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THE EFFECTS OF EUTROPHICATION ON REEF HEALTH

THE EFFECTS OF EUTROPHICATION ON REEF HEALTH; A STUDY IN ZANZIBAR, TANZANIA

THE EFFECTS OF EUTROPHICATION ON REEF HEALTH; A STUDY IN ZANZIBAR, TANZANIA

by

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ABSTRACT

A study of two shallow fringing reefs off the coast of Zanzibar Island was conducted. The study site was Grave Island, 1 km off the shore of Zanzibar town. The comparison site was Chumbe Island, 10 km upcurrent of the town, adjacent a less densely inhabited coast. The major anthropogenic stress on these reefs could be considered nutrient loading from sewage discharge.

Studies of the sea urchin *Diadema setosum*, indicated mean densities at Grave Island of 6.4 urchins/m^2 and 1.2 urchins/m^2 at Chumbe Island. Urchin densities comparable to those at Grave Island have been related to overfishing and reduced coral recruitment. Coral associate densities were also considered with a mean density of 87/m^2 at Grave Island and 31/m^2 at Chumbe Island. High coral associate densities have been linked to structurally and physiologically weakened coral.

Transect studies were conducted and suggested there were significantly reduced coral cover and reduced amounts of live coral at Grave Island (cf Chumbe Island). As well, coral species diversity was significantly lower at Grave Island than at Chumbe Island. Lowered species diversity suggests an unstable community structure, and reduced coral cover may indicate a faltering reef.

Stable Isotope studies were conducted on tissue samples from both sites. They showed no significant difference.

This study reflects the poor health of Grave Island. The high abundance of urchins and filter feeders, combined with reduced coral cover and diversity, suggest high nutrient loading on these reefs. The high abundance of urchins and associates also suggest coral mortality will be high and recruitment low. If these trends continue, it is unlikely the reef at Grave Island will be able to survive.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

LIST OF FIGURES

FIGURE

LIST OF TABLES

TABLE

LIST OF PLATES

PLATE

INTRODUCTION

1.1 INTRODUCTION

In Zanzibar Town, approximately 80,000 people live in about 10 square kilometres. This provides considerable anthropogenic stress to the marine habitat off Zanzibar's shores. Other coastal regions of Zanzibar are less densely inhabitated. Zanzibar is an ideal location to study reef health, focusing on anthropogenic stress.

The location of the study dictated the use of relatively low technology field work, focusing on biodiversity and coral growth rates. Samples for stable isotope analysis were collected and returned from Zanzibar for processing. The combination of these techniques gives a well-balanced cross section of the reef life in Zanzibar.

Corals provide the ideal "tape recorder" for the physical and chemical changes in their environment, both from their tissues and skeleton and from the animals associated with them. For this reason they were the primary focus of this study.

1.2 SITE LOCATION AND SETTING

The majority of East African reefs are shallow fringing reefs, forming a nearly continuous band from the equator to almost 14°S (Hamilton and Brakel, 1984). The modern reefs rest on a shelf of uplifted Pleistocene reefs. The current reef level is a function of sea level, physical and chemical erosion (Hamilton and Brakel, 1984). Zanzibar is a large island, approximately 100 km offshore from Tanzania, lying slightly south of 5°S, and being itself 90 km

Figure 1.1 - Part of the East African Coast, showing the location of Zanzibar Island (from Martin, 1978)

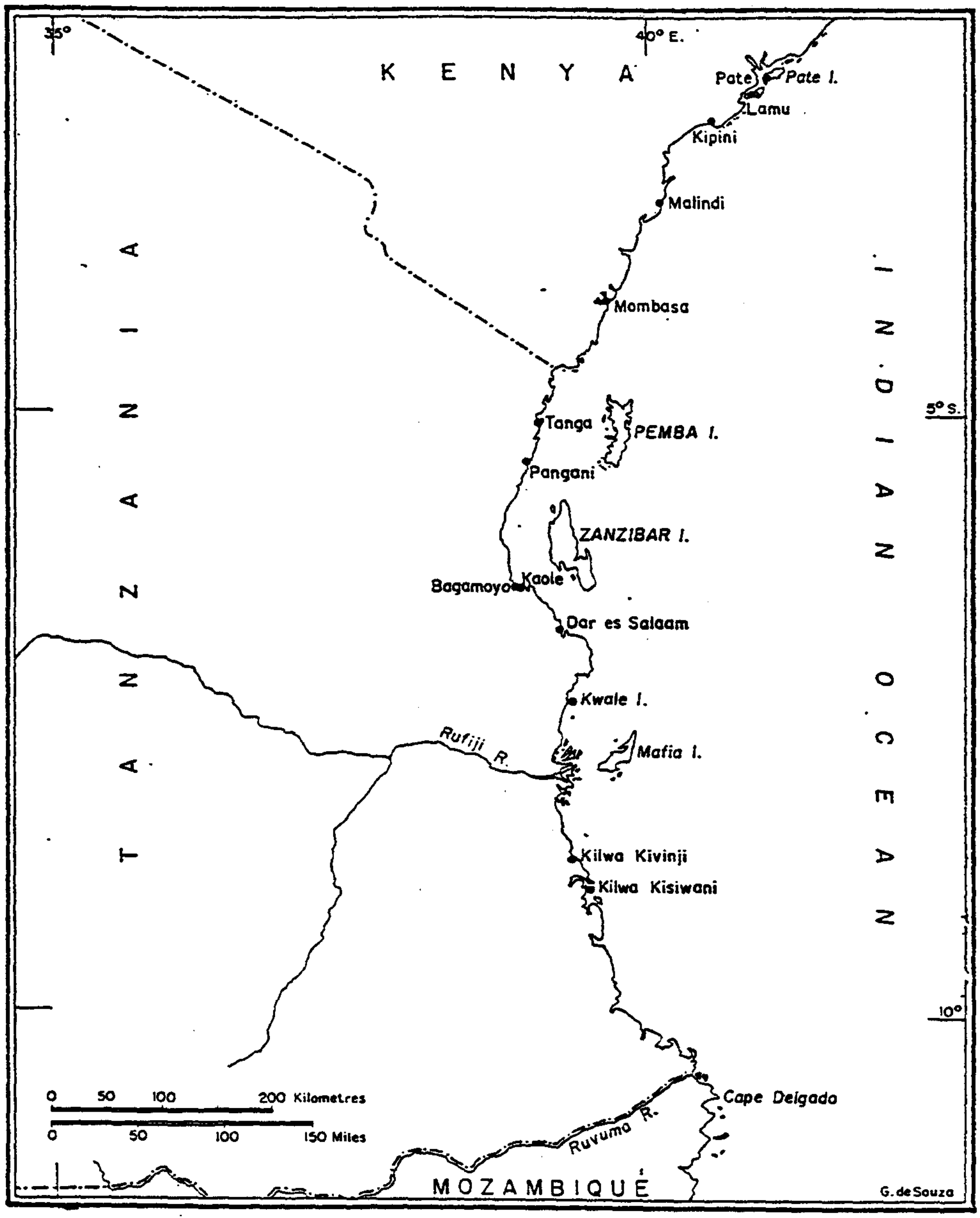
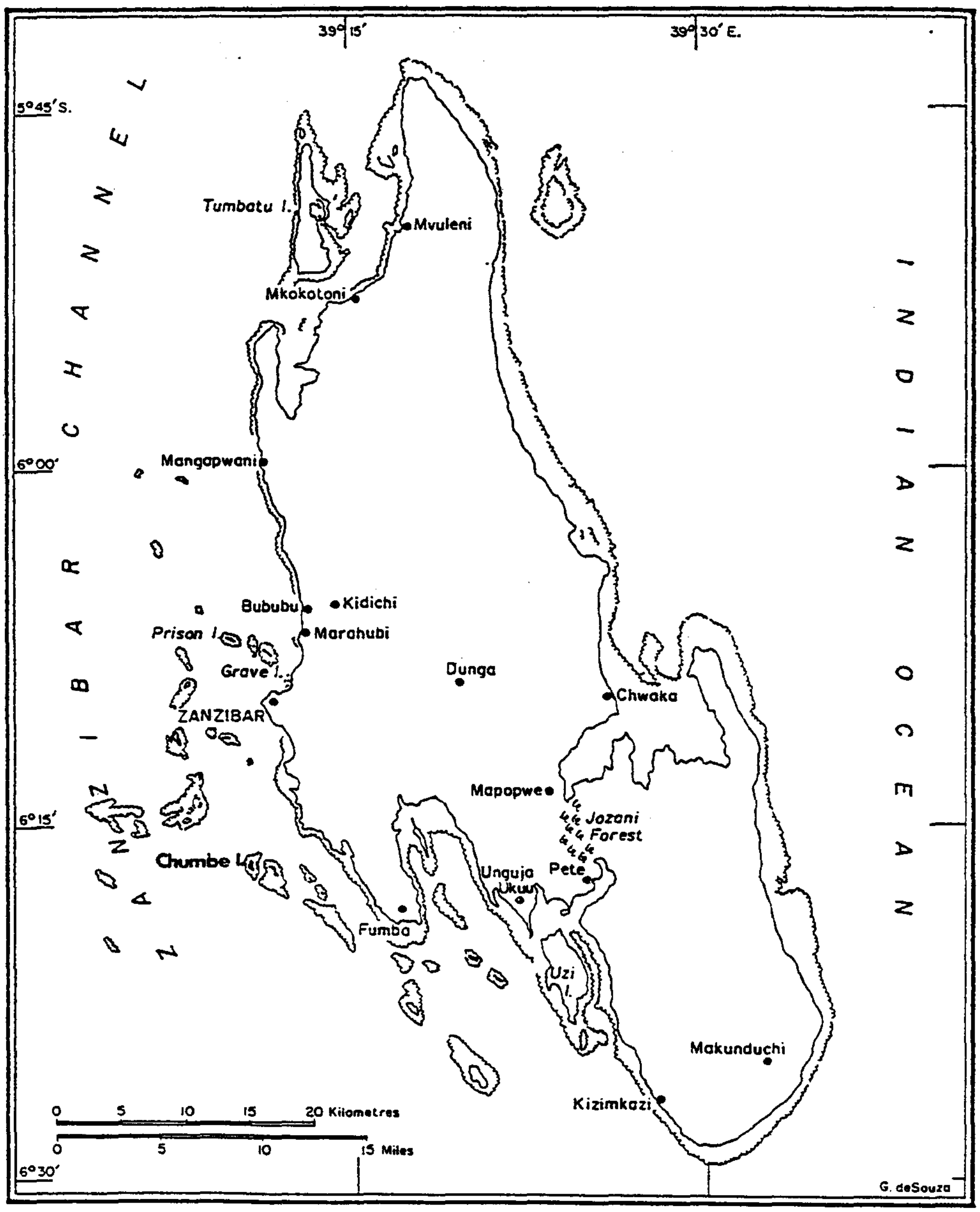


Figure 1.2 - The Island of Zanzibar, showing the study islands of Chumbe and Grave (from Martin, 1978)



long North to South (Pritchard, 1962). Zanzibar, as well as the numerous tiny islands off its coast, is an example of the uplifted Pleistocene reef typical of East Africa.

This study focuses on two tiny islands off the west coast of Zanzibar island. One island, Grave (Chapani) Island, lies 1 km off Zanzibar town. The second island, Chumbe Island, lies approximately 10 km south of the town of Zanzibar, off a sparsely inhabitated section of coast. The position of the small islands between Zanzibar and the mainland places them well within the continental shelf. The water supply to these reefs is driven by surface currents, which flow from the South South East in July and August, driven by winds (Wyrtki, 1973).

