, Australia, where SSC's are dominated by swell waves and re-suspension processes, depth averaged concentrations may reach 50 mg.l^{-1} . With an area of 200 km^2 and an average depth of 5m, the total mass of sediment suspended in the bay is approximately 50,000 tonnes (Larcombe *et al.*, 1995; Taylor, 1996; Larcombe and Woolfe, 1999).

It is important to consider the implications of these processes on the coral reef communities at an organism level in order to help explain spatial variations. Suspended sediment reduces light intensity and has been shown to favour those species that are photoadaptive (Adjeroud, 1997). In a study of *Acropora pulchra* (Brook) in Thailand, Strömberg (1987) found a close relationship between length growth rate and irradiance.

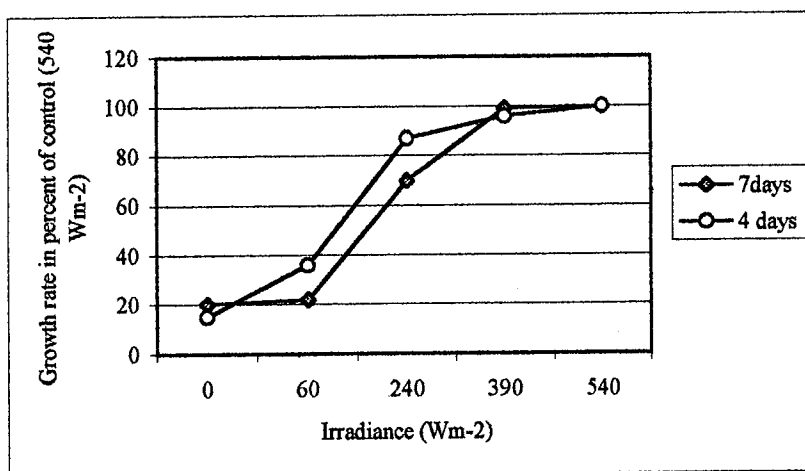


Figure 2.5 Growth rates in percent of growth rate at 540 Wm⁻² (after Strömberg, 1987).

From this, Strömberg goes on to speculate that length growth and calcification are strongly associated with zooxanthellae activity, a similar finding to the work of Goreau (1959, 1963), Pearse and Muscatine (1971) Vandermeulen *et al.* (1972), Chalker and Taylor (1975), Schmitz and Kremer (1977), Leletkin and Zvalinsky (1982), and Kawaguli and Sukmoto (1984).

At the earliest stages of development, coral planulae (larvae) must settle, metamorphose and grow to form the next generation (Hodgson, 1990). Settlement is the period within the first 24 hours of landing, whereas recruitment is the period following this in which the larvae establishes itself and begins to grow. Direct sediment layering on the substrate reduces the ability of planulae to settle and attach. Lewis (1974) observed that settlement of the coral *Favia fragum* on plate glass in a laboratory was greatly reduced when a layer of fine sediment was added. Hodgson (1990) analysed the ability of *Pocillopora damicornis* planulae to settle on horizontal glass surfaces in a series of laboratory experiments in the Philippines. The study found that in control jars (without sediment) six planulae settled, in jars with 50% and 90% of the bottom covered with sediment, one planulae settled in both and with 95% bottom coverage, no planulae settled. It appears reasonable to postulate that coral planulae cannot attach to unconsolidated surfaces (Hodgson, 1990; Rogers, 1990; Stafford-Smith, 1992).

However, in contrast to this, Babcock and Davies (1991) and Te (1992) found that although sediment reduced settlement on horizontal surfaces there was no significant influence on the overall numbers of planulae settling. Both studies also found that larvae settled on the vertical glass faces and those areas not covered by silt.

These studies have only tested the characteristics of a few species. The ability of larvae to judge the suitability of a settlement site provides a clear adaptive advantage (Sato, 1985 as cited by Babcock and Davies, 1991). However in choosing a vertical or underside horizontal substrate surface to avoid sediment deposition, irradiance may be reduced and in turbid waters the conditions would be sub-optimum for development and growth (Babcock and Davies, 1990). This selection process by the larvae will be a significant control on the spatial distribution of corals.

2.4 Temperature

Davies (1980) recognises the outermost tolerance limits of corals to be 16 and 36 °C with an optimum growth range of between 25 and 29 °C. The most apparent effect of these tolerance limits is global coral reef distribution and is illustrated in figure 1.2. Variations on this scale are considered in all relevant textbooks (Davies, 1980; Nunn, 1994; and Dubinsky, 1990) and in papers such as Johannes *et al.* (1983). However, to the best of my knowledge, there has been little work published on temperature variations on smaller scales (less than 10 since 1915) as precise and accurate investigation over a range of timescales require large resources.

Two factors are likely to change this trend. Firstly, the global awareness of coral bleaching events (polyp death associated with heat stress and increases in sea temperature); and secondly, advances in remote sensing.

2.5 Algal competition and coral reefs

The abundance of macro algae relative to corals may be an indication of reef degradation, caused in part by increased sedimentation (Umar *et al* 1998). Despite this, it has been

noted that algae are negatively affected by greater sediment inputs to the marine environment. Limited irradiance as a result of increased depth or turbidity reduces algal growth rates and species diversity (van den Hoek *et al.*, 1978; Morrissey, 1980; Berner, 1990; as cited by Adjeroūd, 1997). Similarly, Umar *et al.* (1998) found algal recruitment, growth, survival and seasonal regeneration to be significantly reduced with an increase in sediment load in the central Great Barrier Reef. In an earlier study of *Sargassum*, also on the Great Barrier Reef, increased sediment load was correlated with a decrease in thallus size and reproductive capability.

However, McCook *et al.* (1997) found Macro algae such as *Sargassum* to be more abundant in reef areas with high sedimentation (Umar *et al.*, 1998). The relationship between macro algae, coral and sediment is complex. It is not only dependent on the characteristics of the coral or algae species, but on the nature of the sediment, in particular its nutrient content (Umar *et al.*, 1998). Further, Umar *et al.* (1998) concludes that macro algae are opportunistic beneficiaries of the detrimental effects of sediment on other organisms. This is recognised by van Katwijk, *et al.* (1993) who states sedimentation, nutrient enrichment and weakened coral conditions facilitate algal growth on coral colonies.

The negative influence of macro algae is summarised by Adjeroūd (1997). Firstly, the intense competition between macro algae and coral is usually favourable to the algae due to their high propagation and growth rates. Secondly, high algal coverage will limit coral recruitment.

Chapter 3 Expedition Team

Expedition Leader: Richard Brantingham, 21.

3rd year geography undergraduate, Loughborough University.

BS-AC Sports Diver.

Diving in Britain, France, Malta and Australia.

Travel throughout The South Pacific, Australasia, South East Asia, Europe and North America.

Assistant Leader/ Treasurer: Simon Philipp, 21.

3rd year engineering undergraduate, Cambridge University.

PADI Advanced Open Water.

6 Weeks Coral Reef Surveying with Coral Cay Conservation in Belize, 1998.

Travel throughout Central and South America.

Medical Officer: Mik Carr, 42.

Registered State Nurse, Business analyst.

BS-AC Diving Instructor (PADI instructor).

Expeditions: Archaeological expedition - Peru and Bolivia, 1980; Archaeological expedition - Cabo Verde, 1980; Raleigh International, Belize 1999.

Diving in Britain, Ireland, Malta, Egypt, New Zealand, Cabo Verde, Spain, Belize.

Diving Officer: Jo Barkworth, 37.

Trading standards officer. Bachelor of Dental Surgery.

BS-AC Instructor (PADI Instructor).

Expeditions: Archaeological Expedition – Cabo Verde, 1998; Raleigh International, Belize 1999.

Diving in UK, Ireland, Malta, New Zealand, Red Sea, Cabo Verde, Belize, Canaries.

Scientific Officer: Kat Hadfield, 24.

BA Hons. Zoology, Oxford. Presently, 2nd year veterinary sciences, Cambridge,

PADI Dive Master and enriched air.

2 years Kewalo Basins Marine Mammal Lab. Studying Humpback whales.

Diving in Britain and Hawaii.

Fijian Counterpart: Jakobe Kureleca, 32.

Levuka Council environmental officer. Excellent understanding of conservation needs with awareness of local sustainability knowledge.

Chapter 4 Expedition Administration and Logistics

4.1 Research Material

4.1.1 General literature

Basic guidebooks such as the *Lonely Planet* and *Moon Books* acted as useful introductions, briefing us domestic travel and cultural customs.

4.1.2 Academic literature

Coral Cay Conservation, the Southampton Oceanographic Institute and the Natural History Museum both had useful collections while Bath Information Data Service (BIDS) was a useful Internet tool for locating material.

An essential publication for coastal survey work is the Survey Manual for Tropical Marine Resources published and available from the Australian Institute for Marine Sciences (AIMS).

Professor Nunn at the University Of South Pacific (USP) Geography Department was kind enough to send a selection of his work, in particular an article devoted to coastal developments of the Bureta Estuary over the past 200 years. Also at the USP, the main and PIMRIS libraries were a large source of journal reprints.

4.2 Maps, Materials and Equipment

Any form of the above material was difficult to obtain from the UK either due to poor communications or co-operation. However, OS maps and aerial photographs can be bought from the Lands and Survey Department in Suva, while nautical charts can be bought from Carpenters Shipping also in Suva.

Personal contact proved to be the most useful method of meeting other interested groups, acquiring specific literature and more advanced equipment. For example, Professor South at the Marine Studies Programme of the USP recommended we speak to Dr. Russell Howorth at the South Pacific Geoscience Commission (SOPAC). As a result they lent us Seabird CTD and a Global Positioning System. These types of situations should be

considered when allocating the amount of time spent in the host country before the survey work begins. As the resources we obtained from the UK were limited this was the primary role of the advance group and it proved very successful.

4.3 Training and Testing

Training and testing was limited to three trial surveys on the northern reef of Motoriki Island. No testing could be done in Britain because the team members were widely spread and limited for time. It was also difficult to gain information about the reefs as they had never been dived and therefore we had to remain flexible.

4.4 Permission and Permits

Research Permits for Fiji were hard to obtain due to international communications and co-operation. Our situation was further complicated by the unexpected political crisis of May 19th in Suva. Attempts were made to contact the Fijian High Commission in the UK and the Permanent Secretary for Education and Research at the Department of Environment in Fiji.

In light of the situation and advice from Fiji we proceeded with the expedition. Although an official permit was never obtain due to complete political breakdown we considered it equally important to acquire the appropriate land and water rights from the local chief (*Ratu*). This is essential in Fiji and much of the South Pacific.

4.5 Fund Raising

We acquired £1,500 from three different sources all in the EAC (RGS & IBG) '*Guide to Grant Giving Organisations*' publication. Similarly, the CAF Directory to Grant Giving Organisations is an excellent source of information.

A large proportion of the expedition funds came from Loughborough and Cambridge Universities. Many Universities have travel funds to encourage participation in research expeditions. Later in the planning stages (within three months of departure) our efforts concentrated on commercial sponsorship and donation and although many replied, almost

all were unsuccessful. Commercial sponsorship and donation was limited to a personal link with the company. See *Acknowledgements* for a full list of expedition supporters.

4.6 Insurance

Selected companies were considered for insurance including stand travel agencies and those orientated towards diving trips. However, due to the nature of the expedition and the developing political situation in Fiji throughout the summer of 2000, it was necessary to take insurance with AON Risk Services. The standard package cost £100 for 10 weeks. No claims were made.

4.7 Communications

The expedition was extremely dependent on Internet and telephone communications in the planning phases. Firstly, because, conducting a 'pump-priming' operation was unfeasible due to finances and time and secondly, the team members were always widely spread to the extent that the full team did not meet until in Fiji.

All communication with the USP, David Kirton and Jakobe Kureleca was via e-mail. It was used to make most of our arrangements and to keep us up to date on the political situation.

4.8 Field Communications

The boat was equipped with VHF radio and although it was never needed, its use was limited by the lack of 'line of sight' marine traffic.

Bureta village has one phone but it is dependent on a solar panel set. Levuka has several phones using a phone-card system (cards can also be bought from Levuka).

4.9 Medical

4.9.1 Pre-expedition

Every member was inoculated for Tetanus, Typhoid, and Hepatitis A.

4.9.2 Qualification

Mik Carr is a registered state Nurse.

Mik Carr and Jo Barkworth are BSAC/ PADI diving instructors and Kat Hadfield is a Dive Leader all with a high level of diver specific medical training.

4.9.3 Medical Facilities

Bureta Nursing Station with basic facilities.

Levuka Hospital. 20km from Bureta but accessible by regular truck or boat.

Suva:

- i. Fijian Dive Operators Association (FDOA). A 24 hour recompression chamber facility and MEDEVAC system.
- ii. More advanced hospital facilities.

4.9.4 Field Equipment

3M Healthcare, Boots and Smith and Nephew were all approached for donations of medical supplies. A comprehensive dressing kit was donated by Smith and Nephew. The Cambridge University Occupational Health Centre designed a medical kit for the expedition.

4.9.5 Treatment Needed

- i. Septic Sore: Mosquito bite on Achilles rubbed by dive boot resulted in broken skin and infection. 7 day Flucloxacillin course, petroleum jelly (sealant) and daily dressing. No diving.
- ii. Deep cut on finger: domestic accident. Immediate treatment, suture stitches and daily dressing. Kept dry.
- iii. Gastrointestinal infection: 2 days rest and rehydration. No diving.
- iv. Ear Infection: 7 days penicillin and painkiller course. No Diving.

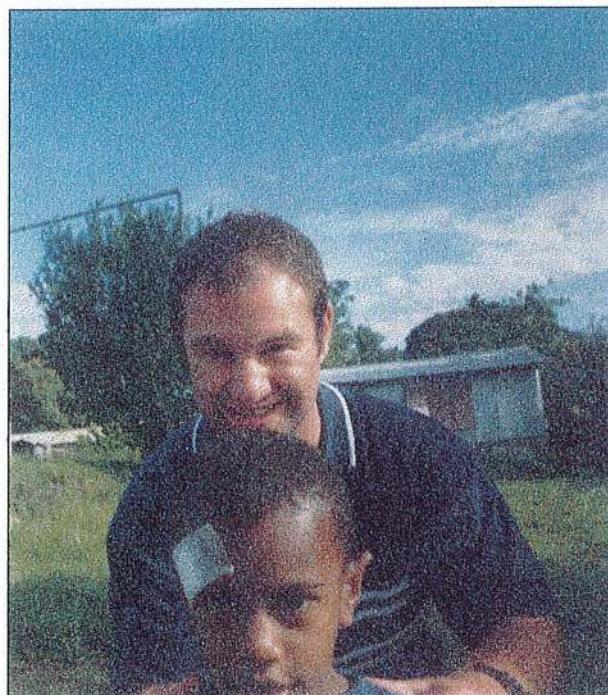


Figure 4.1 Si and Luké (photograph: Kat Hadfield).

