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THE EFFECTS OF SILTATION ON CORALS OF THE GREAT BARRIER REEF NEAR THE DAINTREE RIVER, NORTH-EASTERN QUEENSLAND, AUSTRALIA

The Effects of Siltation on Corals of the Great Barrier Reef Near the Daintree River, North-Eastern Queensland, Australia

by

Mark P. Fingland

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ABSTRACT

Effects of siltation were measured by determination of growth rates through x-radiography and trapped clastics sediments through coral sample decalcification. Results show an increase in growth rate with an increase in suspended particulate matter. This is attributed to an increase in nutrient levels with increased SPM values.

Support of algal banding being an annual indicator was given by comparison of x-radiographs to actual coral slabs.

Observation of radiographs reveal an offshore trend in regard to the distinctiveness of annual banding, with the bands being less obvious on outer shelf corals.

Large variations in growth rates found within the sample population as a whole, as well as intra-reef samples reveal the limited applications to which these determinations can be used.

ACKNOWLEDGEMENTS

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Thanks again to everyone.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

This project studied corals found in an area of the Great Barrier Reef(GBR) located off the Queensland coast in north-eastern Australia. The study area is approximately midway between Cooktown and Cairns (long. 145 15'-146 00', and lat. 16 00'-16 45'S) [figure 1]. This area of Australia is a region of very marked seasonal rainfall and cloud cover, with both having a summer maximum. This seasonal distribution of rainfall and cloud cover is largely a result of the prevailing winds associated with the dominant secondary circulation of each season. As a result, skies over north- eastern Queensland are normally continuously cloudy during the summer wet season (Jan-April) but are mostly clear during the winter dry season (July-Oct). Average monthly rainfall for the area between Cooktown and Cairns for January is 300-400 mm and for July 10-50 mm (Parkinson,1986). The variability of both annual and monthly rainfall is low, thus this seasonal variation has been in place for some time. Rainfall during the wet season comes as cyclones and thunderstorms and is intense. Although intensity varies with the duration of storms and with the average storm recurrence interval, a measure of annual rainfall intensity (maximum amount of rain in 24 hrs. that can be expected once a year) is calculated. For the study area , the value of this annual rainfall intensity is 5.0-6.0 mm/hr (Parkinson,1986). The seasonal temperature variation over this area is not substantial. Although day temperatures are lowered as a result of extreme

Figure 1 Location of study area.


30′
45′
146° 00′
COOKTOWN
55 km
16° 00′
15′
30′
CAPE
KIMBERLY
DAINTREE R.
SNAPPER
ISLAND
LOW
ISLE
KOREA
ISLAND
CAIRNS
50 km
RUDDER
REEF
OPAL
REEF
TONGUE
REEF
NORMAN
REEF
X
AUSTRALIA
CAIRNS
QUEENSLAND
LEGEND
COASTLINE
REEF OUTLINE
CONTINENTAL SHELF EDGE
(100 m DEPTH)
X SAMPLE LOCATIONS
SCALE:
0
5
10
15 km

cloud cover during the rainy season, the temperature remains above 18 C year round. Very little is presently known about current patterns in the area except on a gross scale (Pickard,1977). These climatic variations are expected to be reflected to some degree in the coral growth record.

My coral samples were taken from chosen so as to represent three positions within the reef tract, namely inshore, midshelf and outer shelf. In the project area, the continental shelf is close to 65 km in width while the maximum N-S distribution of sampled reefs is 40 km. It is known from past studies (summized in Buddemeier and Kinzie,1976) that corals can record changes in environmental conditions which affect growth. Corals are also capable of reflecting climatic changes indirectly by playing host to boring algae and recording boring intensity within the skeleton. The activity of the boring algae is increased during the sunny, dry season which results in a corresponding dark band due to the high concentration of borings (Risk et al.,1987).

This particular study was undertaken to measure the effects on coral growth rate of increased siltation due to logging on the Queensland coast. With increasing distance from the sediment source, there should be a decrease in suspended particulate matter (SPM). The hypotheses of this study were that this trend to decreasing SPM values across the shelf would be reflected in both a decrease in trapped clastic material found within the coral skeleton and an increase in growth rate due to decreased siltation pressure. The latter hypothesis is based on conclusions from a study of siltation stress on a coral reef at

Cahuita, Costa Rica (Cortes and Risk,1985) where elevated SPM values were determined to be the reason for decreased growth rates. Similiar results were discovered by Aller and Dodge (1974) using samples of Montastrea annularis from Discovery Bay, Jamaica where the average annual band widths of specimens decreased in regions of high resuspension of bottom sediments.