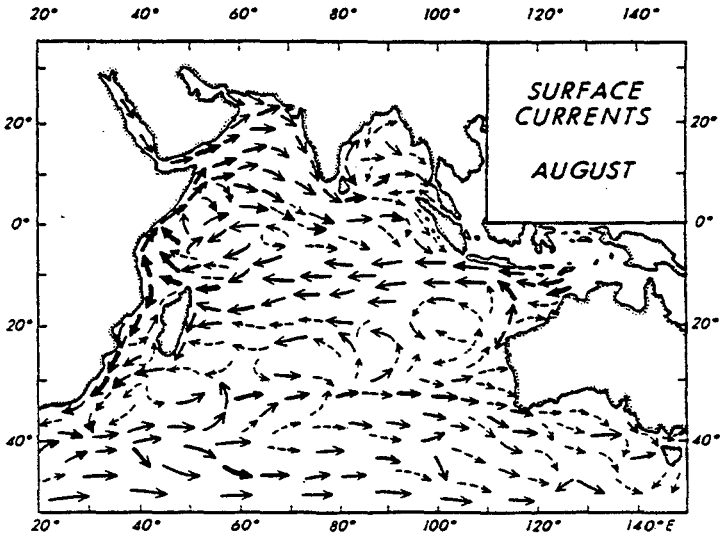


Figure 1.3 - Surface currents of the Indian Ocean in August (from Wyrtki, 1973)

This means that any water supply that Chumbe Island receives will be relatively uncontaminated by human habitation, whereas the water received by Grave Island will be influenced by the town's effluent.

Both study islands had shallow northwest fringing reefs, ranging from 3 m to 12 m in depth at high tide. The region has a 1.7 m to 1.8 m dynamic range in sea level during July and August (Wyrtki, 1973), leaving the reefs within 1 m of the water's surface during low tide. The reefs were studied using SCUBA between 10:00 and 16:00, usually high tide, at depths ranging from 4 m to 7.5 m. The underwater visibility at Chumbe was approximately 10 m while at Grave the visibility was about 4.5 m. Given the shallow depth of these reefs, however, the lowered visibility at Grave probably does not represent a light limiting stress on the corals. The visibility differences do suggest a phytoplankton bloom at Grave Island, however, a possible eutrophic indicator as will be discussed later. Salinity for the region is 35.1 ppm, and the mean temperature is 26°C; these figures are well within coral tolerances (McGill, 1973).

The similarity of the settings of Grave Island and Chumbe Island suggest they are comparable sites for coral and reef development. Any differences which arise, may be tentatively attributed to the effects of human habitation.

1.3 FACTORS AFFECTING REEF HEALTH

Siltation stress is likely low, as both islands are low lying and well vegetated, as is the main island of Zanzibar. Pollution by heavy industry (including thermal and chemical pollution) is also a negligible concern, in the relatively low technology town of Zanzibar. Overfishing is a valid concern, considering the dependence of the people on the local reefs for their major food source. Overfishing tends to disrupt the natural balance of the ecosystem, allowing algae blooms, an increase in sea urchins (McClanahan and Shafir, 1990) and a general decrease in species diversity.

The most severe threat to the reefs of Zanzibar is eutrophication, resulting from an excess of sewage (brought to the reefs via the town's effluent). A eutrophic system has been defined by Hutchinson (1970) as one in which the potential concentration of nutrients is high, although their apparent concentration in the water may be low. Reefs are typically nitrogen and phosphorous limited (Endean, 1976; Schlesinger,1991), and increases in dissolved nutrients typically lead to an increase in algal growth and reduction in coral cover (Endean, 1976).

Although corals can absorb nutrients directly across their tissues (Muscatine, 1973) the increase in nutrients is only an aid to the coral up to a certain maximum concentration (Tomascik and Sander, 1985). Above this, there will be algal blooms, resulting in lowered light levels to the coral as well as spatial competition between the slow growing corals and their more quickly growing neighbours (ie algae). The rapidly growing algae may tend to smother the coral (Tomascik and Sander, 1985) thereby weakening it and reducing its growth. The increase in nutrients may also cause a change in the benthic fauna and the overall community inhabiting the reef (Endean, 1976).

CHAPTER 2 - BIODIVERSITY

2.1 INTRODUCTION

Reefs are highly complex ecosystems, dependant upon species interaction for survival. In the natural system this balance may be disturbed by many factors, such as storms, phytoplankton blooms or disease. Human activities, however, may tend to enhance these imbalances, or possibly create devastating new effects on the ecosystem's inhabitants (Bryceson, 1981).

Keystone species are keys to the maintenance of balance in many ecosystems. Their numbers greatly affect the environment in which they live (Endean, 1976). It is possible, then, that disruption of even one species in an ecosystem may lead to decline. As McClanahan and Shafir (1990) noted, the removal of the fish family Balistidae (triggerfish) from Kenyan fringing reefs resulted in a serious imbalance in the urchin community, both in numbers and in species diversity. The removal of fish was a result of a serious overfishing problem, possibly also present in Zanzibar, especially at Grave Island.

When studying biodiversity, the mobile inhabitants of the reef should be considered. Fish are perhaps the most obvious inhabitants; however, their scarce numbers, multiple species and extreme mobility make them an impractical choice for a study such as this. An ideal choice would be a slow moving, easily identifiable species that is relatively common. For this reason the sea urchin, *Diadema setosum*, is an ideal choice as a representative species. The presence of high numbers of sea urchins has been correlated with lower hard coral cover, lower coral diversity and higher algal turf and sponge cover (McClanahan and Shafir, 1990). Urchins have also been noted to prey upon living coral (Bak and van Eys, 1975) and reduce coral recruitment (Sammarco,1982; Sammarco, 1980). Therefore, as well as providing absolute numbers, the sea urchins give us an idea of the state of the reef's health.

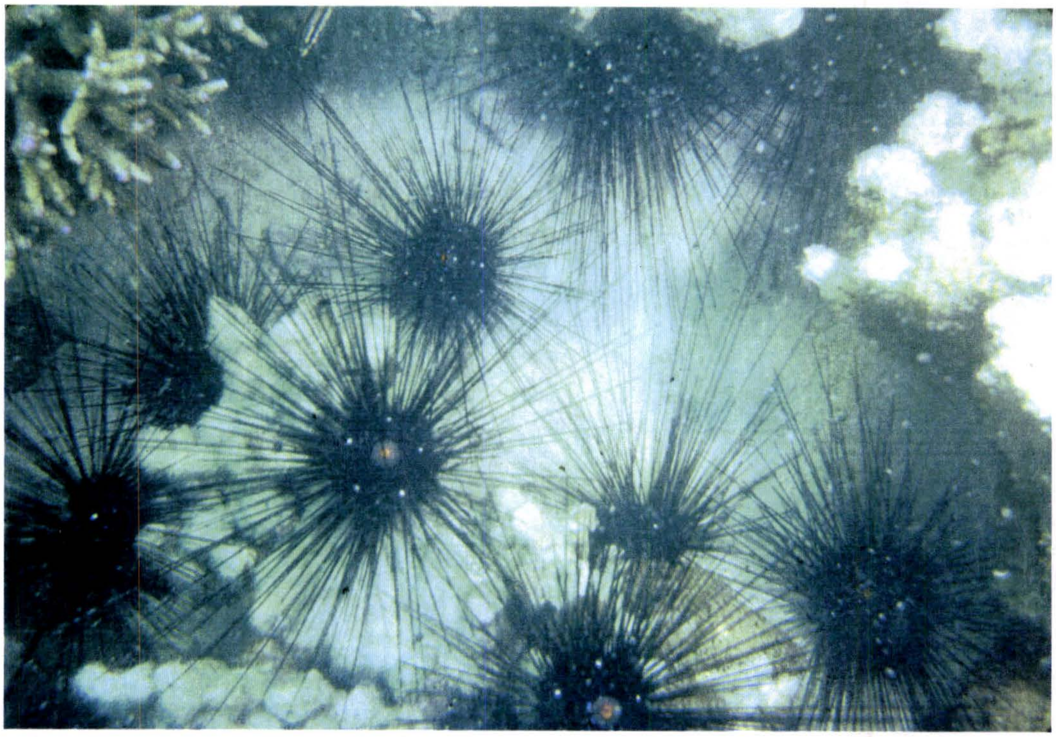
2.2 MATERIALS AND METHODS

2.2.1 SEA URCHINS

The sea urchins which inhabit the study areas are *Diadema setosum*, a long-spined echinoid native to the Indo-West Pacific region. The urchins are black with all black spines, orange/red anuses and five tiny blue dots rimming the anus (see plate 2.1). Their tests range in size from 30 mm to a maximum of 156 mm (Clark, 1976) with spines that may reach lengths up to 600 mm (Clark, 1976). Fortunately, at the study areas test diameter averaged 80 mm and spine length 200 mm.

These urchins are often troublesome to divers, as the spines will point in the direction of impending shadow (thus allowing more of their brittle, needle sharp spines to penetrate the feared attacker; Clark, 1976). This light sensitivity also supports suggestions that these urchins are primarily nocturnal, and will seek shelter in the day (Clark, 1976). Although the spine-pointing response was noted, there seemed to be urchins present on the reefs, at all times (possibly linked to lowered predation;

Plate 2.1 - Examples of the sea urchin species indigenous to the reefs in Zanzibar, *Diadema setosum*



McClanahan and Shafir, 1990). In order to avoid bias, all counts were done at the same time each day.

The urchins were counted using a one meter square quadrat constructed from PVC pipe. Urchins on the upper and left boundaries of the quadrat were not considered, whereas urchins on the lower and right boundaries were. The only urchins considered were ones with at least half of their tests within the quadrat. All urchins visible from a vertical position above the quadrat were considered, as well as those hiding underneath ledges and in crevasses.

The initial quadrat at every site was placed by throwing the quadrat from the boat. Subsequent placement involved rotation of the diver for a count of five, followed by five kicks in the resulting direction. The quadrat was then released and allowed to sink. The urchins were counted and recorded as number per square meter. Results are shown in Table 2.1.

2.2.2 CORAL ASSOCIATES

By nature, corals provide numerous temporary and permanent habitats for reef dwellers. Some of these inhabitants are harmless to the coral, other associates feed on the coral and destroy it, and still others inhabit the coral skeleton, weakening it (Patton, 1976). It is these latter associates which are of concern to reef health. A large number of associates may suggest the coral has become structurally and biologically weak.

The coral associates which were of concern in this study were those found commonly inhabiting the coral species *Porites lobata* (the coral species also used in this study for tissue samples and growth rates). These associates proved to be mussels, *Lithophaga*, vermetids, sabellids, serpulids, *Cliona*, and tunicates. The family Clionidae is a group of boring sponges which inhabit coral heads by chemically excavating cavities. Their absence from dead coral suggests a nutritional relationship with/on the coral (Patton, 1976). Serpulids are polychaetes (feather duster worms), and vermetids are gastropods. Both survive the death of the coral, suggesting that they use the coral only for shelter (Patton, 1976). Mussels were attached byssally to the corals' surface, though some appeared to be surrounded by the coral, perhaps as a result of coral growth. This was similar to some *Tridacna* specimens seen. *Lithophaga* are elongate bivalves which burrow into the coral head both physically and chemically; the only sign of their presence is the dumbbell shaped aperture left for their siphons (Patton, 1976). The presence of false floors found in their burrows suggest that the bivalve is an unwelcome inhabitant.

The associates considered here are all filter feeders, reliant on the water immediately around the coral head for food supply. Some rely on the coral itself, while others only use the coral for shelter. A large number of associates would suggest not only a weakened coral but a nutrient rich environment.

The associates were counted using the quadrat technique, as employed for the sea urchin counts. The quadrat used for the associates was one quarter of the area used for urchin counts (ie. 0.25 meters squared), as dictated by the size of the organisms in question. The method of placing the quadrats differed, as only *Porites lobata* heads were considered in the study.

2.2.3 TRANSECTS

In order to ascertain the diversity and amount of coral cover at each site, transects were conducted (Grassle, 1973). Linear transects have been shown to reflect accurately coral coverage on reefs (Chiappone and Sullivan, 1991).