- v. Possible, but not confirmed cases of Gardia due to the water in most of team.

4.10 Emergency Evacuation

A basic emergency evacuation plan was drawn up during the early stages of planning. Due to the political 'crisis' commencing May 19th, this plan was reconsidered in greater detail in consultation with The Foreign and Commonwealth Office, The British High Commission in Suva, The Royal Geographical Society and Expedition Advisory Centre, Air New Zealand and AON Risk Services. Throughout the expedition, the plan was re-evaluated depending on the situation and events on Viti Levu and Ovalau.

4.11 Specialist equipment

- i. Boat: *Flyfish* life jackets, toolkit, flares, VHF radio.
- ii. Bauer Air Kompressor,
- iii. 12 Aluminium Dive Cylinders,
- iv. Personal Dive kit,
- v. Buoys and shot line,
- vi. 1 KVA generator,
- vii. SBE Seabird CTD,
- viii. 2 x 100m nylon transect lines.
- ix. 1 x 20m glass fibre tape. 1 cm interval markings.
- x. Global Positioning System, Garmin GPS75-Personal Navigator. To be used for site location and in co-ordination with Seabird CTD.

4.12 Food



Figure 4.2 The 'last supper' with the village. (photograph: Si philipp).

4.12.1 Meat

Frozen: - chicken, lamb and beef bought from Levuka town for two days. Wrapped and stored due to lack of refrigeration.

Tinned: - tuna and corned beef and mutton.

4.12.2 Fruit and vegetables

Green peppers, beans, onions, carrots, cabbage, potato, garlic are all available to buy.

Dalo Plant: - *Taro* (root) baked and boiled, high carbohydrate, low protein. Main Fijian staple.

Rou-rou (leaves) boiled with coconut milk. Leaves can be poisonous if uncooked.

Kasava Plant:- Root boiled or baked. Another Fijian staple.

Coconut: - Mature coconut meat is eaten and used to make coconut milk (*nui*).
Green meat is edible, but better for the 'milk'. High in natural minerals, particularly potassium and nitrate.

Pineapple and Mango: - Viti levu and Vanua Levu islands available all year. On the smaller islands they are only available around Christmas.

Banana (*vudi*) All year.

Breadfruit (*uto*) Eaten raw. High in carbohydrate, low in protein.

Papaya/ *Pawpaw* Available all year and plentiful in supply. Excellent source of vitamin C.

Also available are lemons, limes and kumquats, which are all high in vitamin C.

Also grown locally are a wide variety of Asian and Pacific spices. These are very cheap if bought from a market (eg. Suva, Sigatoka, Nadi, etc.).

4.12.3 Water

Running water in the house, although probably not in smaller islands groups. A small sediment content and stoppages are common after periods of prolonged rainfall (see also medical treatment point v).

4.12.6 Bread

Home baked bread. All ingredients available from Levuka and Viti Levu.

4.12.5 Dairy:

Cheese- Processed cheese available. Fresh 'Rewa' only available from Viti Levu.

Milk- No fresh, only powdered.

Margarine- bought and kept cool.

4.13 Social Impact

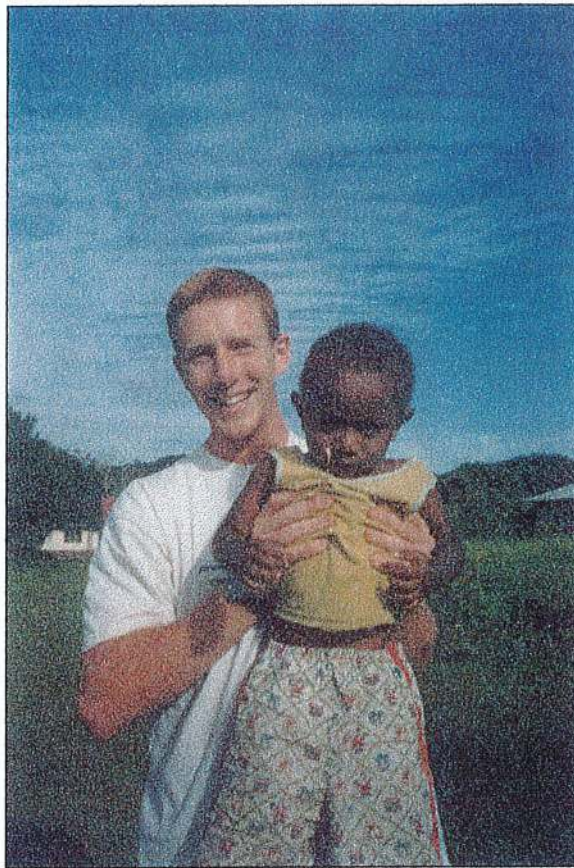


Figure 4.3 Rich and Pede in the village. (photograph: Si philipp).

4.13.1 Compressing

As we had no permanent shelter, compressing was done outside most days and was noisy apart from on Sundays.

3.13.2 Fuel used

Super, diesel, premix, kerosene for different pieces of equipment.

4.13.3 Waste

The majority of our household waste was burnt.

4.13.4 Food

We shared food such as bread and flapjacks around the village and were given fruit and vegetables in return.



Figure 4.5 The Buretan school children and expedition team behind (photograph: Manasa.)

4.13.5 Education

We talked to the village about our project. We gave a talk to the Bureta School and donated stationary, book, posters and environmental awareness material. (See figure 4.5)

4.13.6 Local economy

When the boat from the University of South Pacific had difficulties, we hired a small boat from Sabato, based in Levuka. The money spent locally would stay within Ovalau. This was especially important in Levuka, where tourism had markedly declined due to the political situation.

4.13.7 Medical Equipment

We donated our medical supplies to the Buretan nursing station when we left.

4.14 Other activities

4.14.1 Hiking

- i. To the remains of original Buretan village: a local high point and defensive position overlooking the present village and river (See figure 3.4).
- ii. Frequently to Buresala and to Lovoni and over the Eastern ridge of the Lovoni caldera to Levuka.

4.14.2 Swimming

With village chief and members in an upstream pools of the Bureta River.

4.14.3 Kayaking

Jakobe borrowed a surf kayak which we used on the Bureta River and out at sea. It was used to inspect the reefs more closely at low tides, when the river was inaccessible to the boat.

4.14.4 Rugby

Richard played for Bureta village XV and was picked to play for Ovalau Island 1st XV in the Fijian Provincial Tournament.

Chapter 5 Methods

5.1 Survey Procedure

From site 0 (figure 5.1: 17°42.50'N, 178°45.05'W) survey points were located at the intersection of half kilometre concentric circles and the reef edge. Distances were established using a Garmin GPS-75 from site 0 and backed up with measurements from Fiji OS Series Map 027.

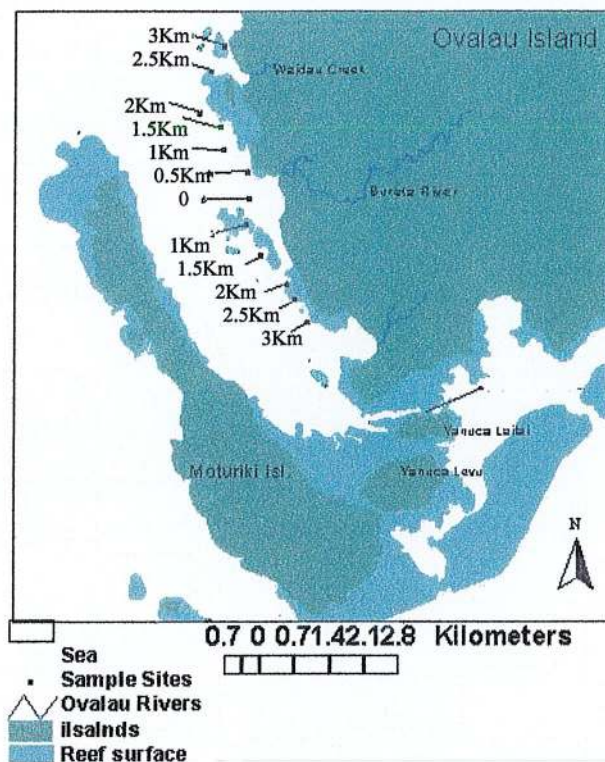


Figure 5.1 The south-west coast of Ovalau Island and survey sites.

5.1.1 Environmental Parameters

Turbidity, temperature and salinity were measured throughout the water column at each site. 13 sites (figure 5.1) were sampled within two hours of each other and at high tide. Sampling was repeated on two further days in an attempt to capture different conditions. Sampling was conducted using an SBE Seabird CTD device.

Although we had the advantages of GPS navigation, consistent and accurate positioning of sampling sites was made difficult by satellite errors and limited boat manoeuvrability. This in itself was not a major problem as changes in environmental variables in this context generally occur over distances greater than tens of metres.

However, despite coral surveying (section 5.1.2) being conducted at three and seven metre depths without problems, these were often un-attainable when sampling environmental parameters due to the high variability in depth of reefs, especially close to the river. Where the maximum depth was less than three metres, there were voids in the environmental variable data set. Although there will definitely be a sampling error, comparisons will still be made between coral results at 3m and environmental parameters measured at 0.5m. Unfortunately, due to the method of data storage in the SBE Seabird, these difficulties were not recognised until the surveying programme had finished.

5.1.2 Coral

A total of 18 coral transect lines were surveyed in July and August 2000. Adapting the Line Intercept Transect method (English *et al*, 1997) 100m nylon transect lines were deployed at all survey sites (excluding 0.5km South) at 3m depth and at kilometre intervals at the 7m depth. Depths recorded on dive computers were corrected to chart datum for consistency throughout all surveys. The two survey depths are designed to represent shallow and deep reef communities (Loya 1978, Burns, 1982; English *et al*, 1997). The transect lines followed the appropriate contour away from site 0 (river) and were marked to signify the start of each transect tape.

The beginning of the line was temporarily marked by a weighted 'shot line' and Surface Marker Buoy (SMB). A negatively buoyant 20m tape measure was deployed, following the transect line. The survey pair, using SCUBA equipment, moved along the transect tape very slowly, recording the benthic information. The role of Diver 1 was to indicate the classification code directly under the tape and the distance at which it changed to another type, while Diver 2 recorded the data on underwater slates. Three replicate samples were taken, before the line, tape and SMB were recovered.

5.1.3 Fish

Although fish are not the principal element of this study, the variations in abundance and diversity will be studied, as they are fundamental constituents of the reef community.

Fish and coral surveys were conducted at the same sites and on the same transect lines. Surveys were carried out by visually estimating the abundance of ten reef fish families within an eight metre cube every 4m on the transect line.

As it is a recognised fact that fish populations vary between tidal levels (Barbault, 1992), all sites were sampled at high tide for consistency. It is also recognised that populations are greatest at this time.

5.2 Classification and Identification

In co-ordination with the literature (English, *et al.*, 1997; Allen and Steene, 1998), pre-survey assessment was carried out in order to determine different benthic categories. 2 conclusions were reached.

Firstly, under conditions of very poor visibility (<2m) differences between *Acropora* and non-*Acropora* corals were not discernable while carrying out surveying. Therefore the *Acropora* / non-*Acropora* distinction recommended by English, *et al.* (1997) was rejected in favour of a more morphological classification.

Secondly, the classification 'water' (w) defined as 'fissures deeper than 50cm' (English, *et al.*, 1997) was replaced by recording the benthic category below the transect tape.

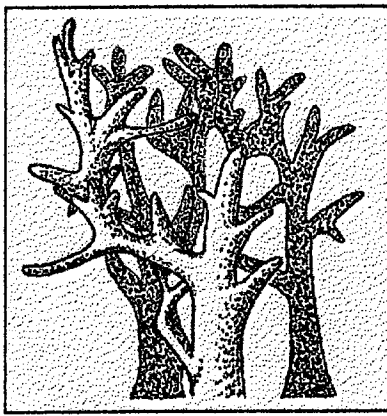
5.2.1 Benthic Identification Categories

<i>Abiotic</i>	Dead Coral	DC
	Dead Coral with Algae	DCA
	Dead Coral with Silt	DCS
	Rock	Ro
	Rubble	R
	Sand	S
	Silt	SI
	Other	OT
<i>Biotic</i>	Coral Branching	CB
	Coral Digitate	CD
	Coral Encrusting	CE
	Coral Foliose	CF
	Coral Massive	CM
	Fire Coral (<i>Millepora</i>)	CME
	Mushroom Coral	CMR
	Coral Submassive	CS
	Coral Tabular	CT
	Soft Coral	SC
	Sponge	SP
	Algae	AA

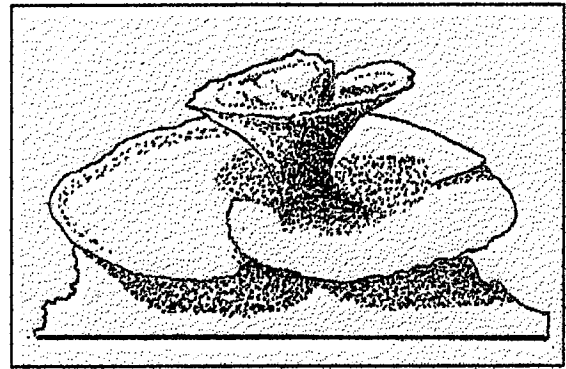
5.2.2 Fish Identification Categories

Acanthuridae	(Surgeonfishes)
Apogonidae	(Cardinal fishes)
Blenniidae	(Blennies)
Chaetodontidae	(Butterflyfishes)
Gobiidae	(Gobies)
Labridae	(Wrasses)
Pomacanthidae	(Angelfishes)
Pomacentridae	(Damsel fishes)
Scaridae	(Parrotfishes)
Serranidae	(Grouper and Baslets)

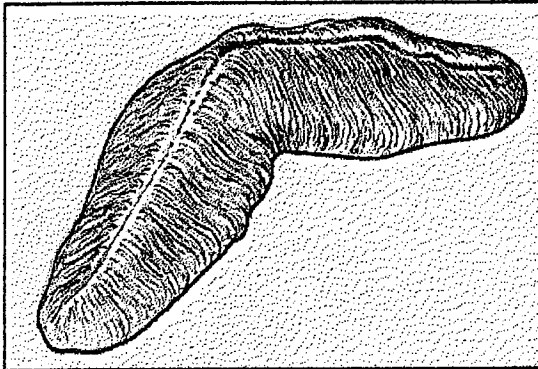
(Figure 5.2 illustrates the key coral morphologies)