Each transect was 20m long, and at least two randomly located transects were conducted at each site, with six sites at each island. From these transects, I obtained data on coral cover, live: dead ratios, and species diversity. Coral species diversity can be determined by considering the number of species encountered along each transect. A lowering in absolute amount of coral would suggest that success of coral larva as well as survival of coral colonies was being hampered.

2.2.4 STATISTICAL ANALYSIS

One Way Analysis of Variance (ANOVA) tests (with pooled standard deviations) were completed on between-site data. Various dive sites at each island were considered replicates. All statistics were completed through use of the computer software package Minitab.

2.3 RESULTS

Table 2.1 shows the urchin data collected at each study site. Density of sea urchins were significantly different between Chumbe and Grave Islands (one-way ANOVA $p<0.000$). Bar graphs of the data also show the difference (see figures 2.1 and 2.2), with the mean sea urchin density for Chumbe Island being 1.2 and for Grave Island 6.4 per square meter.

The coral associate data show a similar increase from Chumbe Island to Grave Island. The mean number of associates per square meter of *Porites lobata* was 36 at Chumbe and 87 at Grave Island. A one way ANOVA shows a significant difference with $p=0.000$. These differences were illustrated graphically in figures 2.3 and 2.4.

The transect data show a significant difference in coral species diversity ($p=0.000$), with the mean number of species 14.8 at Chumbe and 6.1 at Grave Island. A significant difference was also seen between total coral length and total amount of live coral at both sites, $p=0.000$ in both cases. There was little difference in the amount of dead coral between sites ($p=0.616$) which is to be expected with the high rate of bioerosion present at the Grave Island site, as indicated by the associate counts. The transect data are illustrated in Tables 2.3 and 2.4 and figures 2.5 through 2.8.

Table 2.1 - Sea Urchin Density per square meter. The difference between the two sites is significant (one-way ANOVA p<0.000).

Site	Chumbe	Grave
1	1.65	4.40
2	2.10	6.70
3	0.20	7.90
4	1.95	6.80
5	0.05	5.95
Mean	1.19	6.35

Figure 2.1 - Sea Urchin Densities at Chumbe Island sites.

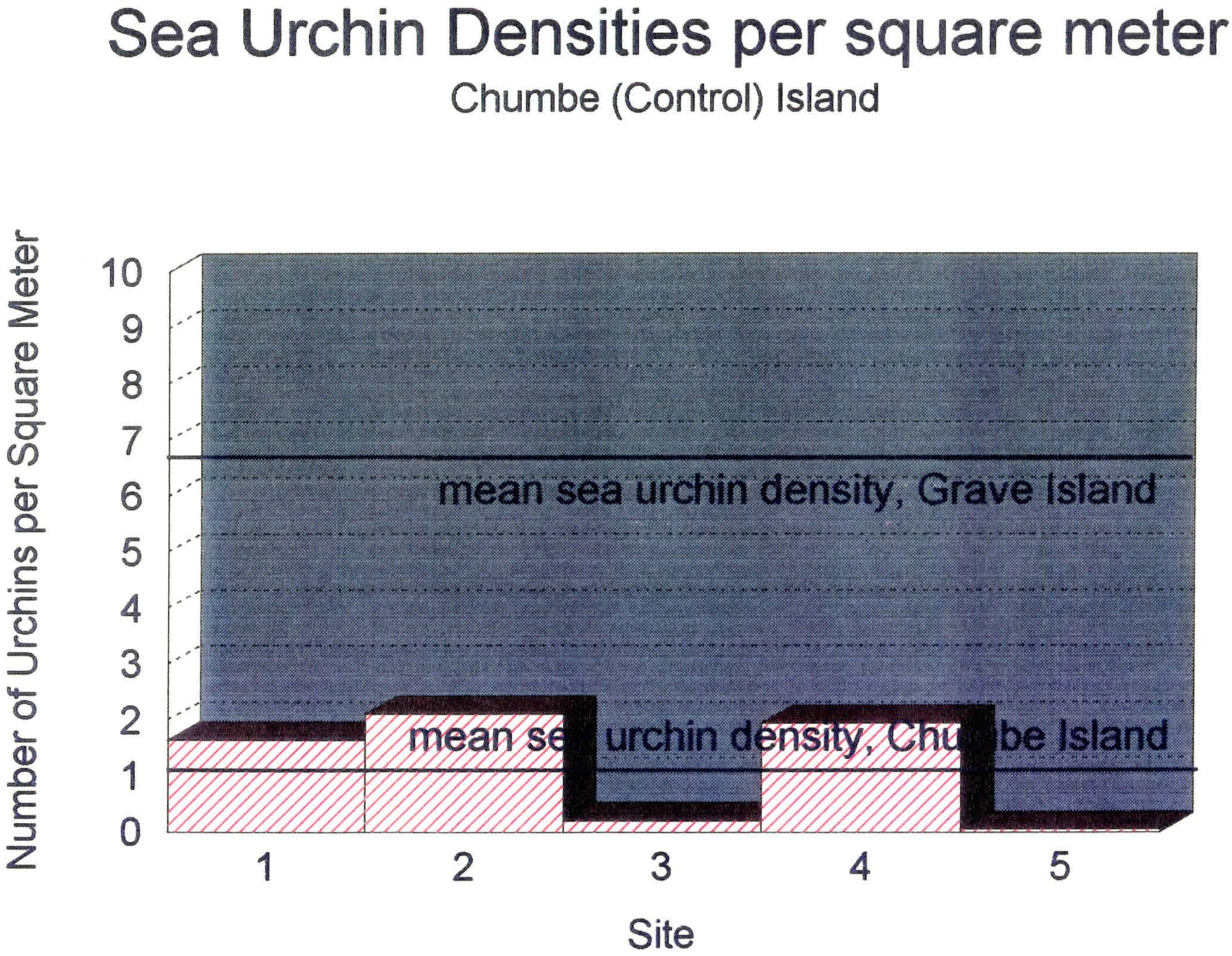


Figure 2.2 - Sea Urchin Densities at Grave Island sites.

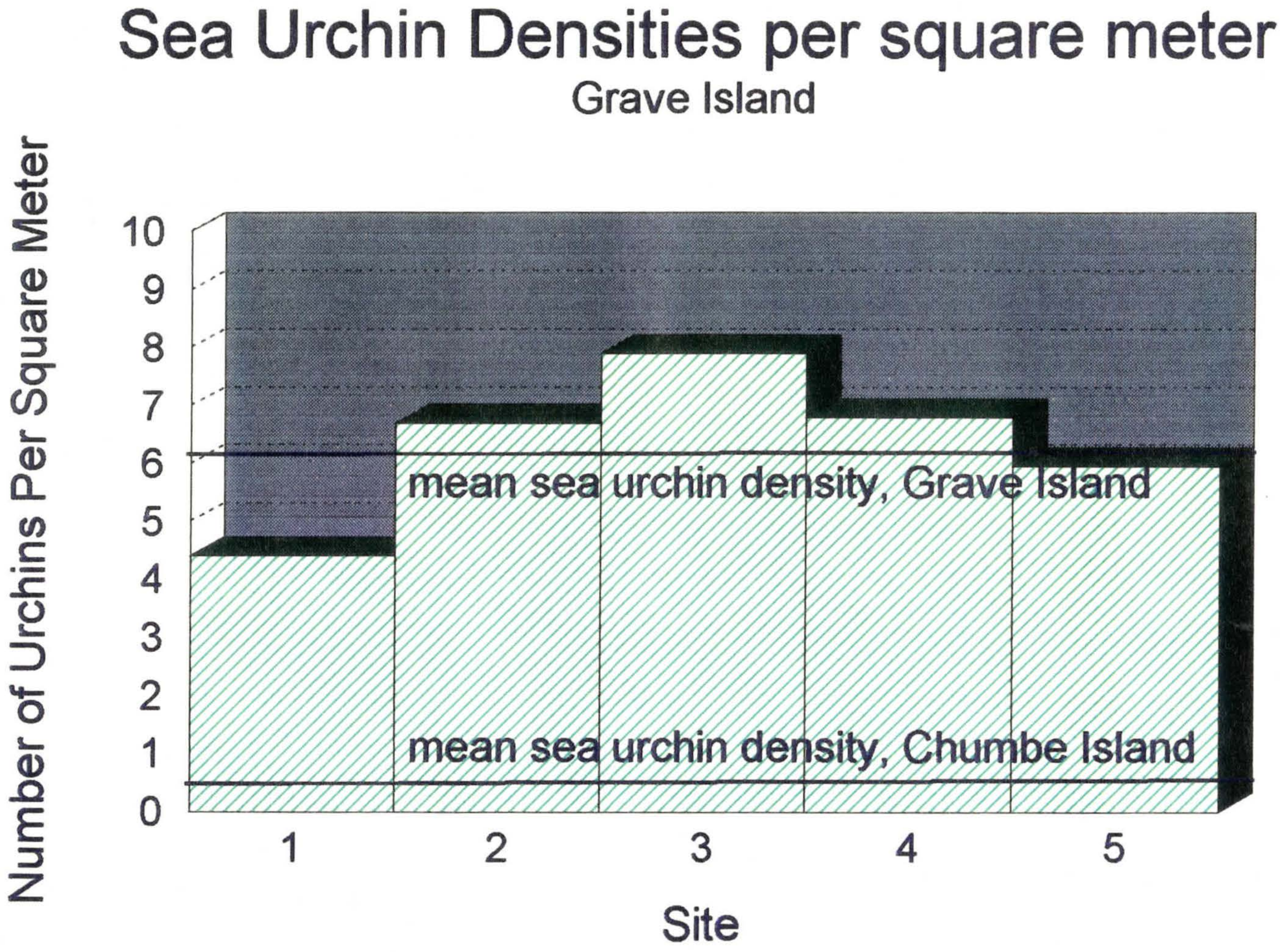


Table 2.2 - Coral Associate Densities per square meter. There is a significant difference between sites ($p<0.000$)

	Site	Total	Mean
Chumbe			
	2	29.2	
	5	38.8	
	6	28.8	
			32.27
Grave			
	1	79	
	2	103.6	
	3	80	
			87.53

Figure 2.3 - Coral Associate Densities per square meter at Chumbe Island sites.