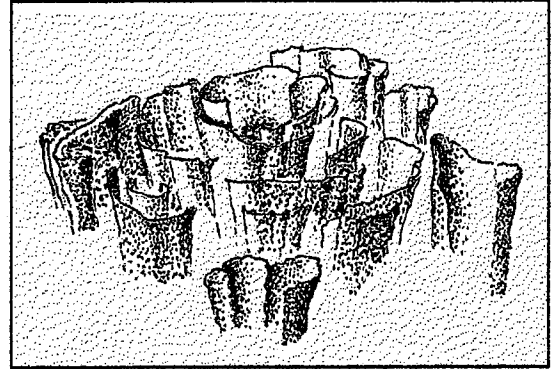
Branching Coral (CB)



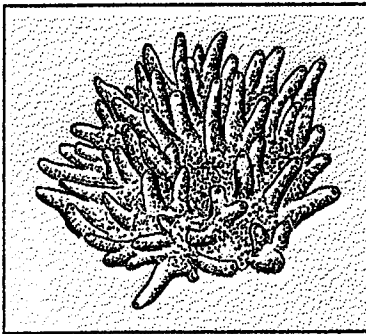
Tabular Coral (CT)



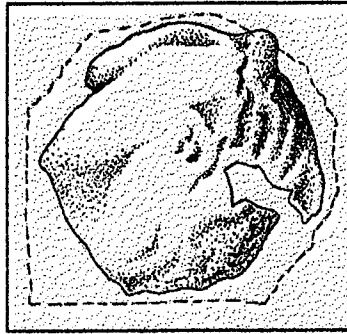
Mushroom Coral (CMR)



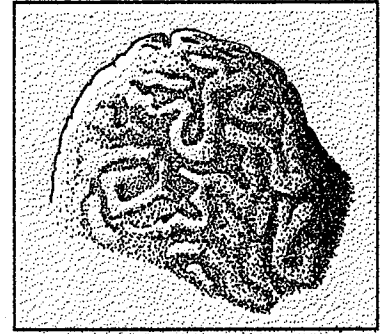
Foliose Coral (CF)



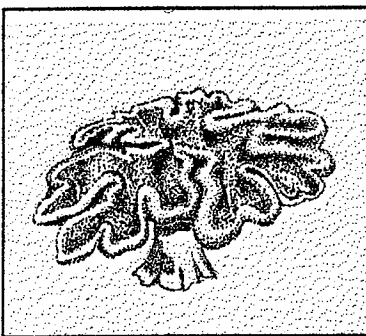
Digitate Coral (CD)



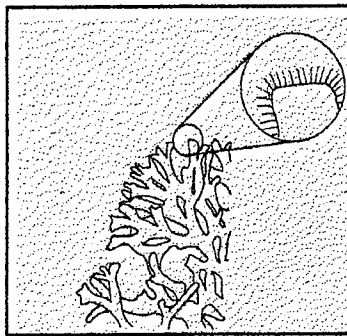
Encrusting Coral (CE)



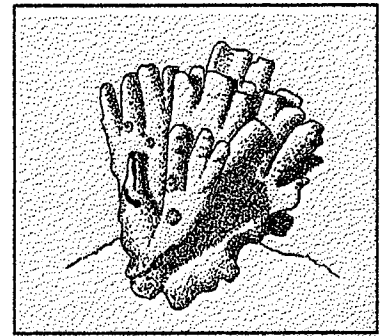
Massive Coral (CM)



Soft Coral (SC)



Fire Coral (CME)



Coral Submassive (CS)

Figure 5.2 The classification of coral according to morphology (illustrations: R. Brantingham).

5.3 Data Analysis

At each site, data from the four twenty metre 'coral' transect tapes were averaged to produce a single estimate of abundance for each morphological category. All forms of hard coral and soft coral and sponges (biotic classifications) were analysed separately from the 'abiotic' classifications (silt, dead coral with silt, algae, dead coral with algae and rubble) in which algae was included due to its competitive relation with coral. Data from each fish observation box were averaged to produce single estimates of fish populations at each site. Data was further analysed by calculating the Shannon-Weiner Diversity Index of coral morphologies and fish populations, H' , where: -

$$H' = -\sum (p_i)(\ln p_i)$$

for all classifications and p_i is the proportion of each category in the total abundance and $\ln p_i$ is its natural logarithm.

The results from all three SBE Seabird sampling days were averaged to produce a single estimate at each site for analysis and further comparison. The variations were graphically represented and entered as independent variables in stepwise multivariate regression analysis against coral and fish abundance and diversity.

Relations between distance from the river and biotic and abiotic abundances and diversities were investigated using graphical correlation and linear regression. Relations between distance and environmental parameters, and distance and fish abundances and diversities were also investigated using graphical correlation and regression.

Stepwise multivariate regression analysis was used in an attempt to isolate dominant influences upon coral and fish abundances and diversities north and south of the Bureta River.

Chapter 6 Analysis of Environmental Parameters.

The following analysis will concentrate on variations in temperature, salinity and turbidity and discuss relations between these environmental parameters and distance from the river. It is also the basis for conducting correlation and regression between coral and fish characteristics, and these parameters, which will be in chapter 7.

6.1 Temperature

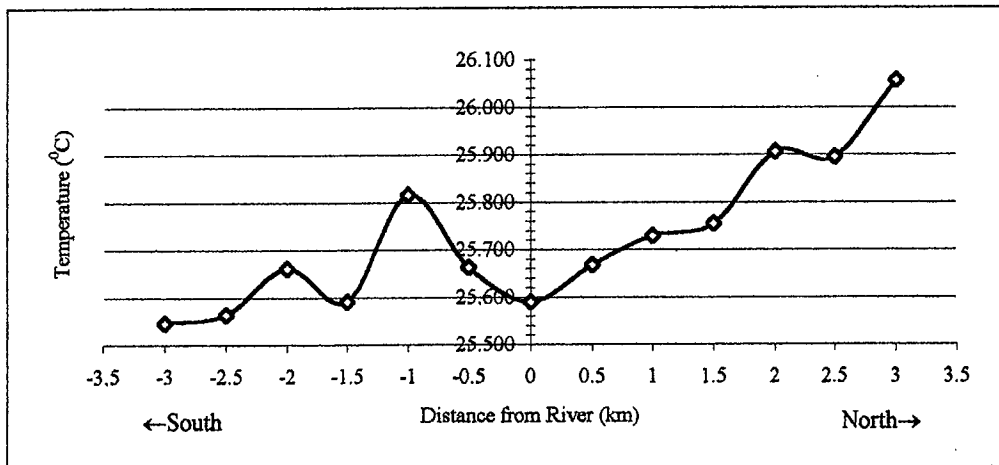


Figure 6.1. Variations in temperature with distance from the Bureta River.

Water temperature in the study area is at the lower end of the optimum coral growth range, outlined by Davies (1980). However, this does not represent the summer temperatures, which are likely to be higher. South of the river, temperature has a negative relation with distance and although the variations are erratic from site to site, the r^2 value (figure 6.2) below demonstrates that it is a strong relation.

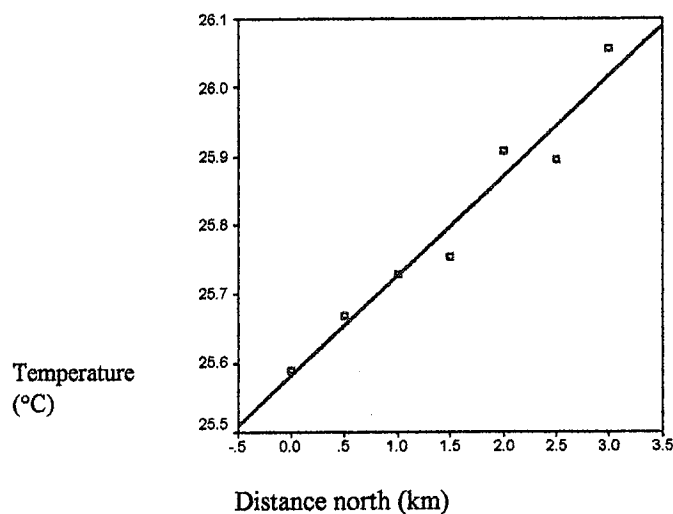


Figure 6.2 Regression between distance north and temperature. $r^2 = 0.95$

The fluctuations are suspected to be due to differences in suspended sediment, water depth or substrate. However, the occurrence of the lowest water temperatures at the southerly sample point rather than the river, suggest a cooling process or an alternative source of cold-water input.

North of the river, there is a strong positive correlation between distance and temperature (0.98). The difference between temperature at the river and at 3km north is only 0.4°C and the lower limit is within the optimum range, suggesting temperature does not directly influence the composition of the reef in this area.

The influence of the Waidau Creek can be identified where the temperature drops at 2.5km north.

6.2 Salinity

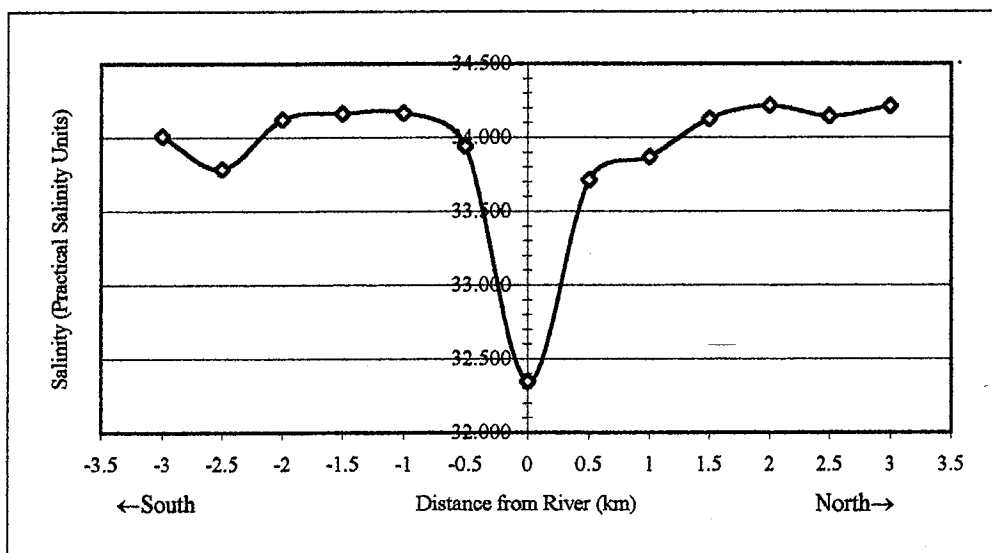


Figure 6.3 Variations in salinity with distance from the Bureta River.

The majority of the 2‰ (Practical Salinity Units) change is within the first kilometre in either direction, after which salinity varies relatively little. However there are correlation coefficients of 0.78 and 0.65 exists between salinity and distance north and south, respectively. The profile in figure 6.3 suggests either the majority of discharge is directly offshore or mixing mechanisms are effective. The influence of Waidau Creek is also indicated in salinity as well by a small decrease at 2.5km north.

Kinsman (1964) identifies the optimum growth range to be between 34 and 36‰ and although the sample at the river lies outside this range, only the top 0.5m was completely sampled. Depending on the site, this depth approximately marks the vertical boundary between salt and freshwater. Therefore, it is unlikely that salinity is a dominant factor in controlling reef health at three and seven metre depths.

6.3 Turbidity

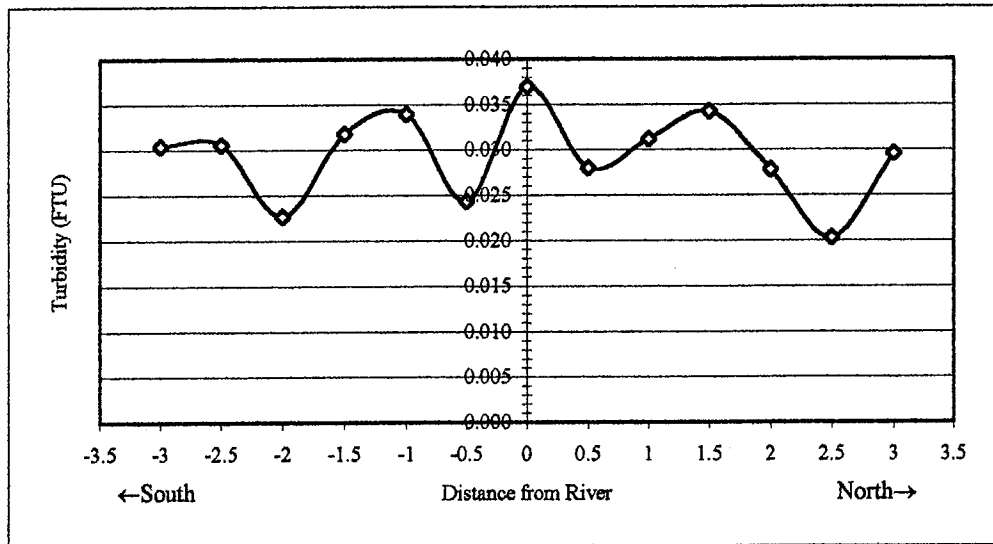


Figure 6.4 Variations in turbidity with distance from the Bureta River.

The profile is highly erratic, but there is an element of consistency between peaks and troughs in both directions and both have moderate negative correlations (N: -0.59; S: -0.62). The cause of these almost cyclical variations may either be the influence of diurnal tidal ebbing and flooding on the concentration of suspended sediments in certain areas or the result of recent storm events discharging large quantities of suspended sediments into the marine basin.

Chapter 7 Analysis of Benthic composition

7.1 Three - metre survey

7.1.1 Biotic Composition

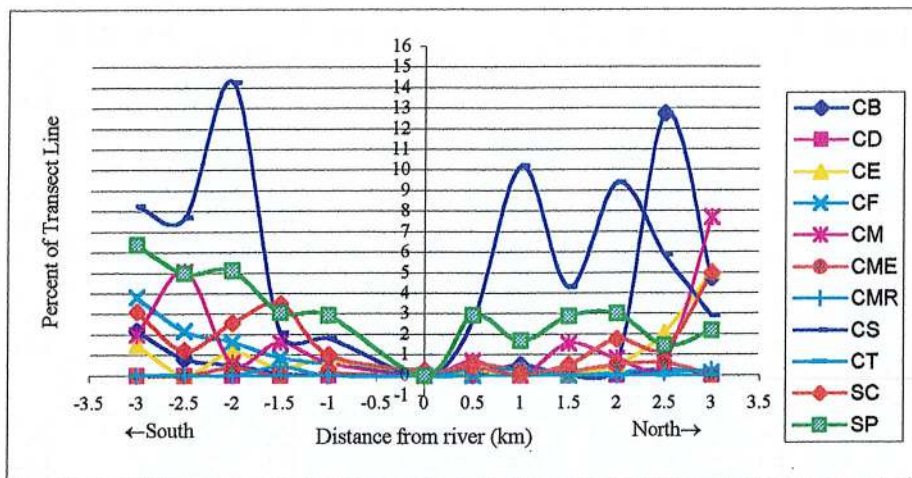


Figure 7.1 Variations in biotic categories at 3m.

Figure 7.1 highlights the large erratic variations in certain coral forms, such as increases in submassive coral at 2.5km south and 1 and 2 km north. It can be speculated that these sporadic increases are not caused by the success of one morphological type over another in a certain area, but by well developed colonization by a particular species of a certain morphology. However, it raises the question about what other factors influence reef composition, which are addressed at the end of this section. The influence of coral species competition, and how this can be quantified for use in further analysis is discussed in outline but is beyond the terms of reference of this study.

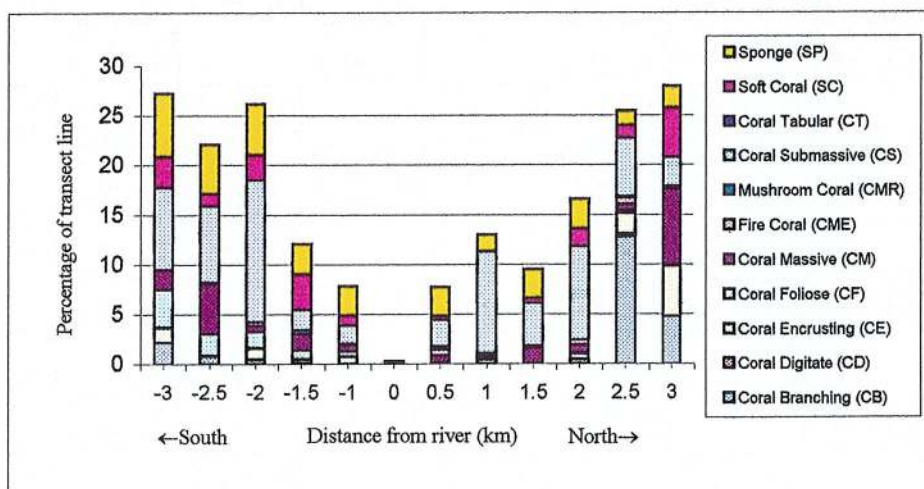


Figure 7.2 Biotic composition of 3m reef transect.

Figure 7.2 clearly illustrates the negative influence fluvial input has on coral abundance. In co-ordination with this, table 7.1 shows the correlations between distance (and direction) and abundance for each morphological group. The dominant morphological forms exhibit moderate or strong correlation with distance (with the exception of submassive coral-north) but more importantly, the consistency between north and south, suggests that one or more governing factors influences coral abundance and diversity in both directions in the marine basin.

	North	South
Coral Branching (CB)	0.64	0.83
Coral Digitate (CD)	0.41	0.00
Coral Encrusting (CE)	0.80	0.58
Coral Foliose (CF)	0.73	0.94
Coral Massive (CM)	0.67	0.65
Fire Coral (CME)	0.11	0.05
Mushroom Coral (CMR)	0.07	-0.02
Coral Submassive (CS)	0.30	0.71
Coral Tabular (CT)	0.00	0.00
Soft Coral (SC)	0.79	0.63
Sponge (SP)	0.35	0.98

Table 7.1 Correlations between biotic category abundance and distance.

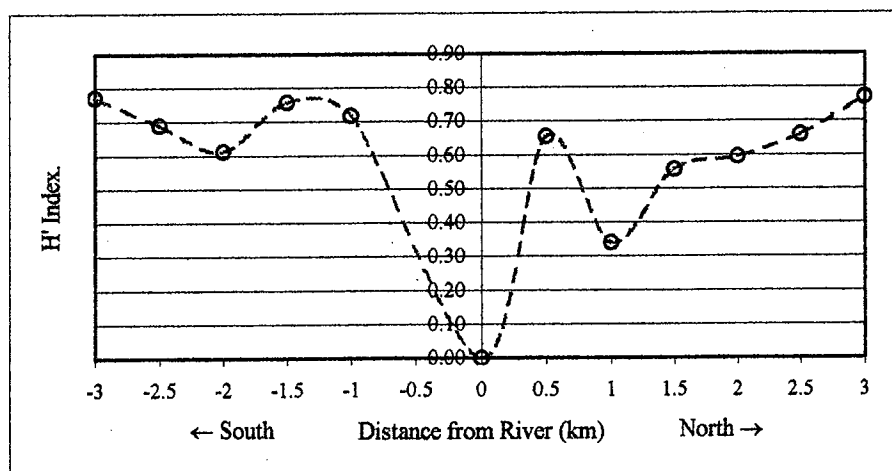
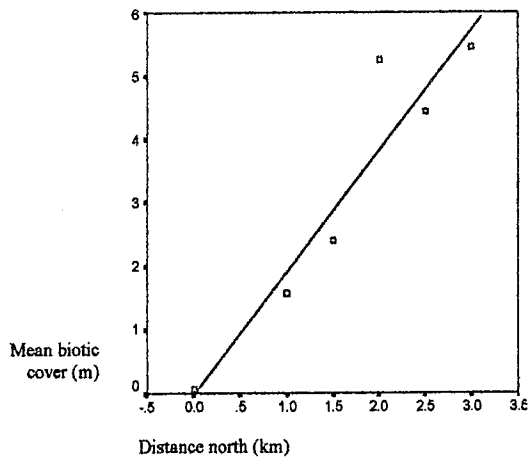
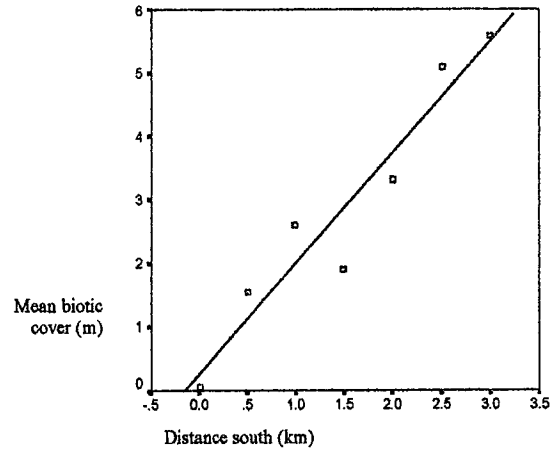


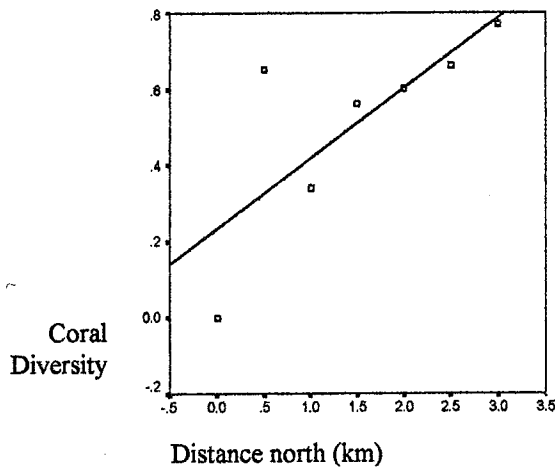
Figure 7.3 Shannon diversity index (H') for biotic categories at 3 metres.



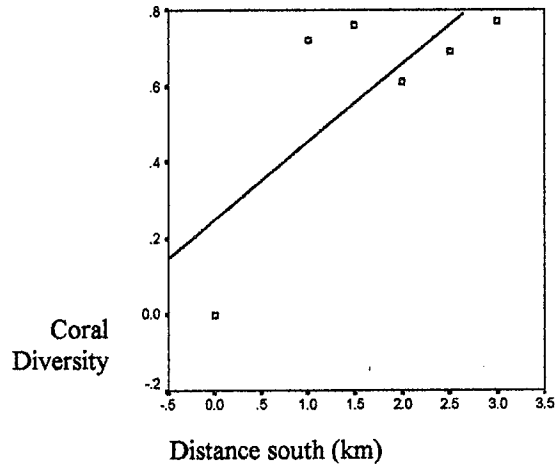
7.4 Relations between coral abundance - abundance -and distance north.
 $r^2 = 0.89$ eqⁿ: $y = 0.255 + 1.744x$



7.5 Relations between coral and distance south.
 $r^2 = 0.92$ $y = -4.29 \cdot 10^{-3} + 1.917x$.



7.6 Relations between coral diversity - and distance north.
 $r^2 = 0.59$ eqⁿ: $y = 0.249 + 0.205x$



7.7 Relations between coral diversity - and distance south.
 $r^2 = 0.56$ $y = 0.234 + 0.185x$

Figure 7.3 illustrates the increase in Shannon- diversity index away from the Bureta River and the presence of negative influences at 1km north and 2km south. Figures 7.4, 7.5, 7.6 and 7.7 represent these strong and moderate relations between total coral abundance and Shannon diversity index, and distance in both directions. Abundance relations have high r^2 values (maximum = 1), showing the significance of each relation in accounting for variations in the variables.

It is evident from these results that there are strong relations between increased coral cover and distance from the river. The extent of relations between reef composition and environmental parameters will be discussed later; however, there may be other issues, such as coral species competition that are inadequately discussed in the

literature. This issue is above and beyond the reach of this study, however a simple graphical representation of biotic categories as a percentage of total biotic transect cover (figure 7.8) is a useful step in attempting to understand the extent of biotic influences on reef composition.

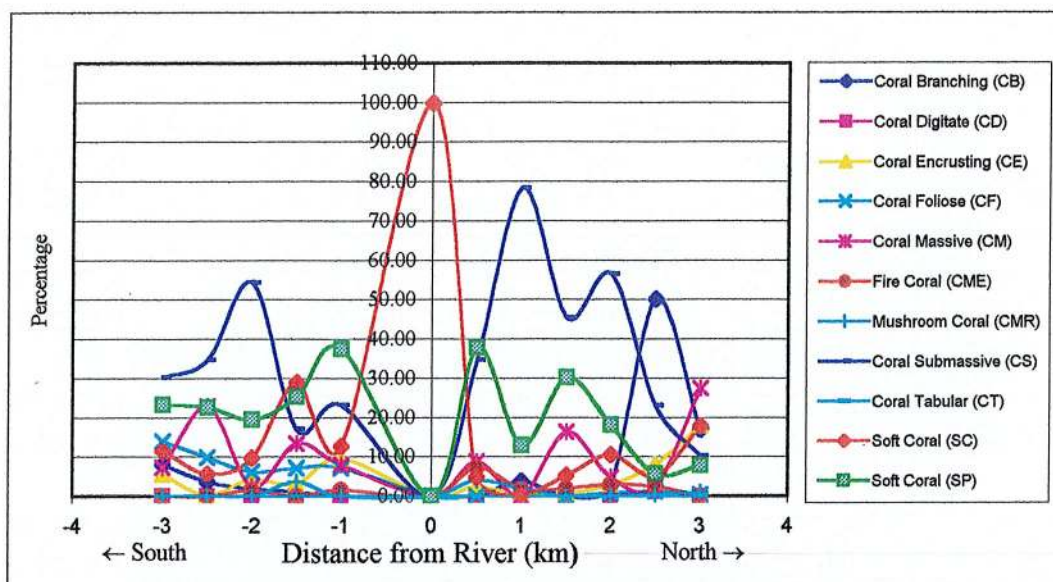


Figure 7.8 Biotic Categories as a percentage of total biotic cover.

For example, soft corals are relatively tolerant of sediment rich environments, accounting for all biotic cover at site 0. They have clear morphological and genetic advantages, such as; a soft structure that allows flexibility and high passive sediment loss, an ability to settle and recruit on loose sediments and low light requirements. However, soft coral also appears to be a poor competitor against other biotic groups in all but sites 0 and 1.5km south. Filling an environmental niche in this way can be seen in other categories such as sponges and branching and submassive coral forms, whereby other morphologies are less abundant due to the success of one of the above.

7.1.2 Regression analysis

SPSS multivariate regression analysis was carried out in order to establish the most influential environmental parameters on coral and fish abundances and diversities at the three-metre depth survey. Table 7.2 summarises the results from this analysis and figures 7.9 - 7.13 are graphical representations of these analyses.

Table 7.2(A and B) indicates that of the coral abundance variations north of the river approximately 86% can be accounted for by temperature differences. However, south of the river, 63% of the variations in coral abundance can be attributed to turbidity fluctuations. Interestingly a large proportion (80%) of southerly variations in fish abundances (table 4.2E) can also be attributed to turbidity fluctuations. These two results support the theory that the abundance and influence of sediment south of the river is greater than that to the north, although the cause is still speculative.

Table 7.2 (C and D) also highlights salinity as the dominant influence upon coral diversity in both directions, accounting for 79 and 93% of variations north and south, respectively. The consistency between these two results adds confidence to the relations, and although the salinity tolerance limits are not breached, it implies salinity has a discernible effect on the diversity of coral morphologies.

There were no other significant relations indicated by multivariate regression.

	Variable 1	Variable 2	Adjusted r^2	Std. Error
A	Coral abundance north	Temperature	0.863	0.7291
B	Coral abundance south	Turbidity	0.627	1.3377
C	Coral diversity north	Salinity	0.742	0.1326
D	Coral diversity south	Salinity	0.908	0.08955
E	Fish abundance south	Turbidity	0.802	2.0598

Table 7.2 Model Summaries of stepwise regression analysis between the coral and fish population characteristics and environmental variables. The column 'variable 2' is the parameter indicated as the most influential in determining the variability of 'variable 1'.