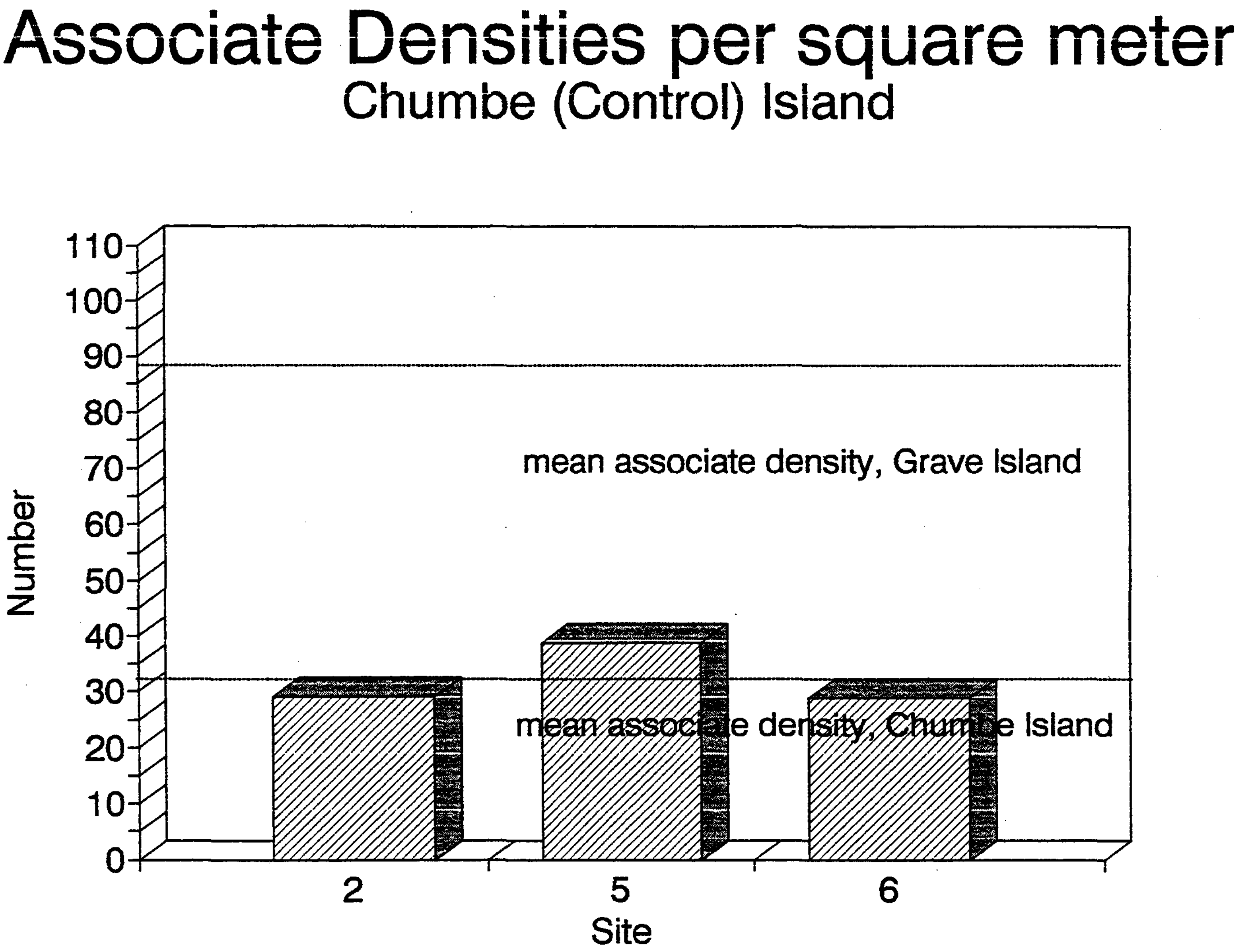


Figure 2.4 - Coral Associate Densities per square meter at Grave Island sites.

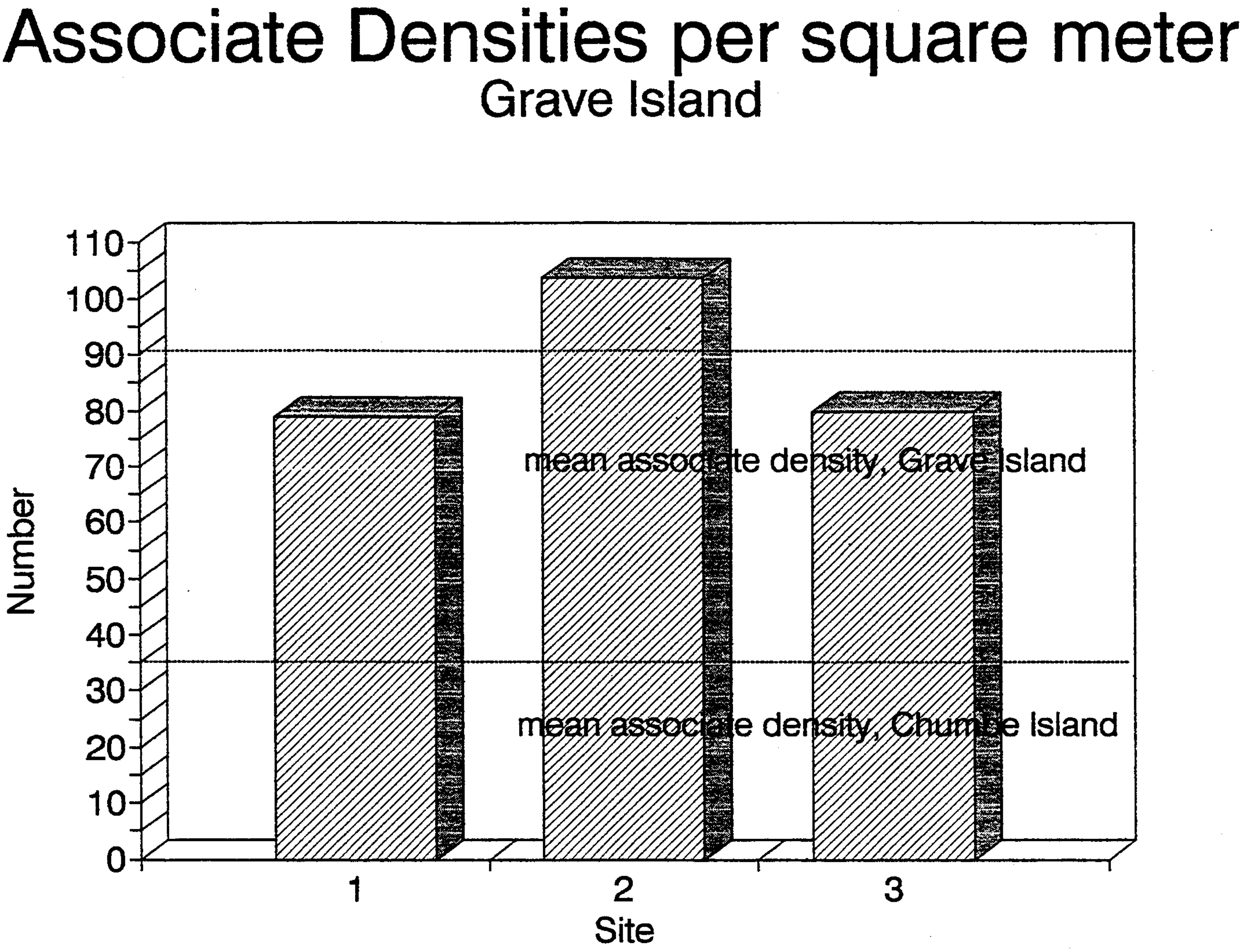


Table 2.3 - Transect Data, showing length of live, dead, and total coral length per transect (in centimeters).

	Site	Live	Dead	Total
Chumbe	1-1	1371	199	1570
	1-2	1571	147	1718
	2-1	1620	0	1620
	2-2	1375	0	1375
	3-1	1484	93	1577
	3-2	1406	364	1770
	4-1	1537	147	1684
	4-2	1680	99	1779
	5-1	1580	248	1828
	5-2	1785	53	1838
	6-1	1387	110	1497
	6-2	1633	115	1748
	Mean	1536	131	1667
Grave	1-1	590	0	590
	1-2	872	158	1030
	1-3	1106	102	1208
	1-4	765	115	880
	2-1	683	96	779
	2-2	512	22	534
	3-1	1399	122	1521
	3-2	1177	9	1186
	4-1	1517	0	1517
	4-2	1205	42	1247
	5-1	545	511	1056
	5-2	1134	281	1415
	6-1	1159	30	1189
	6-2	1672	0	1672
	Mean	1024	106	1130

Figure 2.5 - Coral Cover per Transect at Chumbe Island.

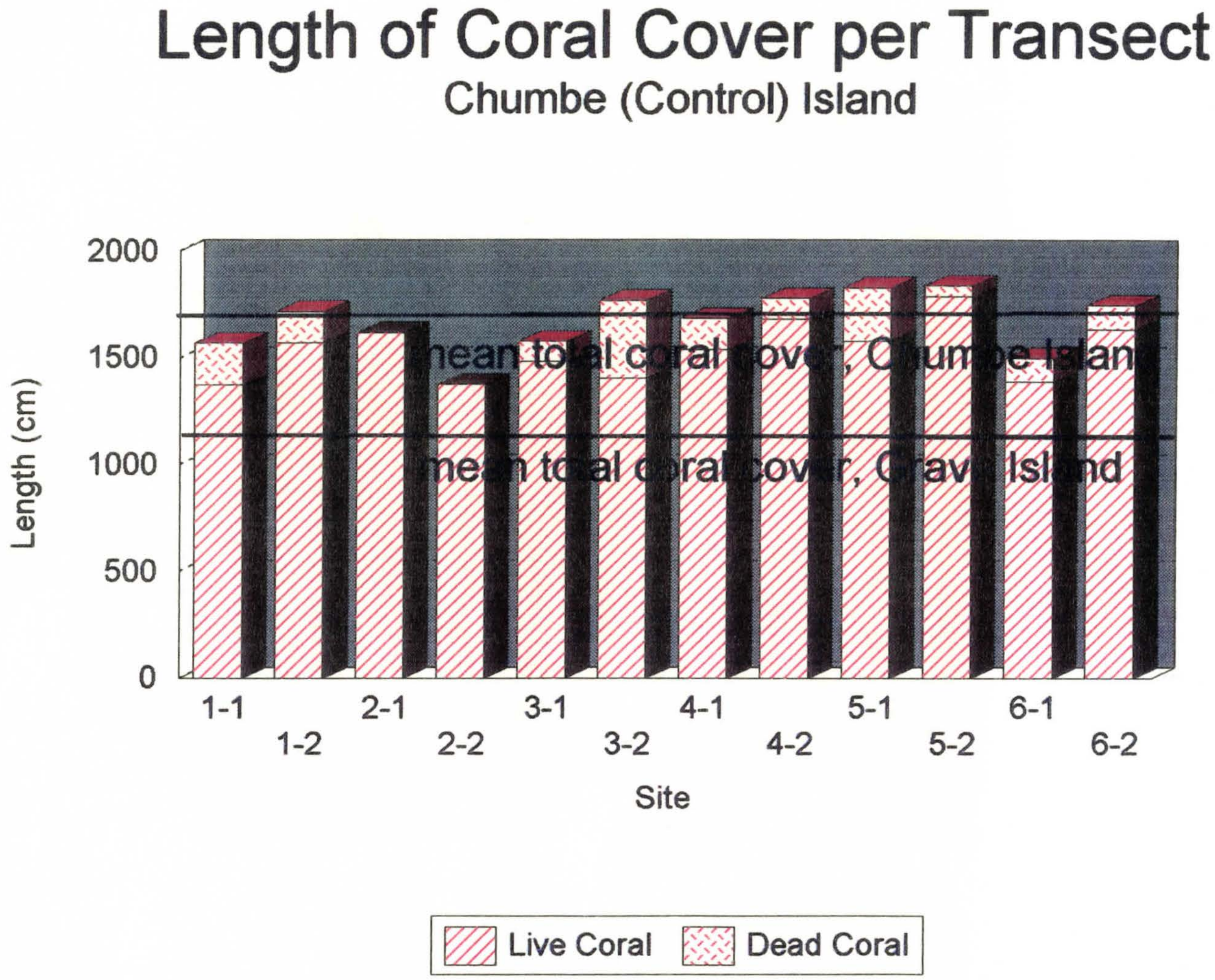


Figure 2.6 - Coral Cover per Transect at Grave Island.