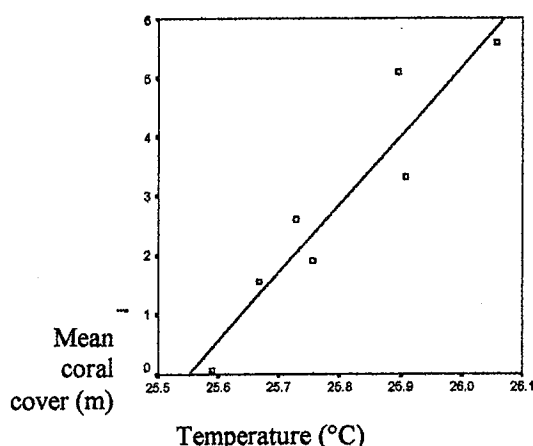


Figure 7.9 Coral abundance north against temperature ($^{\circ}\text{C}$). $r^2 = 0.89$

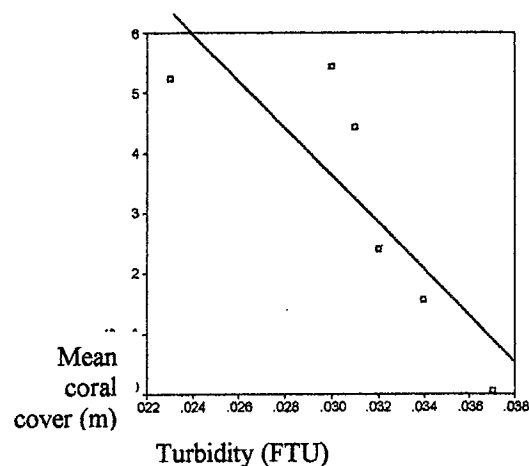


Figure 7.10 Coral abundance south against turbidity (FTU). $r^2 = 0.70$

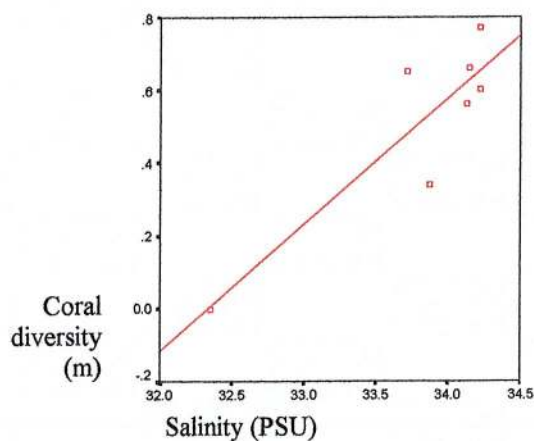


Figure 7.11 Coral diversity north against salinity (PSU)
 $r^2 = 0.79$

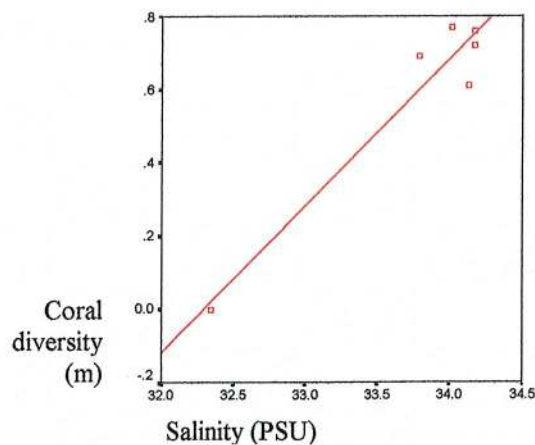


Figure 7.12 Coral diversity south against salinity (PSU)
 $r^2 = 0.93$

7.1.3 Abiotic composition

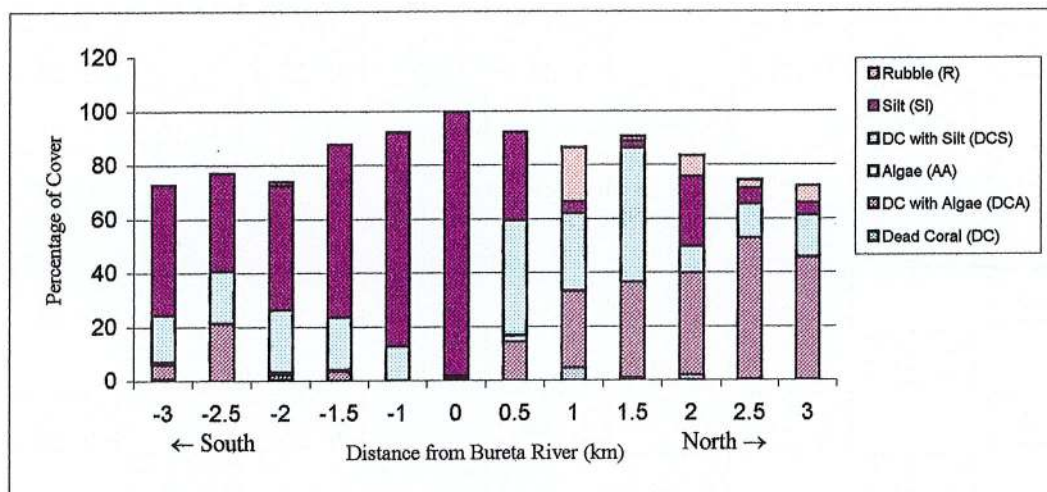
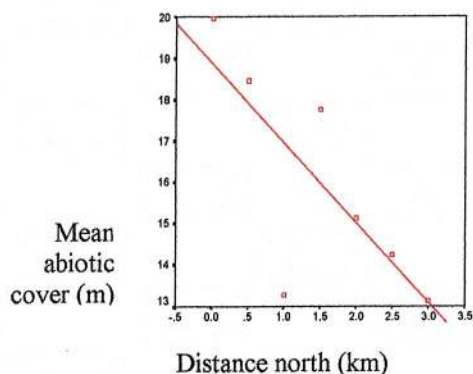


Figure 7.13 Abiotic composition of mean transect at 3 metres.

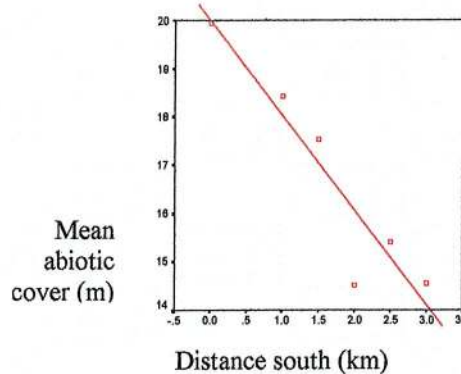
Figure 7.13 effectively shows the inverse of biotic transect cover, whereby the maximum abiotic cover occurs at the river, site 0 and the minimums occur at the furthest distances of sites 3km south and north. Figures 7.14 and 7.15 are graphical representations of the relation between distance and abiotic cover in both directions. Three categories dominate this composition; dead coral with silt, dead coral with algae and silt. Variations in rubble, algae and dead coral are of little significance.



7.14 Relations between abiotic cover - and distance north.

$$r^2 = 0.59$$

$$\text{Line eqn: } y = 18.88 - 1.92x$$



7.15 Relations between abiotic cover - and distance south.

$$r^2 = 0.88$$

$$\text{Line eqn: } y = 19.99 - 1.95x$$

In a southerly direction, two of these categories are of consequence. Firstly, although silt declines by approximately 60% between the river and 2.5km south, it increases towards 3km south and accounts for 50% of the mean transect cover. Secondly, dead coral with silt increases towards 2.5km south and decreases marginally further south. Together however, these two categories account for almost 70% of the mean transect line at 3km south. The causes of these variations shall be discussed in section 7.3.

7.2 Seven - metre survey

7.2.1 Biotic composition

It is important to analyse reef composition at seven metres as well as three metres to better understand coral composition at deep as well as shallow reef communities.

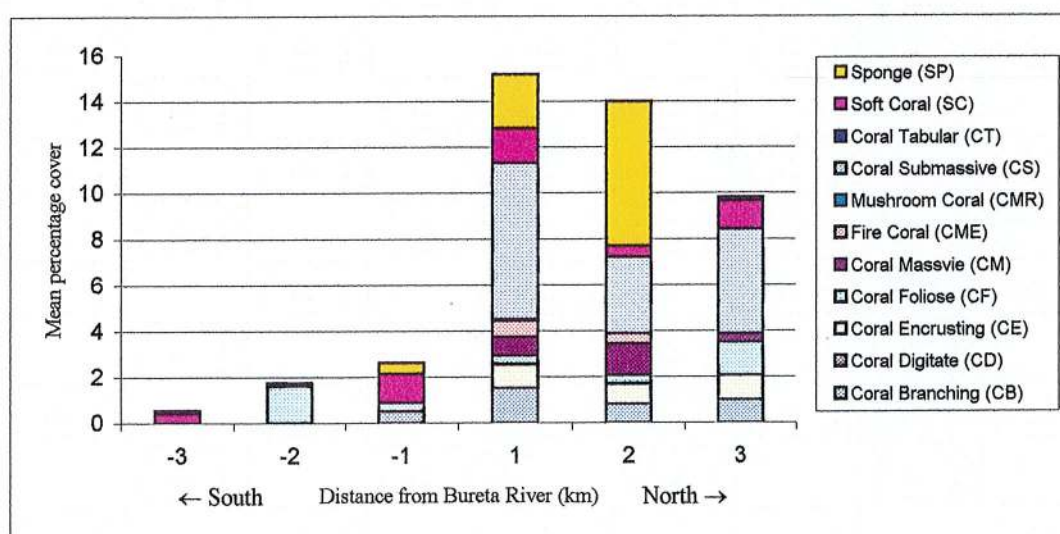
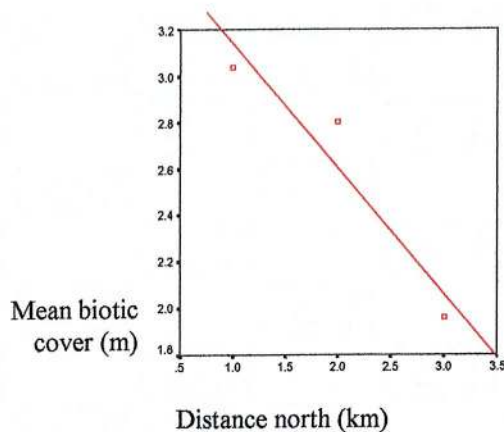
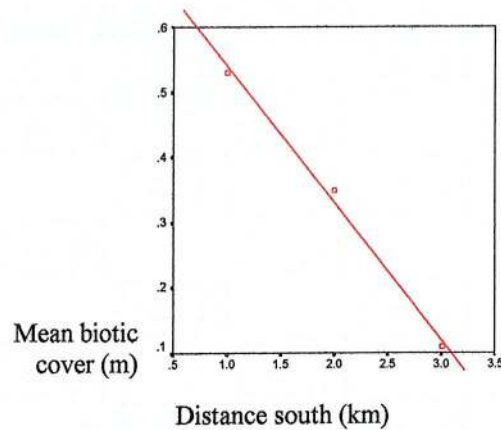


Figure 7.16 Biotic composition of reef at 7 metres.



7.17 Relations between coral abundance and distance north at 7 metres.
 $r^2 = 0.91$



7.18 Relations between coral abundance and distance south at 7 metres.
 $r^2 = 0.99$

In contrast to the 3m-depth survey, biotic abundance decreases away from two minimums at 1km north and 1km south (figure 7.16). The relation between distance in either direction and coral abundance is best represented by figures 7.17 and 7.19. There are no prominent patterns in abundances of individual coral morphologies and there were no relations between distance (in either direction) and Shannon Diversity Index.

Figure 7.16 also shows the contrast in abundances between north and south, confirming the presence of a strong negative influence upon one or more elements of the coral life cycle south of the Bureta River, which will be discussed in section 7.2.4.

7.2.2 Abiotic composition

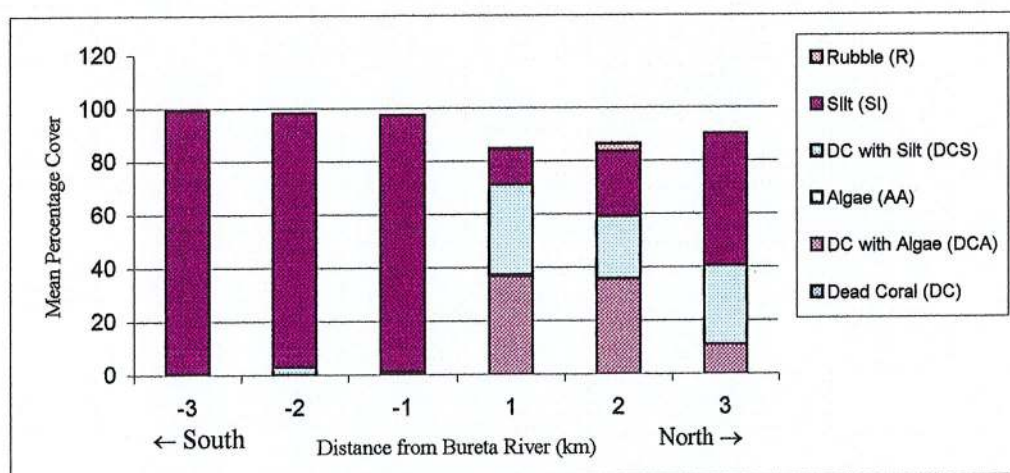
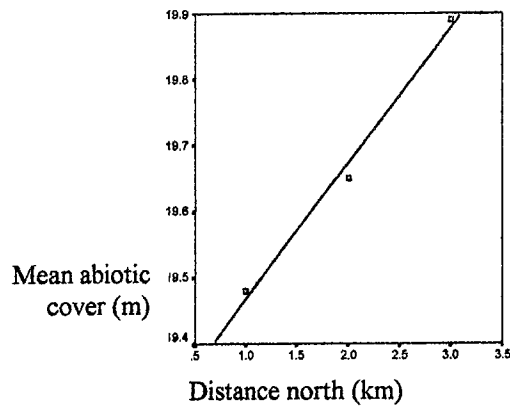
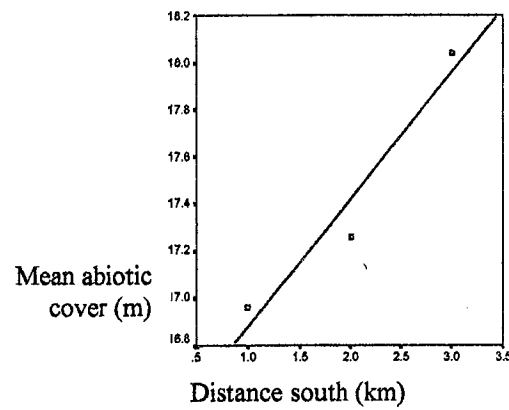


Figure 7.19 Abiotic composition of reef at 7 metres.