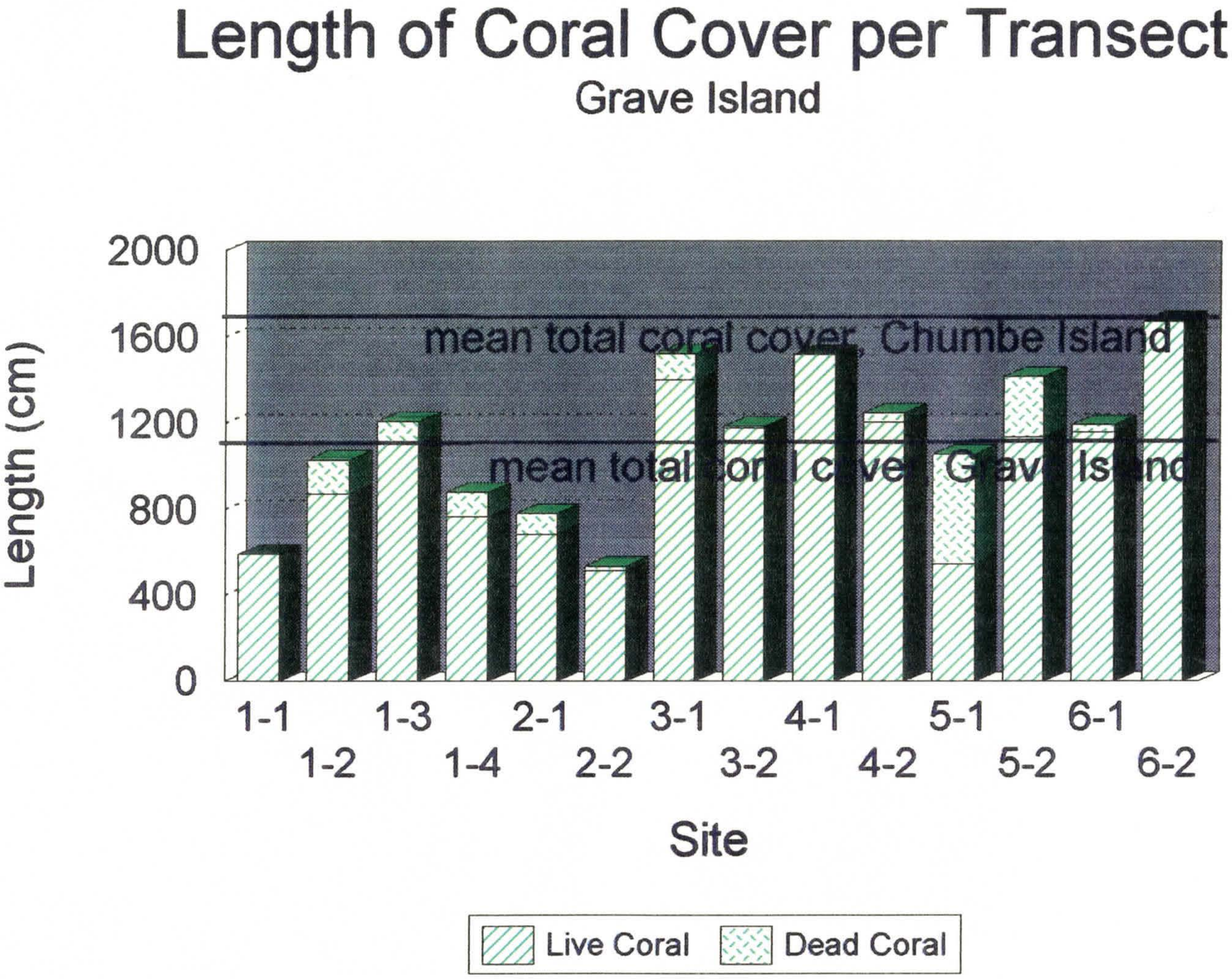


Table 2.4 - Transect Data, showing number of coral species per site.

Site	Chumbe	Grave
1	15	3.75
2	12	8
3	15	6
4	15.5	6.5
5	13	5.5
6	18	7
Mean	14.8	6.1

Figure 2.7 - Number of Coral Species per site at Chumbe Island.

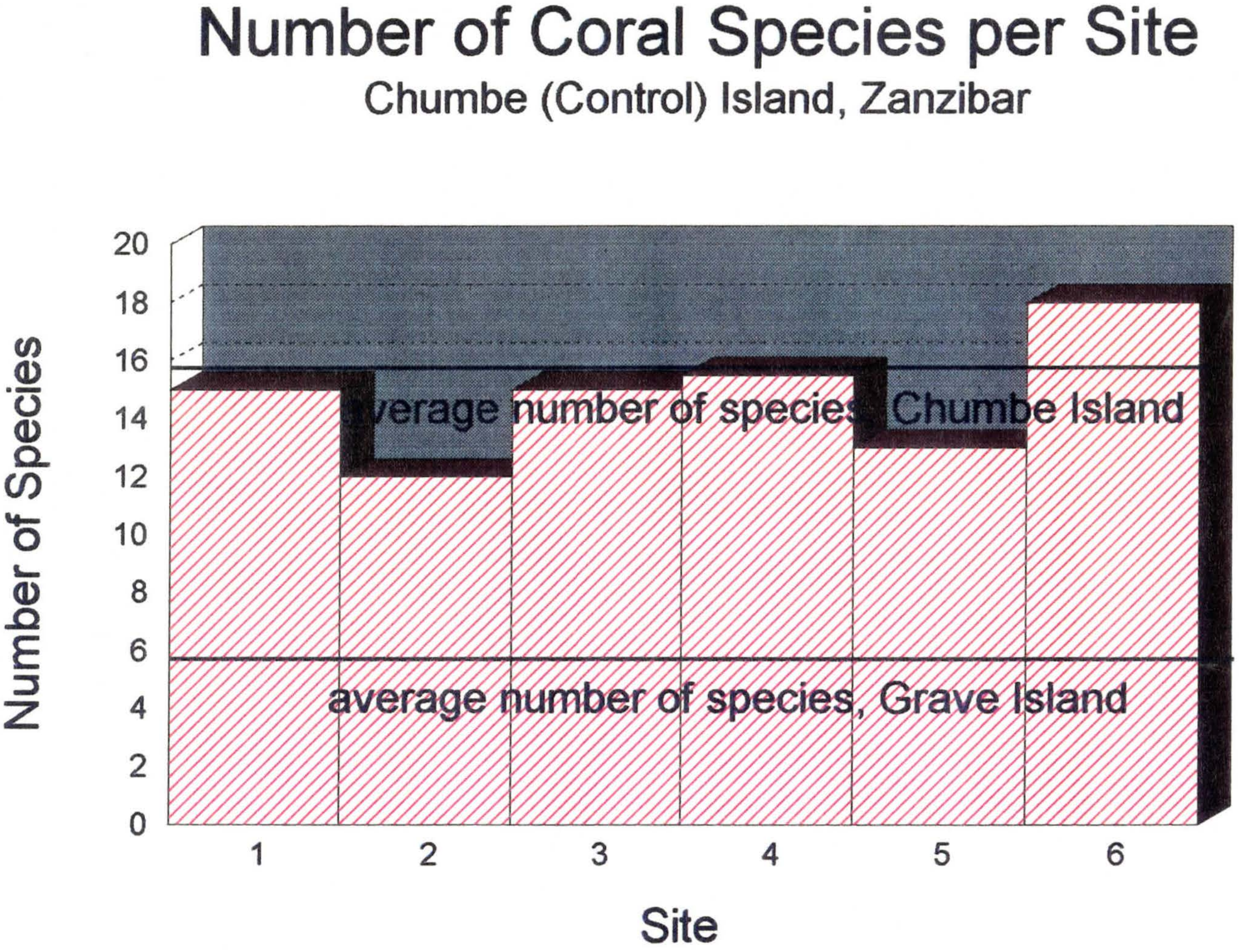
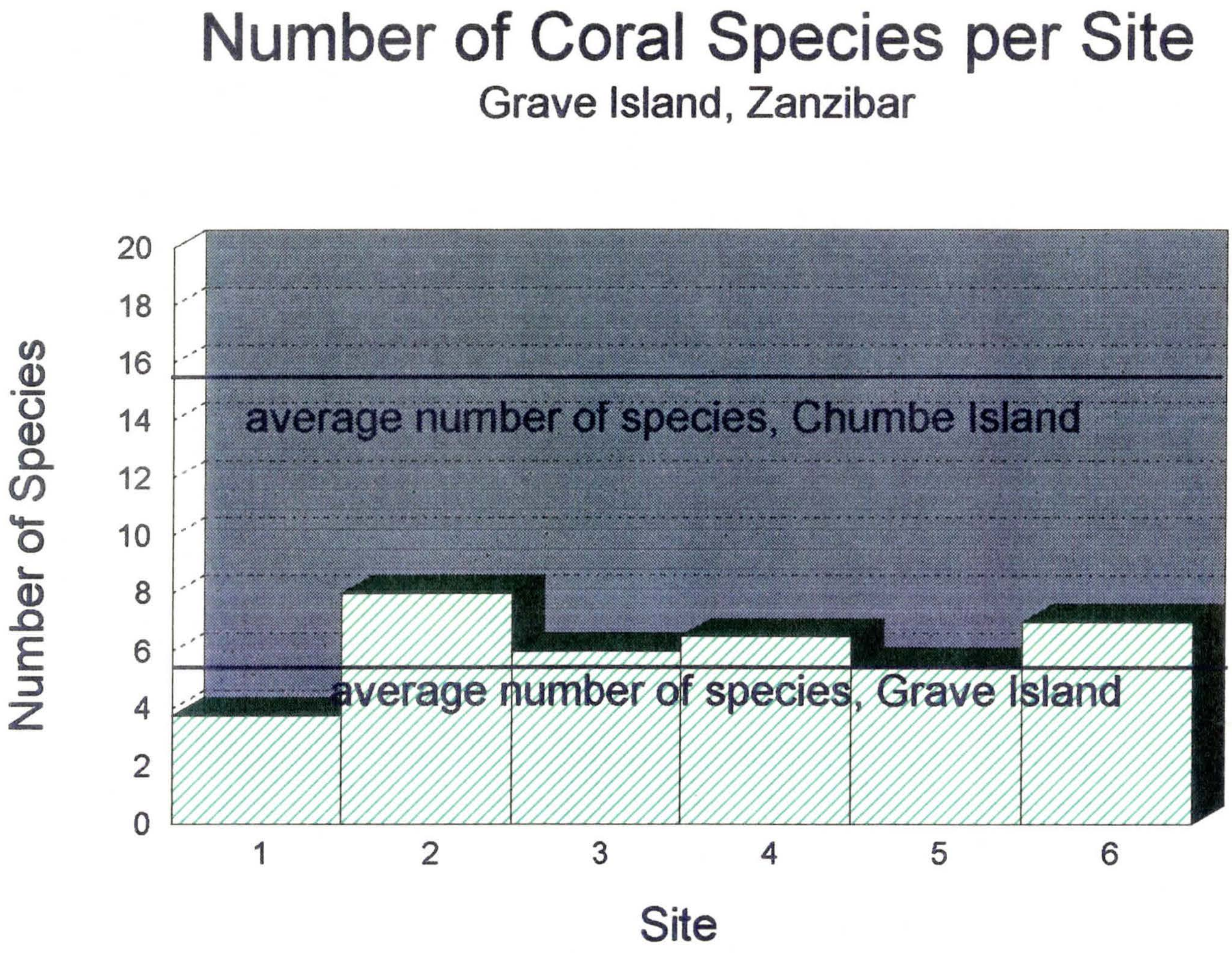


Figure 2.8 - Number of Coral Species per site at Grave Island.



2.4 SUMMARY

As discussed by McClanahan and Shafir (1990), increasing urchin densities can be attributed to decreased predation (mainly by triggerfish), in turn linked to overfishing. With lowered predation, more larvae survive as do more adults. Eutrophication would also be an assistance to the survival of sea urchins, as the algae on which they feed would be sufficiently increased, as would the dissolved organic matter in the water (another food source). Therefore, although not the direct cause of the increase in sea urchin density, it is likely that the eutrophication of the ecosystem plays a vital role in the ecosystem's ability to sustain an increased number of sea urchins.

The lowering of the amount of live coral at Grave Island, as well as an increased mortality among mature corals, suggests there is likely to be a decreased larval survival rate. Since the survival of coral larva is dependent on finding suitable substrate, escape from predation, and ability to out-compete surrounding organisms, it is reasonable to assume that some, if not all, of these factors have changed, hampering the young coral. Eutrophication has already been indicated as possibly changing the benthic fauna; it is possible that such a shift would decrease the suitability of settlement for the coral larva. Further, species of *Diadema* have been related to lowered success of coral spat (Sammarco, 1982; Sammarco, 1980).

The insignificant difference between the amount of dead coral at the study sites suggests that there must be a significant increase in the amount of bioerosion occurring at Grave Island, confirmed by the coral associates data collected. It would appear that the mature corals have an increased mortality at Grave Island, as well as a weakened existence.

CORAL GROWTH RATES

3.1 INTRODUCTION

Changes in the environment are reflected in the calcium carbonate skeleton which coral secretes (Rhoads and Lutz, 1980; Tomascik and Sander, 1985; Hudson et al, 1976; Moore and Krishnaswami, 1974). Fluctuations of temperature and light (Highsmith, 1979; Hudson et al, 1976; Moore and Krishnaswami, 1974) as well as depth (Highsmith, 1979) and periods of stress to the coral (Hudson et al, 1976) have all been shown to be reflected in the skeleton. Most importantly, these changes can be seen to be periodic events related to seasonality.

Coral skeletons are characterised by couplets of high density and low density bands forming one period of growth (Weber et al, 1975; Dodge and Vaisnys, 1980). These periods of growth have been linked to annual cycles, the high density band being created during the time of year least favourable to the coral's growth (Hudson et al, 1976; Weber et al, 1975; Dodge and Vaisnys, 1980). The coral skeleton could then be used as a type of chronometer, with changes in its growth reflecting changes in the environment.

The effect of eutrophication on coral growth has been studied and can be seen to be recorded in coral skeletons (Tomascik and Sander, 1985). The corals tend to respond positively to the increase in nutrients (Tomascik and Sander, 1985) and growth rates will increase. At a certain maximum concentration, however, growth rates drop, presumably a result of smothering, reduced light and reduced photosynthetic capabilities of the coral (Tomascik and

Sander, 1985). Coral growth rate is intimately linked to the symbiotic zooxanthellae and their ability to photosynthesis (Dodge and Vaisnys, 1980).

There are problems associated with the use of corals as chronometers. Some corals do not show bands, some are banded in response to different environmental parameters and some produce bands at different times of the year. If there is no absolute control on the dates given by the coral, ie an Alizarin red stain or nuclear weapons test, it may be difficult to determine what cyclicity the bands are controlled by. It is true that corals may create annual growth bands, but monthly and even daily growth bands (Risk and Pearce, 1992) have been shown to be created as well. Which periodicity is being shown by the bands in the coral skeleton may be difficult to determine.

3.2 MATERIALS AND METHODS

Heads of *Porites lobata* were marked with a dive knife in situ to confirm the "top dead center" position on the coral head. All coral heads were collected from approximately the same depth of 2.5m. After a minimum 24 hours of immersion in fresh water, the corals were slabbed with a carbide saw. The slabs were carefully cut to include the top dead center of each coral head. The average slab thickness was 5 cm. These slabs were then exposed to pressurised water to remove any remaining tissue. The cleaned slabs were bathed in dilute bleach for 24 hours in an attempt to minimise odour during their return to Canada. These bleached slabs were then allowed to dry in the sun.

Upon return to Canada, the slabs were sectioned with a diamond saw. These sections averaged 0.4 cm in width and were carefully obtained so as to be totally parallel. Each section included the top dead center of the coral head and the growing point of the coral head. This maximised the number of corallites parallel to the surface of the section, thereby giving the most reliable growth rates available.

These sections of coral head were then taken to McMaster University Hospital where they were x-rayed. Exposure time of the x-rays was reached by trial and error. These x-ray negatives were then developed into x-ray positives. It was from a combination of x-ray negatives and positives that the coral growth rates were retrieved.

Transparencies were laid over the x-ray positives and negatives, and the couplets were transferred with superfine point permanent markers. Each couplet was measured to the bottom of the high density band. This method was arrived at because collection of the coral heads occurred while low density bands were being laid down. Thus the top of the next low density band (or bottom of the high density band) would approximately represent one year from the collection time. Not each high density band was considered to represent one year's growth, as there were many very thin or very faint bands. It is possible that these bands represent monthly banding or stress bands affecting the corals growth.

The amount of coral growth per year was measured along the coral's growth axis and recorded in centimeters per year. Coral growth rate was then plotted against time. Results are shown in tables 3.1 and 3.2 and figures 3.1 through 3.5. This technique to retrieve growth rates is similar to the technique outlined by Dodge (1990).

3.3 RESULTS

Seven samples at Chumbe and twelve samples at Grave Island had growth banding clear enough to use; other heads had indistinct banding.

The corals from Chumbe showed no change in growth through time, with an average growth rate of 0.7 cm/yr (std dev 0.14). The constancy of the environment through time was as expected, and confirms that there are no increasing stresses affecting the coral's growth at this site.

The corals from Grave showed a wide range of growth rates, with an average growth rate of 1.1 cm/yr. This growth rate is significantly higher than at Chumbe. This suggests that the increased nutrients in the water are assisting the coral to grow. [See figure 3.4].

The mean growth rate at Grave in the years 1977 and 1976 are somewhat suspect, as they rely on a small sample size. If these points are considered in error, a slight growth rate decrease can be seen in the Grave Island data. This suggests that the conditions which are more or less constant may be taking a turn for the worst.

Table 3.1 - Coral Growth Rate Data in centimeters per year for Chumbe Island.

CHUMBE (CONTROL) ISLAND

	CORAL GROWTH RATE (CM/YR)								
YEAR	C1	C2	C3	C4	C5	C6	C7	MEAN	STD.DEV
1992	1.00	0.80	0.30	0.70	0.55	0.60	0.60	0.65	0.20
1991	1.00	0.70	0.60	0.70	0.40	0.55	0.90	0.69	0.19
1990	1.20	0.90	0.85	0.80	1.05	0.80	1.10	0.96	0.15
1989	1.20	1.00	0.65	0.60	1.25	0.50	1.05	0.89	0.28
1988	1.10	0.50	0.70	0.90	0.95	0.90	1.05	0.87	0.19
1987	1.00	0.70	1.00	0.20	0.65		1.25	0.80	0.34
1986	1.40	0.50	0.90	0.60	1.10			0.90	0.33
1985		0.80	0.80					0.80	0.00
1984		0.60	0.80					0.70	0.10
1983		0.60	0.30					0.45	0.15
1982		0.30	0.40					0.35	0.05
1981		0.40	0.30					0.35	0.05
1980		1.30	0.40					0.85	0.45
1979		1.00	0.50					0.75	0.25
1978		0.80						0.80	0.00
1977		0.80						0.80	0.00
1976		0.30						0.30	0.00
1975		1.30						1.30	0.00
1974		0.40						0.40	0.00
1973		0.50						0.50	0.00
1972		0.70						0.70	0.00
							ALL	0.705442	0.135193

Figure 3.1 - Coral Growth Rate Data, Chumbe Island.

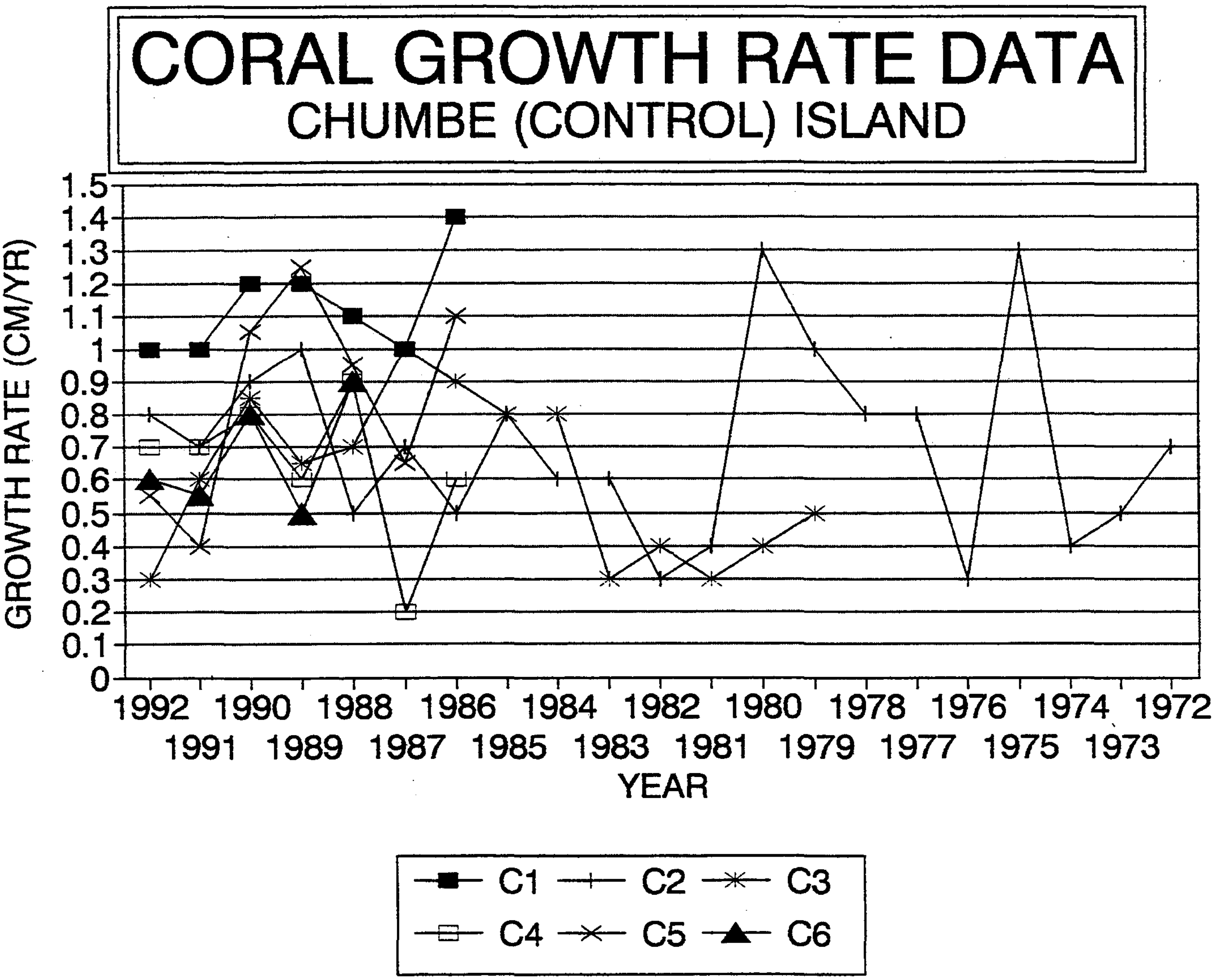


Table 3.2 - Coral Growth Rate Data in centimters per year for Grave Island.

GRAVE ISLAND

	CORAL GROWTH RATE (CM/YR)															
YEAR	G1	G2	G3	G4	G6	G8	G9	G11	G12	G13	G14	G15	MEAN G1-G3	STD DEV G1-G3	MEAN G4-G15	STD.DEV G4-G15
1992	0.90	1.40	0.70	0.50	0.70	0.45	0.15	0.40	0.60	0.40	0.70	0.30	1.00	0.29	0.47	0.17
1991	1.50	1.40	1.20	0.60	0.65	0.20	0.50	1.25	1.10	0.80	1.10	0.40	1.37	0.12	0.73	0.34
1990	1.80	1.60	1.35	0.80	0.40	0.40	0.35	0.60	0.60	0.70	0.70	0.40	1.58	0.18	0.55	0.16
1989	1.75	2.30	0.90	0.75	0.55	0.70	0.30	1.40	0.50	0.90	0.80	0.40	1.65	0.58	0.70	0.31
1988	1.35	1.80	1.40	0.80	0.40	0.50	0.30	1.35	0.60			0.40	1.52	0.20	0.62	0.33
1987	1.70	1.60	1.45	0.60	0.50	0.80	0.50	1.05	0.40			0.40	1.58	0.10	0.61	0.22
1986	2.15	2.05	1.60		0.50	1.50	0.50	0.90	0.80			0.50	1.93	0.24	0.78	0.36
1985	1.55	1.80	1.50		0.55	0.90	0.40	1.00	0.40			0.35	1.62	0.13	0.60	0.26
1984	1.90	1.95	1.10		0.45	0.90	0.60	1.10	0.50			0.50	1.65	0.39	0.68	0.24
1983		1.90	1.20		0.80	0.54	0.45	0.90	0.50			0.45	1.55	0.35	0.61	0.18
1982		2.30	1.20			0.30	0.50	0.60	1.10			0.20	1.75	0.55	0.54	0.31
1981		1.80	1.45			0.30	0.60	0.50	0.80			0.50	1.63	0.18	0.54	0.16
1980		2.35				0.35	0.60	0.80	1.20			0.50	2.35	0.00	0.69	0.29
1979		1.20					0.40	1.00	1.00			0.50	1.20	0.00	0.73	0.28
1978		0.85					0.60	0.95	1.20				0.85	0.00	0.92	0.25
1977							0.60								0.60	0.00
												ALL	1.55	0.18	0.65	0.09

Figure 3.2 - Coral Growth Rate Data for Grave Island samples G1, G2, G3, G4, G6, G8.