7.20 Relations between abiotic cover and distance north at 7 metres.
 $r^2 = 0.99$



7.21 Relations between abiotic cover and distance south at 7 metres.
 $r^2 = 0.94$

The strong negative influence on biotic benthos mentioned in the previous section is best discussed in the context of the above results. Figure 7.19 indicates that silt is clearly the dominant transect constituent and will affect coral reefs on three levels, as discussed in section 1.2.3. Firstly, direct sedimentation will reduce light and food (van Katwijk, 1993) and abrade coral tissue (Hubbard, 1986); secondly, sediment layering on substrate will reduce settlement and recruitment of coral planulae; and finally, sediment re-suspended by tidal and wave action will severely impede light penetration (Larcombe *et al*, 1995). It is not the aim of this project to consider these processes in detail, however, it is reasonable to assume that, especially in these three sites all of these influences are present and active to a different extent.

North of the river at 7m, the strong positive correlation between silt cover and distance from the river opposes my hypothesis that silt will decrease away from the expected source, the Bureta River. This is either due to the influence of the Waidau River on sediment deposition to the north or the effectiveness of reef systems in rejecting and transporting sediment. The high proportion of sediment cover at 7m south (site average silt cover:- 7m = 96.8%; 3m = 62%) suggests that there may be a sediment transport process operating in both direction. Despite most reef systems growing to depths of 20m and more, 7m was frequently found to be the approximate lower limit of coral growth in the study area. It is most likely that this is the depth at which insufficient light is available for zooanthellae photosynthesis.

7.3 General Discussion

7.3.1. Macroalgae competition.

Despite the different correlations with distance (0.94 at 3m and -0.89 at 7m) the dominance of dead coral with algae at both depths north of the river suggests the existence or absence of a significant influence. The 'absence' of an influence and abundance of dead coral with algae can be accounted for by relatively low sediment cover and the processes associated with it. The complex but negative influence of silt upon macroalgae as found by van den Hoek *et al* (1978) is confirmed here by a Pearson's correlation coefficient of -0.96 between silt and dead coral with algae north of the river. The 'presence' of other influences is only speculative because macroalgae and the processes operating within the marine basin are so complex. However, small-scale commercial agriculture using unknown chemical spray was observed on floodplain of the Waidau River (see figure 2.2). The spraying application is likely to be in the form of fertilizers, pesticides or herbicides and all will have an effect on the composition of the reef and the abundance of algae. Fertilizers will increase the nutrient content of fluvial discharge, which is known to increase the development of many macroalgae (Umar *et al*, 1998), while pesticides and herbicides allow algae to benefit from adverse effects of these chemicals on coral (Umar *et al*, 1998).

7.3.2 Sediment load.

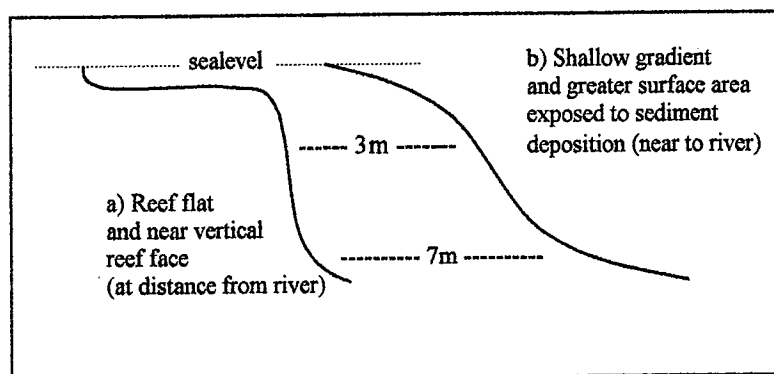


Figure 7.22 Dominant reef profiles observed in study area.

The differences in correlations between silt and distance north at 3m (Pearson: -0.70) and 7m (Pearson: 0.98) can be partially explained by the profile of the reef. While carrying out the surveying, it was observed that the northern most sites had reef profiles shown in figure 7.22a, whereas those nearest the river are best represented by

figure 7.22b. Therefore sampling at 3m was often carried out on near vertical faces, which are of great benefit to passive sediment rejection mechanisms (Rogers, 1990). The abundance of silt at 7m strengthens this argument, implying that sediment rejection (passive or active) is highly effective within the shallower coral reefs. Surprisingly, there is very little literature with which comparisons can be made, despite its apparent significance in sediment – reef interactions. Furthermore, it may be of even greater consequence if the cause of these structural variations is the negative impact of fluvial discharge upon vertical reef development. For example, a negative feedback mechanism may exist, whereby the primary influence on passive rejection (reef structure and vertical walls) is governed by the effects of sediment on coral development.

7.3.3. Marine basin morphology.

At all survey sites and the basin as a whole, it can be speculated that the morphological composition of corals is largely dependent on the interaction between living horizontal surface area and sediment deposition. For example, although some tabular coral (figure 5.2) has a spiralling structure to aid sediment loss, it is largely flat and easily smothered. No tabular coral was recorded or even observed in the study area, while it was observed with some frequency on the north – eastern barrier reefs of Ovalau Island where there is no sedimental influence.

The key feature is the natural reef and island bridge between Ovalau and Moturiki Islands (figure 7.23), which has the following effects on the movement of sediments. Firstly, the mass of islands and reefs will shelter the southern most area of the study site, and any sediment deposits from the prevailing south-easterly winds. Secondly, it restricts sediment ‘flushing’ from within the basin. This will be most apparent in tidal movements, which are forced to flood and ebb, from and to the north, respectively (Fijian Admiralty Chart: 774). The majority of suspended sediments being transported southeast by the tidal flood will undergo deposition during the ‘slack’ waters of high tide (Pethick, 1997) producing increased fluvial sediment deposition south of the Bureta River. This combination of processes is believed to be the prime cause for elevated levels of silt and reduced coral cover on the southerly transects at 3 and 7m depths. Furthermore, despite a large proportion of sediments being deposited south of the Bureta River, this is not the immediate direction of sediment transport. Reef

distribution surrounding the Bureta River and Waidau Creek (figure 7.24 and figure 7.25) indicates that the dominant direction of fluvial discharge is towards the northwest; the same direction as the prevailing winds.

Fluvial plumes begin in the top 1.5 to 2 metres of the water column (Larcombe *et al*, 1995), however the freshwater and its sediment content are eventually mixed by wave action, reducing the impact of wind driven surface currents on sediment transport. At this point, the tidal process mentioned above is thought to become the principal influence.

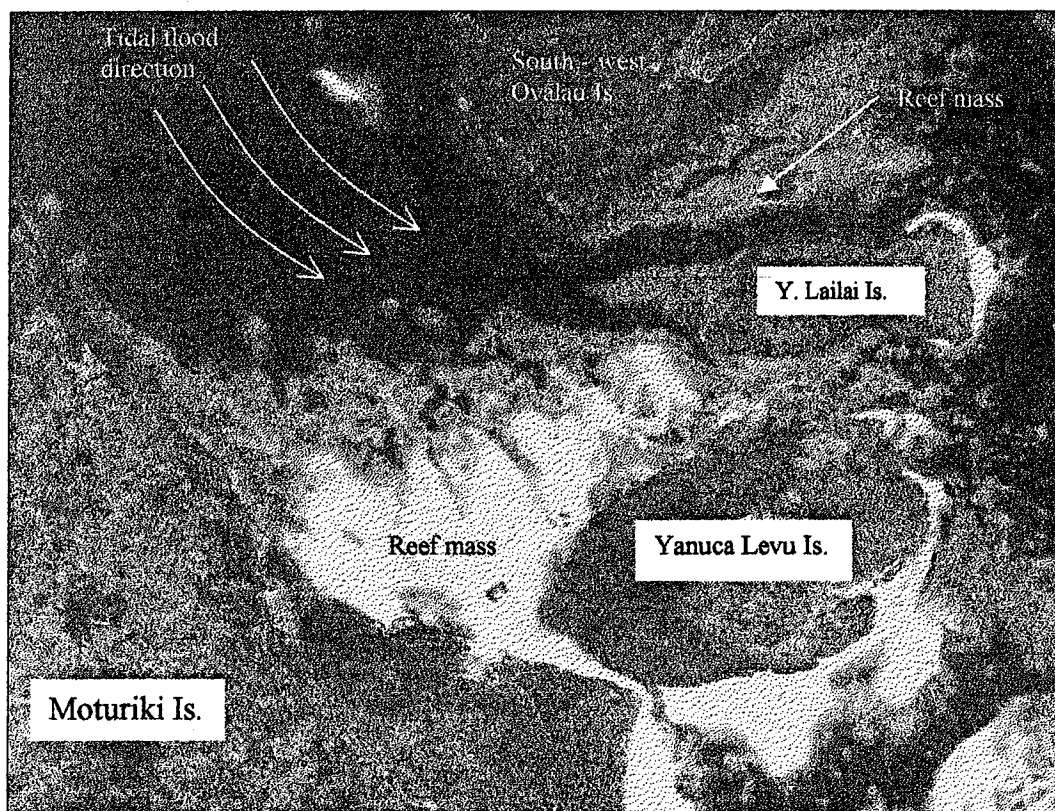


Figure 7.23 The constriction created by the islands and reefs.

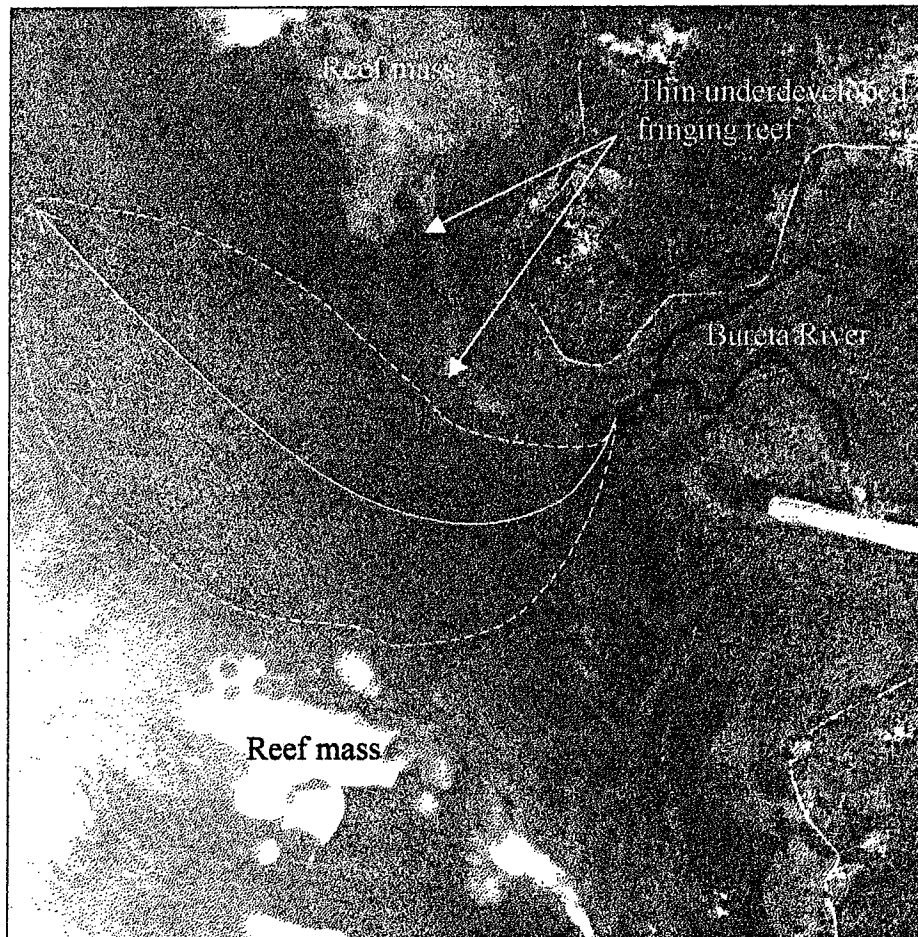


Figure 7.24 The suspected discharge path north-eastwards from Bureta River.

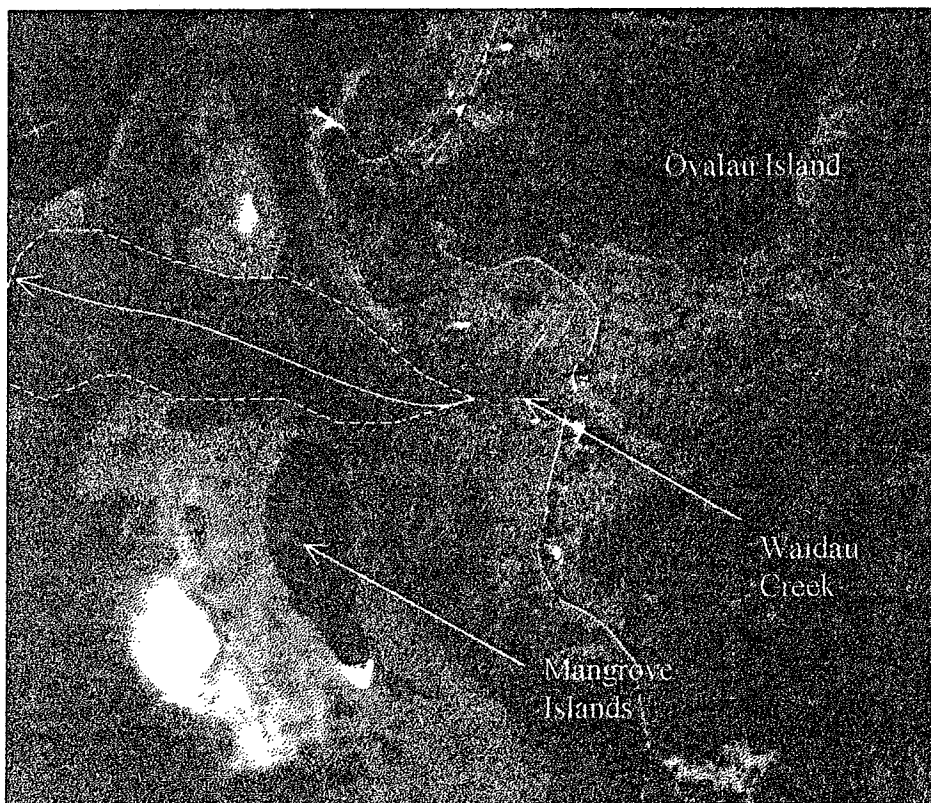


Figure 7.25 The suspected discharge path eastwards from Waidau Creek

Chapter 8 Fish Population Analysis

8.1 Three - metre survey

With the exception of 2km south, Damselfish (Pomacentridae) are the dominant fish family throughout the study area. However, their populations are subject to variations with distance as illustrated by figure 8.1 and strong positive correlations between mean abundance and distance (Pearson's North: 0.78; South: 0.96).

The second family of significant abundance is the cardinalfishes (Apogonidae). North of the river, populations remain relatively unchanged, while south the abundances vary erratically with a maximum at 2km south. Interestingly, this maximum and the northern maximum, also at 2km coincide with peaks in submassive coral.

The other group of interest to this study are Gobies (Gobiidae), as they are known to be silt bottom dwelling and burrowing fish. Indeed, their greater abundance at both survey depths, south of the river (table 8.1) highlights an affinity with higher sediment loads. However, it is suspected that this family is underrepresented because of their timidity, camouflage and rapid movement (Allen and Steene, 1998).

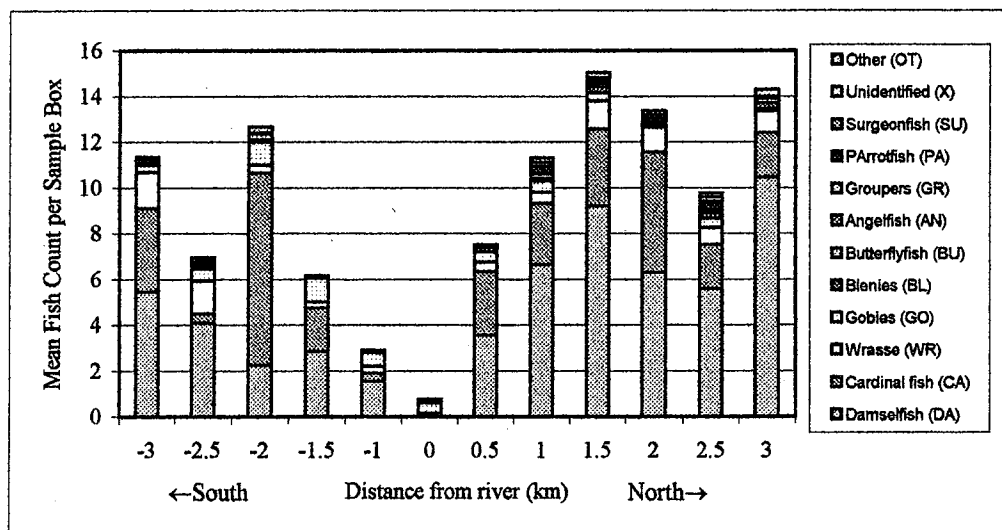


Figure 8.1. Variations in mean fish composition at 3m.

Furthermore, although there are no significant correlations between coral and fish diversities (in either direction or at either depth), there are positive correlations between diversity of coral forms and abundances of fish. These correlations

coefficients of 0.74: north and 0.58: south support the work of Barbault (1992) who demonstrated that highly complex reef environments are the key to providing a variety of habitats capable of supporting many species. Similar relations have been found by Luckhurst and Luckhurst (1978), Talbot *et al.* (1978), Gladfelter *et al.* (1980), Carpenter *et al.* (1981), Sano *et al.* (1984, 1987), Hixon and Beets (1989), Grigg (1993), Galzin *et al.* (1994). However, Risk (1972) found no correlation between habitat complexity and fish abundance and/ or diversity, while Chabanet (1997) suggests that these inconsistencies can be attributed to geomorphological, ecological and methodological factors.

8.2 Seven metre survey

The three families already discussed are the most abundant south of the Bureta River at 7m. The tolerance of gobies to sediment rich environments is particularly well illustrated in figure 8.2 This also shows Damselfish as the dominant family North of the river, the decrease in total fish abundance with distance south (Pearson's: -0.96) and the rapid drop in abundance at 3km north.

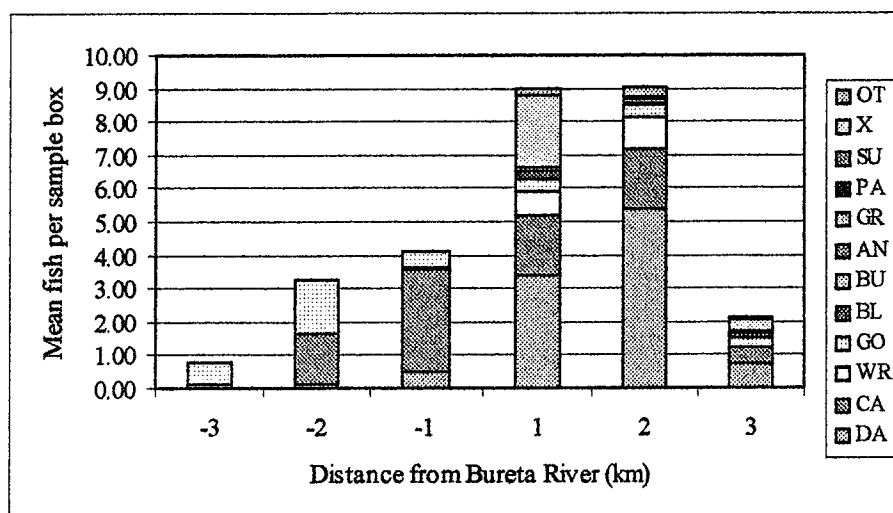


Figure 8.2 Variations in mean fish composition.

Depth (m)	North	South
3	0.34	0.65
7	0.33	0.93

Table 8.1 Comparison of mean Goby (Gobiidae) abundance per survey direction.

8.3 General Discussion

Direct effects of sedimentation on fish populations are not widely documented. However, Roger (1990) highlights that the death of major reef building corals, due to sedimentation (or other causes) can lead to a reduction in habitat diversity and therefore fish abundance and diversity. Sano *et al.* (1987) founds greater abundance and diversity on living coral (*Acropora spp.* mainly) than on primarily dead coral, and a greater decline 2 years later when it had turned to rubble. Similarly, van Katwijk *et al.* (1993) observed siltation as having an impact on fish densities at Malindi-Watamu reefs in Kenya. The results from the present 3m surveys (and to a lesser extent the 7m survey) agree with these findings. Therefore, it can be speculated that differences in mean fish populations are indirect consequences of variations in environmental parameters; linked by the adverse effects fluvial discharge has on structural complexity and habitat diversity.

Chapter 9 Conclusions

9.1 Site Specific Conclusions

With respect to the Bureta River, the characteristics of the marine basin have a considerable influence upon the development and health of coral reefs. Furthermore, it is the complexity of the systems involved here and in coral reef development that makes successful quantification so difficult.

However, the following key characteristics can be identified from the study: -

- i) At a coral colony scale, individual morphology is an influential factor in determining the coral colonies passive sediment rejection ability, and therefore its abundance.
- ii) These results lend support to the theory that complex reef structures sustain high fish abundances. However, the analysis of both reef structure and fish taxa were not detailed enough to carry out effective analysis between coral diversity and fish diversity.
- iii) Reef morphology and sediments are suspected to act in a negative feedback mechanism, whereby poor vertical reef development hinders the ability of the reef system to reject further sediment deposition, which in turn limits vertical reef growth, and so on.
- iv) Seven metres was observed to be the approximate depth limit of coral development. This may be due to a combination of shallow marine bathymetry and reduced light penetration due to suspended sediments.
- v) Environmental parameters do not vary in synchrony throughout the basin. The spatial heterogeneity of the parameters is thought to be a function of the characteristics of the individual parameter and the basin.
- vi) The island and reef mass has a considerable influence upon the distribution of suspended and deposited sediments and therefore the development and health of reefs.
- vii) Variations in reef health north of the river vary in a relatively simple and predictable manner when compared to the complex system operating to the south of the river.

- viii) There are strong positive correlations between coral and fish abundances and distance in both directions at three metres. The opposite was true for both coral and fish at seven metres.

The influence of environmental parameters upon morphological variations justifies continued investigation into the response of taxonomic groups to different conditions. Analysis on this scale, including algal and interspecies coral competition are the foundations for understanding morphological variations in coral reefs.

9.2 Applications of the research

As a comparative tool for future work, it could be argued that this study would be ineffective because characteristics of the marine- (E.g. the reef/ island restriction and tidal movements) and terrestrial basin (E.g. the irregular caldera based catchment) are exceptional. However, to a certain extent this is true for all basins as no two marine or terrestrial environments will be identical. However, this research paper will form a useful comparator to other reef systems as: -

- i) to the best of my knowledge it is the first of its type in the South Pacific, to be studied; geology, climate and reefs are different from many other, well-documented reef supporting areas, such as the Caribbean, Central America and the Red Sea.
- ii) the fluvial input is relatively stable. The two key anthropogenic impacts, agriculture and urbanisation are both limited by the availability of flat land.
- iii) the research was carried out on a small scale. Analysing one river is a useful comparative scale for further undergraduate or more extensive research.

Another crucial step in reef analysis of this type involves detailed understanding of temporal changes. It is evident from the shortfalls of this project that sampling of this sort should be carried out over longer timescales, and although this is often not logistically possible, it would substantially improve the quality of analysis.

This study also highlights the potential applications of reef analysis in identifying changes within the terrestrial basin. For example, landuse related increases in

sediment discharge and the decline in coral due to smothering, or increases in macroalgae due to anthropogenic changes in water chemistry.

9.3 Global Environmental Change and Coral Reefs

Within the scale of global environmental change, the issues raised in this study should be considered within their terrestrial and marine contexts. There are two key questions in addressing the changes in terrestrial influence. Firstly, will global climatic warming cause an increase in precipitation and subsequent fluvial discharge? Secondly, will these changes have a positive or negative influence upon reef systems?

In the event of increased precipitation, reefs may benefit from the cooling effect of fluvial discharge, but I suspect they are more likely to suffer from increased sediment loads. More extensive projects based on the same aims as the present study, may be one way of understanding and modelling reef characteristics and potential future changes.

Within the marine environments, the key question is whether sea level and temperature rise will change the interactions between fluvial discharge and reef composition? From observations on other Fijian reefs (north-east Ovalau and Beqa lagoon) the bleaching events of the past two years have already had devastating effects upon the reef communities while, generally speaking, there was little evidence of rapid or recent destruction in the study area. Therefore fluvial discharge, although ultimately a negative influence on coral development, may be able to suppress the 'bleaching' effect. It is definitely holds potential as an avenue for further research.

The ambitious task that will yield answers to these questions requires the mapping and modelling the impacts of environmental parameters on reef composition and health in four dimensions: longitude, latitude, depth and time.

9.4 Limitations

- i. As discussed in section two, the environmental parameters recorded are an inadequate sample of the conditions throughout the water column. These results are also only a 'snapshot' of the conditions affecting these reefs, and while they may successfully represent conditions for the Fijian winter, they are

likely to under represent the high level of fluvial runoff associated with the 'wet season'.

- ii. Seven metres depth at 'site 0' and three metres depth at 0.5km south could not be located due to irregularities in the estuarine bathymetry.
- iii. Although all steps had been taken to memorise and test the identification of different coral morphologies, in poor visibility (as low as 0.5m) consistency in identification between the three coral surveyors could not be guaranteed. Similarly, in poor visibility communication between the identifying diver and the recording diver was difficult.
- iv. Daily survey duration was limited to approximately four hours by the tidal depth variations in the Bureta River, which was the only route to survey sites.
- v. Surveying was highly dependent upon our ability to compress air for diving cylinders and because there was no compressing shelter this relied upon regular good weather.

Acknowledgements

For their continued support and academic advice throughout all stages of the expedition, we thank S. Rice, G. Masselink, J. Lee and I. Reid of Loughborough University; A. Harborne from Coral Cay Conservation and K. Teleki from the Cambridge Coastal Research Unit.

We would also like to thank the University of South Pacific for their co-operation and support, in particular; P. Nunn and M. Ferland for providing essential information during planning, R. South and J. Seeto for their help and sample identification and S. Lavaki for his logistical support.

We are indebted to R. Howorth, G. Frost, S. Sharma and R. Smith at The South Pacific Geoscience Commission (SOPAC) for providing technical equipment at short notice, which greatly increased the value and accuracy of our results.

Our greatest logistical assistance came from J. Kureleca, D. Kirton and N. Dehn all based on Ovalau Island. Thanks to the inhabitants of the Bureta area for making us welcome and helping in any way they could.

This research expedition was supported by funds from A.P. Information Services, Cambridge University Commonwealth Fund, Cambridge University Expedition Trust, The Edinburgh Trust (No.2), Geoffrey Osbornes Ltd., The Gilchrist Educational Trust, Holdworth Food Services, The Isaac Newton Trust, Kenwright and Lynch Solicitors, Loughborough University Ede and Ravenscroft Prize, PADI Project Aware, Queens College Cambridge, Reef Conservation UK, The Royal Geographical Society (with Institute of British Geographers) and TSC Consultant Engineers.