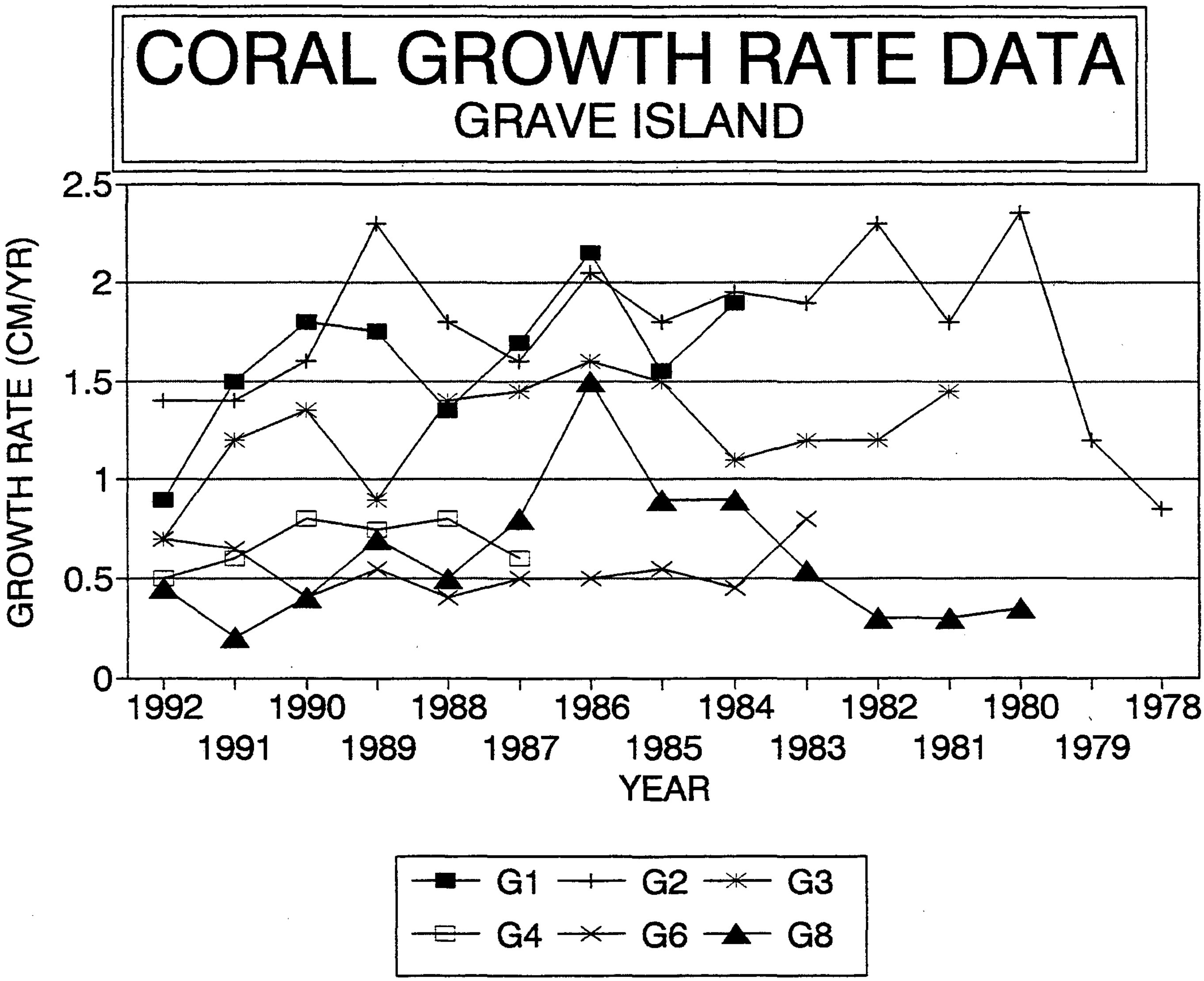


Figure 3.3 - Coral Growth Rate Data for Chumbe Island samples G9, G11, G12, G13, G14, G15.

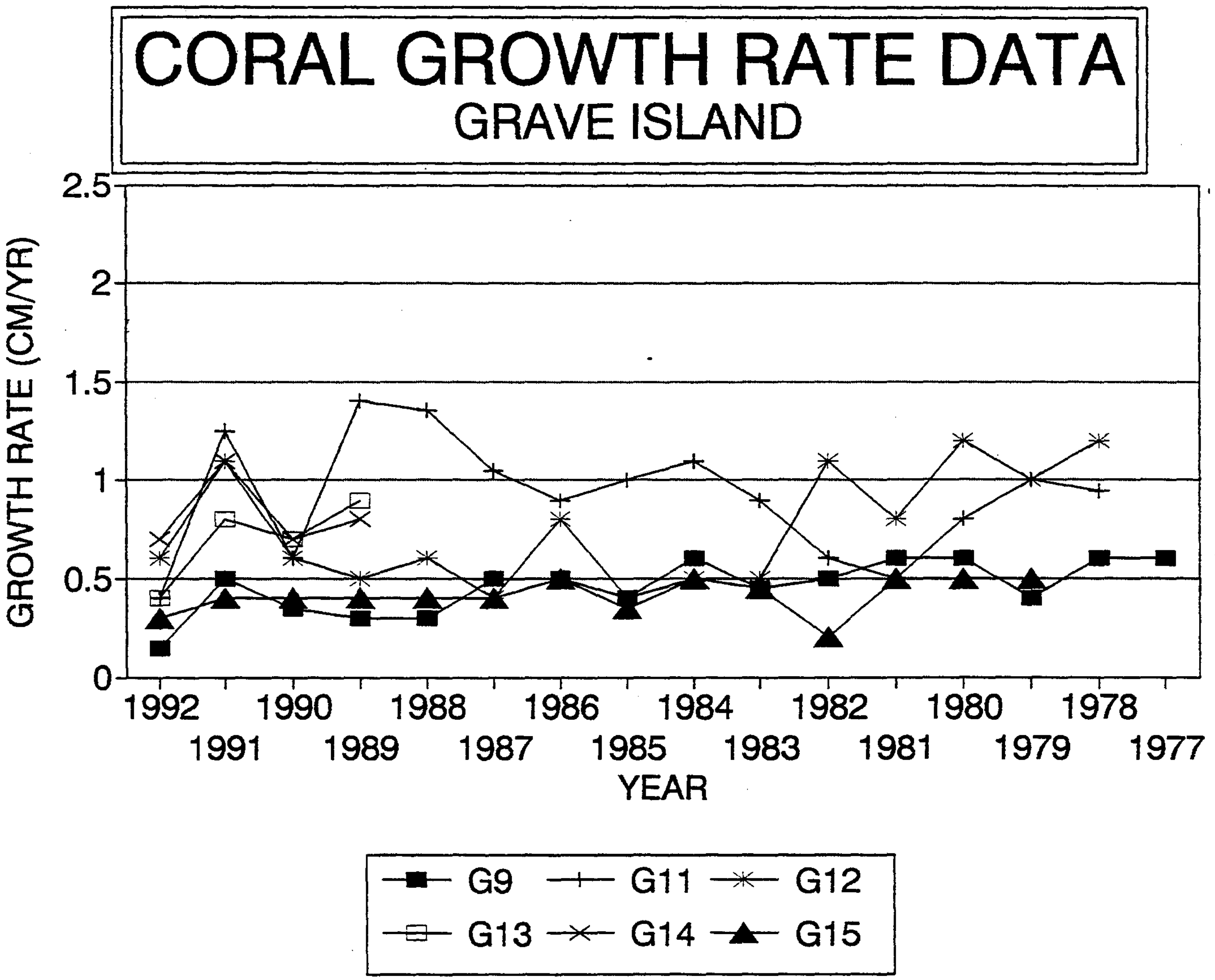


Figure 3.4 - Mean Coral Growth Rates for Chumbe and Grave Islands.