References

- Adjeroud, M. (1997). Factors influencing spatial patterns on coral reefs around Moorea, French Polynesia. *Marine Ecology- Progress Series*, 159: 105-119.
- Allen, G. R. and Steene, R. (1998). *Indopacific coral reef field guide*. Topical Reef Research, Singapore.
- Babcock, R. and Davies, P. (1991). Effects of sedimentation on settlement of *Acropora millepora*. *Coral Reefs*, 9: 205-208.
- Bak, R. P. M. and Elgershuizen, J. H. B. W. (1976) Patterns of oil sediment rejection in corals. *Mar. Biol.*, 37: 715-730.
- Barbault, T. R. (1992) Hétérogénéité spatiale, variabilité temporelle et peuplements. *Ecologie des peuplements: structure, dynamique et evolution*, Masson: p141-163.
- Barnes, D. J. and Lough, J. M. (1999). Porites growth characteristics in a changed environment: Missima Island, Papua new Guinea. *Coral Reefs*, 18: 213-218.
- Berner, T. (1990) Coral-reef Algae. In: Dubinsky, Z. (ed) *Ecosystems of the world 25, Coral Reefs*, Elsevier, Amsterdam, p253-264.
- Blake, S. G. (1997). Distribution of sediments and nutrients throughout the Whitsunday Islands inner shelf region, Great Barrier Reef. *Great Barrier Reef Symposium 1997*. Australian Institute For Marine Sciences.
- Brower, J. E. and Zar, J. H. (1997). *Field and laboratory methods for general ecology* (2nd edition). Brown Co. Publishing.
- Bruckner, A. W., Bruckner, R. J. and Williams, E. H. (1997). Spread of black band disease epizootic through the coral reef system in St. Ann's Bay, Jamaica. *Bulletin of Mar. Sci.*, 61: 919-928.
- Burns, T. P. (1983). Hard Coral Distribution and coldwater disturbances in South Florida: variations with depth and location.
- Carpenter, K. E., Miclat, R. I., Albaladejo, V. D., Corpuz, V. T. (1981). The influence of substrate structure on the local abundance and diversity of Philippine reef fish. *Proc. 4th Int. Coral Reef Symp.*, 2: 497-502.
- Chabanet, P., Ralambondrainy, H., Amanieu, M., Faure, G., Galzin, R. (1997). Relationships between coral reef substrata and fish. *Coral Reefs*, 16:93-102.
- Dodge, R. E., Aller, R. C., Thompson, J. (1974). Coral growth related to resuspension of bottom sediments. *Nature*, 247: 574-577.
- Dubinsky, Z. (ed) (1990). *Ecosystems of the world 25: Coral Reefs*. Elsevier, Amsterdam.
- Edinger, E. N., Risk, M. J. (2000). Reef classification by coral morphology predicts coral reef conservation value. *Biological Conservation*, 92: 1-13.
- Edmunds, P. J. (1999). The role of morphology and substratum inclination in the success of *Millepora alcornis* on a shallow coral reef. *Coral Reefs*, 18: 133-140.
- English, S., Wilkinson, C. and Baker, V. (1997). *Survey manual for tropical marine resources*, 2nd edition. Australian Institute for Marine Sciences, Townsville, Australia.
- Galzin, R., Planes, S., Dufour, V., Salvat, B. (1994). Variations in diversity of coral reef fish between French Polynesian atolls. *Coral Reefs*, 13: p.175-180.
- Gilmour, J. (1999). Experimental investigation into the effects of suspended sediment on fertilization, larval survival and settlement in a Scleractinian coral. *Marine Biology*, 135: 451-462.
- Gladfelter, W., Ogden, J., Gladfelter, E. (1980). Similarity and diversity among coral reef communities: a comparison between tropical western atlantic (U.S.V.I.) and tropical central pacific (Marshall Is.) patch reefs. *Ecology*, 61 (5): p.1156-1168.
- Goldman, B., Talbot, F. H. (1976). Aspects of the ecology of coral reef fishes, in Jones, O. A., Endean, R. (eds) *Biology and Geology of Coral Reefs*, Vol 3, Biology 2. Academic Press, NY: p.125-154.

- Grigg, R. W. (1993) Effects of sewerage discharge, fishing pressure and habitat complexity on a coral reef ecosystem in Hawaii. Proc. Int. Symp. On Biodiversity and Adaptive Strategies on Coral Reef Organisms, Japan, Abstr.
- Guilcher, A. (1988). Coral reef geomorphology. John Wiley and Sons.
- Hixon, M. A. and Beets, J. P. (1989) Shelter characteristics of Caribbean fish assemblages: experiments with artificial reefs. Bulletin. Mar. Sci., 44: p.666-680.
- Hodgson, G. (1990). Sediment and settlement of larvae of the reef coral *Pocillopora damicornis*. Coral Reefs, 9: 41-43.
- Hoek, C. van den, Breeman, A. M., Bak, R. P. M., van Buurt, G. (1978) The distribution of algae, corals and gorgonians in relation to depth, light attenuation, water movement and grazing pressure in the fringing coral reef of Curacau, Netherland Antilles. Aquat. Bot., 5: 1-46.
- Hubbard, D. K. (1986). Sedimentation as a control of reef development: St Croix, U.S.V.I. Coral Reefs, 5: 117-125.
- Hubbard, D. K., Stump, J. D., Carter, B. (1986). Sedimentation and reef development in Hawkesnest, Fish and Reef Bays, St. Johns, U.S. Virgin Islands. Biosphere reserve research report 21. Virgin Island Resource. Management co-operative/ National Park Service: p1-99.
- Jones, R. and Pinheiro, L. (1997) Fiji. Lonely Planet Publications, Australia.
- Kinsman, D. J. J. (1964) Reef coral tolerance of high temperature and salinities. Nature, 202: 1280#####.
- Larcombe, P. and Woolfe, K. J. (1999) Increased sediment load to the great Barrier Reef will not increase sediment accumulation at most coral reefs. Coral Reefs, 18: 163-169.
- Lewis, J. B. (1974). The settlement behaviour of planulae larvae of the hermatypic coral *Favia fragum* (Esper). J. Exp. Mar. Biol. Ecol., 15: 165-172.
- Luckhurst, B. and Luckhurst, K. (1978). Analysis of the influence of substrate variables on coral reef communities. Mar. Biol., 49: 317-323.
- Maragos, J. E. (1972). A study of the ecology of Hawaiian reef corals. PhD disseration, University of Hawaii, Honolulu.
- McCloskey, L. R., Wethey, D. S., Porter, J. W. (1978). Measurement and interpretation of photosynthesis and respiration in reef corals. In Stoddard, D. R. and Johannes, R. E. (eds) Coral Reefs: research methods. UNESCO, Paris: p379-396.
- McCook, L. J., Price, I. R., Klumpp, D. W. (1997) Macroalgae on the Great Barrier Reef: causes or consequences, indicators or models of reef degradation? Proc 8th Int Coral Reef Symp 2: 1851-1856.
- Mitchell, A. W. and Furnas, M. J. (1997). Terrestrial input of nutrients and suspended sediments to the Great Barrier Reef lagoon. Great Barrier Reef Symposium 1997. Published by Australian Institute For Marine Sciences
- Morrissey, J. (1980). Community structure and zonation of macro algae and hermatypic corals on a fringing reef flat of Magnetic Island, Queensland, Australia. Aquat. Bot., 8:91-139.
- Nunn, P. (2000). Coastal Changes over the past 200 years around Ovalau and Motoriki islands, Fiji: implications for coastal zone management. Australian Geographer, Vol 31, No.1: 21-39.
- Nunn, P. (2000). Significance of emerged Holocene corals around Ovalau and Motoriki Islands, Fiji, South West Pacific. Marine Geology, 163 (2000):345-351.
- Nystrom, M., Moberg, F., Tedengren, M. (1997). Natural and anthropogenic disturbance on reef corals in the inner gulf of Thailand: physiological effects of reduced salinity, copper and siltation. 8th International Coral Reef Symposium, 2.
- Peters, E. C. and Pilon, M. E. Q. (1985). A comparative study of the effects of sedimentation of symbiotic and asymbiotic colonies of the coral *Astrangia danae* (Milne, Edwards and Haime, 1847).

- J. Exp. Mar. Biol. Ecol., 92: p215-230.
- Randall, R. H. and Birkeland, C. (1978). Guam's Reefs and Beaches, Part II. Sedimentation studies at Fouha and Yling Bays.
University of Guam Marine Laboratory Technical Report, 47: p1-77.
- Richardson, L. L. (1998). Coral Disease: what is really known?
T.R.E.E., 13, no. 11:438-443.
- Richmond, R.H. (1992), Effects of coastal runoff on coral reproduction.
Mar. Ecol. Prog. Ser., 60: 185-203.*
- Risk, M. J. (1972) Fish diversity on a coral reef in the Virgin Islands. Atoll. Res. Bulltein, 193: 1-6.
- Roberts, C. M. and Ormond, R. F. G. (1987). Habitat complexity and coral reef diversity and abundance on Red Sea fringing reefs.
Marine Ecology-Progress Series, Vol. 41: 1-8.
- Ryland, J. S. (1981). Introduction to the coral reefs of Fiji.
South Pacific Journal of Natural Sciences, Vol 2: 44-51.
- Sano, M., Shimizu, M., Nose, Y. (1984) Changes in the structure of coral reef fish communities by destruction of hermatypic corals: observational and experimental views.
Pacific Sci., 38: 51-79. (from Roberts and Ormond paper)
- Sano, M., Shimizu, M., Nose, Y. (1987) Longterm effects of destruction of hermatypic corals by *Acanthaster Planci* infestation on reef fish communities at Iriomote Island, Japan. Mar. Ecol. Prog. Ser., 37: 191-199.
- Sato, M. (1985). Mortality and growth of juvenile coral *Pocillopora damicornis* (Linnaeus).
Coral Reefs, 4: 27-33.
- Stafford-Smith, M. G. and Ormond, R. F. G. (1992). Sediment rejection mechanisms of 42 species of Australian Scleractinian corals.
Australian J. Mar. Freshwater Resources, 43:683-705.
- Stromgren, T. (1987). The effects on light on the growth rates of *Acropora Pulchra* (Brook) from Puket, Thailand.
Coral Reefs, 6: 43-47.
- Te, F.T. (1992). Response to higher sediment loads by *Pocillopora damicornis* planulae.
Coral Reefs, 11: 131-134.
- Umar, M. J., McCook, L. J., Price, I. R. (1998). Effects of sediment deposition on the seaweed *Sargassum* on a fringing coral reef.
Coral Reefs, 17: 169-177.
- Zann, L. P. (1994). The status of coral reefs in the South-West Pacific islands.
Marine Pollution Bulletin, 29, No's. 1-3: 52-61.

Useful Contacts

Professor Patrick Nunn,
Department of Geography,
University of South Pacific,
Suva, Fiji.
Email: nunn_p@usp.ac.fj

Notes: Extremely helpful coastal geomorphologist with good knowledge of Ovalau. Head of USP Geography Department.

Sunia Lavaki
Chief Technician,
Marine Studies Programme,
University of South Pacific,
Suva, Fiji.
Email: lavaki_sb@usp.ac.fj

Notes: In charge of USP boats, diving equipment, etc. Good for logistical consultation.

Malcolm Russell,
Second Secretary,
British High Commission,
Suva, Fiji.
Tel: 00 679 311 033
Fax: 00 679 301 406

Notes: Able to advise of political situation in Fiji. Will be able to provide evacuation support in case of emergency.

Insurance:
AON Risk Services,
Richmond House,
College Street,
Southampton,
Hampshire,
SO14 3PS.
Tel: 01703 607 518

Notes: RGS recommended expedition insurance company.

Travel arrangements:
Contact: Jim Hooper.
Travelbag plc., 3-5 High Street,
Alton.
GU34 1TL.
Tel: 01420 88724 x2226.

Air New Zealand Inquiries: 0208 741 2299

Foreign and Commonwealth Office, London.
Tel: 020 7238 4446
Fax: 020 7238 4531
<http://www.fco.gov.uk>

Notes: Able to offer travel advice on any area of the world.

Alistair Harborne,
Coral Cay Conservation and Reef Conservation UK contact,
154 Clapham Park Road,
London,
SW4 7DE
Tel: 020 7498 6248
Fax: 020 7498 8447
Email: arh@coralcay.org
[http:// www.coralcay.org](http://www.coralcay.org)

Notes: Well-developed 'ecotourism' company. Good collection of coral literature and able to offer logistical advice.

Australian Institute of Marine Sciences,
P.M.B. No. 3, Townsville Mail Centre, Qld, 4810, Australia
<http://www.aims.gov.au>

Notes: Publish AIMS Manual- essential reading for any tropical marine survey work.

Cambridge Coastal Research Unit,
Department of Geography,
University of Cambridge,
Downing Place,
Cambridge,
CB2 3EN.
Tel: 01223 333399
Fax: 01223 355674
www.geog.cam.ac.uk

The expedition Advisory Centre,
The Royal Geographical Society (with Institute of British Geographers),
1 Kensington Gore,
London, SW7 2AR.
Tel: 020 7591 3070
Fax: 0207591 3071
info@rgs.org

Notes: An essential contact for expedition planners. Logistical help. Largest private map collection. Large collection of past expedition reports. Excellent organisation to be endorsed by. Host the Expedition Planners Forum: November each year.

Russell Howorth,
Acting Director,
The South Pacific Geoscience Commission,
SOPAC Secretariat,
Private Mail Bag, GPO,
Suva, Fiji.
Russell@sopac.org
www.sopac.org.fj

Notes: Advanced, well-equipped and extremely helpful organisation. Carry out research on many aspects of coastal and terrestrial geography in most south pacific nations.

International Coral Reef Initiative
<http://www.coral.aoml.noaa.gov/icri/icri/html>

Marine Conservation Society

<http://www.mcs.org>

Notes: well established organisation, able to provide info and guidance.

Suzanne Pleydell,

Director,

PADI Project Aware (UK),

Unit 7, St Philips Central,

Albert Road, St. Philips,

Bristol, BS2 0PD.

<http://www.padi.co.uk>

Notes: Project developed to increase knowledge and awareness of coral reefs.

Ovalau Reef Expedition Accounts Summary

Simon Philipp.

income			Expenditure		
				£	F\$
Grants		£	Pre expedition		
RCUK		250	flights	3631.5	
RGS		750	Insurance	705.01	
Queens College		50	Medical kit	60	
Loughborough University aw		500	equipment	101.36	slate, line, stationary
CEF		250	admin	47	CEC, website
Edinburgh Trust		300	t-shirts	105	
Isaac Newton award		200			
Gilchrist Award		500	Expedition		
Commonwealth Trust		400	USP Kit	1392.8222	£1000 travellers cheques + F\$1200
Lindeth Charitable trust		100	Boat and fu	417.68787	
PADI AWARE		1600	Accomodat	176.63906	
			Employmer	222.59926	Jake
			other equip	163.67593	Manassa generator and Noby kit
Companies			Food	560.20378	
A P I S		750	Gifts	113.49289	
TSC		100	Transport	61.542149	flight, carriers, taxi
Keryl Lynch		300	Other	80.528556	map.admiralty chart, phonecalls, permits, photocopying
Holdsworth Food		100			
building company		250	Post Expedition		
Nedas contact		50		250	
Personal		4081.5			
Interest		0.85			
TOTAL		10532.35	TOTAL	8089.0617	note this does not include £85.51 for int flights
			Difference	2443.2883	
Money Owed to people			money owe totals		
RB	681.186619		RB	681.18662	
SP	-855.12		SP	-837.88	
SP	-42.76	flight	CH	62.25	
SP	60	paid for MIK / JO flight changes	Neda	60	
CH	105	t-shirts			
CH	-42.75	flight			
NEDA	60	medical kit			
	-34.443381				
money in account		1058			
PADI		1600			
owed		34.44			
post expedition		-250			
final balance		2442.44			
Personal contributions			total to be paid after taking into account owed		
Mik / Jo	1502.6	852.6		852.6	
Rich	1001.3	676.3		1357.4866	
Si	776.3	451.3		-386.58	
Kat	751.3	426.3		488.55	
		2406.5			
I.e should leave approx £35 spare + £250 for reports and photos					