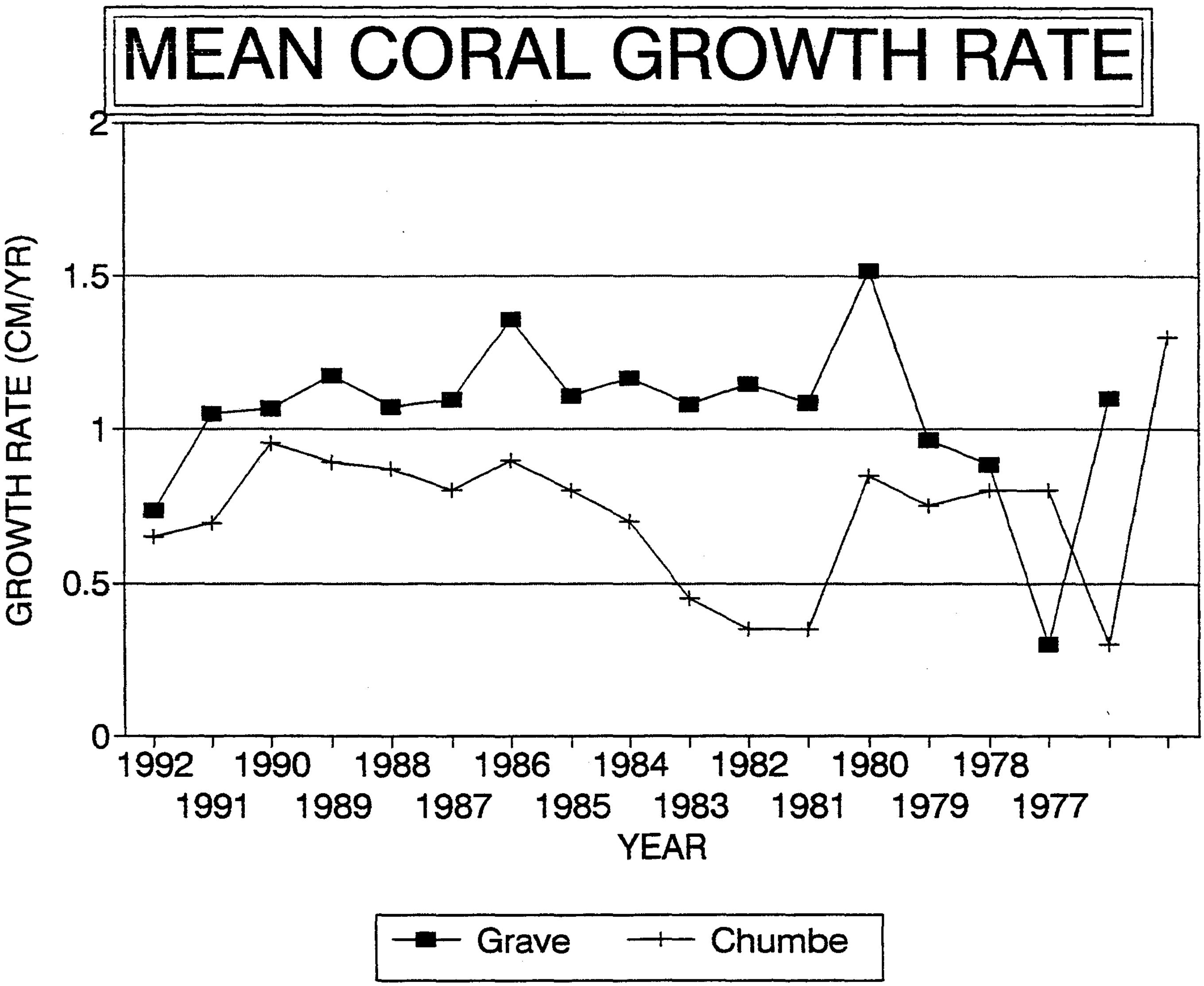
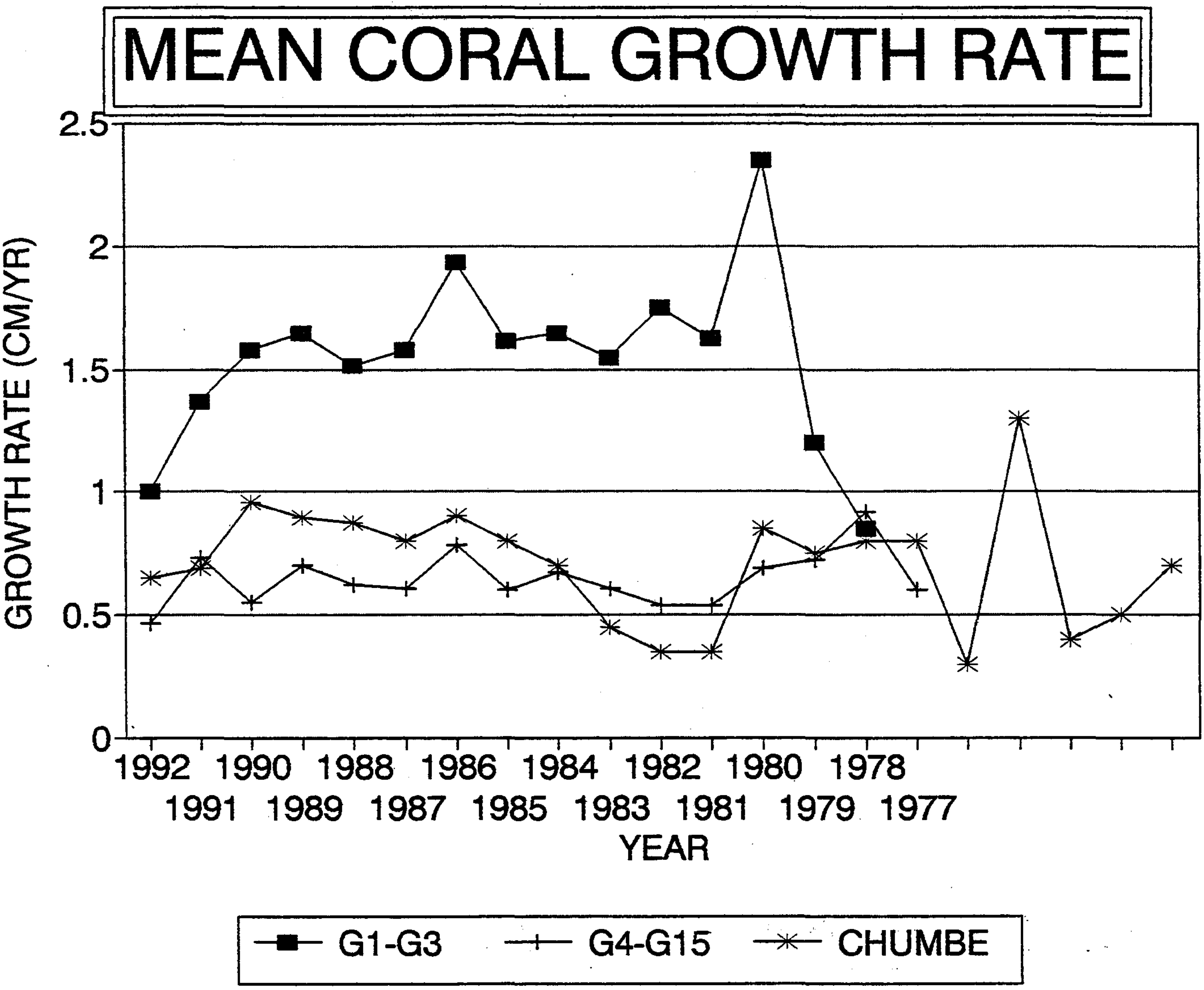


Figure 3.5 - Mean Coral Growth Rates for Chumbe and Grave Islands, showing possible sub-population in Grave Island corals.



Grave Island coral samples G1-G3 have an average growth of 1.55 cm/yr (std. dev of 0.2), while the other samples have an average growth of 0.65 cm/yr (std. dev. of 0.1). These growth rates are significantly different, as confirmed by a one way ANOVA with p=0.000. This result is shown in figure 3.5, and may reflect two sub-populations.

3.4 SUMMARY

The coral growth rates are significantly different between the two study sites, with Grave Island showing an increased growth rate. This suggests that the eutrophication at Grave is acting to assist the coral growth (Tomascik and Sander, 1985). A slight recent decrease in the Grave Island data may suggest that the nutrient flux has reached a critical level (Tomascik and Sander, 1985) and is now becoming detrimental to the corals.

The data suggest the possibility of two coral populations at Grave Island. One subset of corals would appear to be able to benefit from the increased nutrient flux, as demonstrated by the rapid growth rate. The other subset has a very low growth rate. This suggests that these corals may have a higher mortality under increased eutrophication, unable to respond to algal smothering.

Further research must be completed to confirm the hypothesis of subsets within the coral community at Grave Island. Current results suggest that the eutrophication has not yet reached the critical level, at which coral growth would be reduced.

STABLE ISOTOPES

4.1 INTRODUCTION

Stable isotope analysis of Carbon and Nitrogen in coral tissues has been shown to reflect diet and trophic status of the coral. Extensive recycling of nutrients between the coral tissue and the zooxanthellae in an autotrophic coral may minimise the amount of nutrients lost by excretion (Muscatine and D'Elia, 1978). This would suggest that isotopic signatures in the coral tissue would reflect the ambient environment's isotopic signature.

Studies on coral nutrition have also shown that corals have the ability to absorb dissolved nutrients directly across their tissues (Muscatine, 1973). In a nutrient rich environment, it is possible that dissolved matter may become a major food source for the coral. Risk (1991) has shown that $\delta^{15}N$ is enriched in fecally polluted areas of a reef at Male, Maldives.

Fractionation of Nitrogen in the food chain occurs by excretion of lighter Nitrogen (Peterson and Fry, 1987), resulting in a stepwise enrichment of heavy Nitrogen up the food chain. The resulting signature of human effluent would therefore be expected to be significantly enriched in heavy Nitrogen. Thus the isotopic signature of human sewage should be significantly different from the signature of the marine environment.

4.2 MATERIALS AND METHODS

Tissue Samples were collected from *in situ* specimens of *Porites lobata* at both Grave and Chumbe Island. The samples were removed from the top surface of the coral with a hammer and dive knife. Care was taken to sample from the same depth.

Collected samples were placed in whirlpack bags while still underwater. These samples were returned to the lab where they were dried in an oven at 60°C for a minimum of 48 hrs. These dried samples were then returned to Canada for further processing.

The dried tissue was removed from the coral skeleton by gentle decalcification in 10% Hydrochloric acid. The samples were allowed to remain in their individual acid baths until such time that bubbling from the Calcium Carbonate skeleton had slowed virtually to stopping. At this time more dilute HCl was added in order to maintain a constant chemical reaction. This process continued until no calcium carbonate remained. This solution was then neutralised by addition of distilled water. Straining through nylon captured the tissue sample.

The tissue samples were centrifuged until the supernatant was virtually free of tissue. These tissue pellets were then placed on dry ice for 24 hours. The frozen tissue pellets were then placed under vacuum for approximately 4 hours in order to freeze dry the sample. These freeze dried samples were then prepared to be run in the mass spectrometer.

Samples were powdered with a pestle and carefully weighed to 0.015 g. Precombusted Pyrex tubes were then filled with CuO to a depth of 3.5 cm, followed by the powdered tissue, and another 3.5 cm of CuO. The tubes were then placed under vacuum for 12 hours after which time they were flame sealed. These sealed tubes were then heated to 550°C for 2hrs in order to combust the tissue and CuO. Mass spectrometric analyses was then completed on the tissues.

The mass spectrometry returned $\delta^{13}C$ and $\delta^{15}N$ data. The reference sample for the ^{13}C data was GCS (Grenville Calcite), corrected to PDB using NBS19. The experimental error was ±0.02 per mil on three gelatine samples. For the ^{15}N data the reference was liquid Nitrogen, with precision of ±0.09 per mil.

Results are shown in Table 4.1 and Figures 4.1 and 4.2. One way ANOVAs were completed between data sets.

4.3 RESULTS

The values from the $\delta^{13}C$ analyses suggested that all sampled corals were autotrophic (Muscatine, 1989) with values ranging from a low of -12.7 (at Chumbe Island) to a high of -8.7 (at Grave Island). There was no significant difference between the $\delta^{13}C$ values at the two study sites. The $\delta^{15}N$ values did not show any significant difference between sites.

Table 4.1 - $\delta^{15}N$ and $\delta^{13}C$ values for Chumbe and Grave Island tissue samples. The data show no significant difference.

	Sample	Delta 15N	Delta 13C
Chumbe	ch1	4.556	-9.448
	ch2	4.745	-10.109
	ch3	3.224	-9.625
	ch4	4.373	-10.434
	ch5	3.600	-12.738
	ch6	4.400	-10.222
	ch7	4.354	-11.713
	ch8	4.271	-10.770
	ch9	4.040	-11.016
	Mean	4.174	-10.675
Grave	g1	4.219	rejected
	g2	3.583	-10.129
	g3	4.145	-8.924
	g4	4.452	-10.993
	g5	4.526	-10.146
	g6	4.124	-10.996
	g7	4.388	-9.535
	g8	4.326	-10.092
	g9	4.189	-9.365
	g10	4.066	-8.735
	g11	4.317	-10.774
	Mean	4.281	-9.95

4.4 SUMMARY

The 1 km distance of Grave Island from Zanzibar town may have been sufficient to have erased any characteristic isotopic signature of the sewage. This may have occurred through extensive biological recycling by phyto and zooplankton, which remove ^{15}N and excrete ^{14}N. Previous studies (Risk, 1991) in which the sewage fingerprint manifested in the coral tissues had substantially shorter distances between the source and collected corals.

Nitrogen is generally a limiting nutrient in the marine environment (Schlesinger, 1991), therefore any increase in Nitrogen in the water would likely first go to satisfying the needs of the coral and its symbionts. As pointed out by Muscatine and D'Elia (1978), corals have evolved an extensive recycling system to cope with reduced Nitrogen, and as such have virtually eliminated excretion of Nitrogen (excretion of Nitrogen would create an approximate 3 per mil fractionation within the coral tissues). Fractionation of Nitrogen was therefore not expected at the Grave Island study site. Such fractionation would imply very high nutrient loading, to the point where corals could excrete Nitrogen.

SUMMARY

5.1 CONCLUSIONS

The combination of biology, sclerochronology and stable isotopes proved highly effective in showing the nutrient loading on the reef at Grave Island.

The biological data suggest the corals are structurally and physiologically weakened (coral associate data), and being subjected to heavy bioerosive forces (transect and urchin data). The high sea urchin densities may be causing further injury to the coral and possibly lowering coral recruitment at Grave Island. The growth rate data suggest that not all corals at Grave Island are capable of coping with the imposed nutrient load. Some of the slower growing corals may not be able to adequately defend against algal smothering, a proven effect of sewage stress on reefs (Tomascik and Sander, 1985).

Although the stable isotope data are inconclusive, this does not imply that eutrophication has not occurred at Grave Island. Rather, it suggests that further research needs to be completed to begin to comprehend fully the functioning of Nitrogen isotopes in coral tissues.

If something is not done to ameliorate the situation at Grave Island, it is unlikely that these reefs will live long or prosper.

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