Internal structures within the coral skeleton can be observed with the use of x-radiography. These radiographs reveal density variations which are associated with changing thickness of epitheca (Buddemeier and Kinzie,1975). The structures observable on the radiographs fall into two main divisions, large scale banding and much finer scale structure. The large scale banding is composed of a relatively broad dense band and an equally broad, less dense band, although absolute width and proportions vary. These pairs of bands have been shown to represent annual growth by using comparative studies of x-radiography and radionuclides (Knutson et al.,1972; Macintyre and Smith,1974; Moore and Krishnaswami,1974). The annual banding is related to solar radiation and water temperature variations (Buddemeier and Kinzie,1974; Hudson et al.,1976; Dodge and Vaisnys,1981). The finer scale structures may be associated with reproductive cycles, food availablity or low intensity nighttime light (lunar cycle) (Buddemeier and Kinzie,1974). Dodge and Vaisnys (1977) showed the catastrophic effects on corals of siltation and turbidity as a result of dredging, while work by Hudson et al. (1976) revealed the significance of water temperature variations resulting from discharge of cold water from Florida Bay. Hudson's study also made an interesting observation, in that severe hurricanes appear to leave no evidence in the coral growth record. Coral response to increased sedimentation is of particular interest to this project. Also to be kept in mind are the factors of increased nutrients with increased SPM and the seasonal variations of rainfall and cloud cover, all of which could have an affect on coral growth rate.

MATERIALS AND METHODS

Samples of Porites were collected in water depths of less than 5 m, during the summer of 1987 from several reefs located north of Cairns for later sampling and slabbing. Slabs 3-4 cm thick were taken so as to include a point of origin of the colony as well as the upper growth surface. This ensures that the axis of maximum growth will be found within the slab. Slabs were then packed in a crate and shipped to McMaster University. Upon arrival, the slabs were washed using warm water only and set out to be dried and photographed. They were then cut in half using an industrial masonary saw, with one half being archived and the other being used for this project. From this half was cut a 2 cm wide by 0.5 cm thick strip and a 20-35 g sample for trapped siliciclastics. The strip was cut so as to contain, as closely as possible, the axis of maximum growth by ensuring that the corallites were parallel with the face of the strip. The samples were all taken approximately 2 cm below the outer coral surface with the size of the sample being dependent on the thickness of the original slab and the shape of the colony from which it was cut.

X-RAY PROCEDURES

The purpose of exposing the corals to x-rays is to study the revealed density differences which have been shown by many (Macintyre and Smith,1974; Buddemeier and Kinzie,1975) to represent annual growth patterns. By pairing a light and dark band together, an absolute yearly growth value can be measured directly from a radiograph positive or negative.

This study used a Macrotank-L x-ray unit to produce all radiographs. A series of trial x-radiographs were required to determine the optimum settings for this specfic unit and these particular samples. Best results were obtained using 70 kV and 3 mA with a distance between source and sample of 45 cm and an exposure time of 5 minutes. The film used was Kodak Diagnostic film (NMB 100) with a safelight filter. The x-radiograph negatives were then made into positives on a transparent backing. In order to take some of the subjectivity out of measuring the growth bands, these positives were placed in a double-beam recording microdensitometer. Microdensitometer records were used to mark off annual bands. Measurements were not taken until these bands were compared to the bands evident to the naked eye on the x-radiograph. When these were in relative agreement, direct measurement from the densitometer trace was possible using dividers. [Figure 2]

SAMPLE DISSOLUTION PROCEDURE

Coral samples were dissolved to determine the amount of trapped insoluble residue that was contained within the coral skeleton. This sediment was thought to be fine siliclastics that were present as suspended particulate matter and incorporated into the coral skeleton. Depending on the thickness and shape of the original slab, an attempt was made to cut samples so as to produce a block of roughly similiar weight (20-35 g).Once the

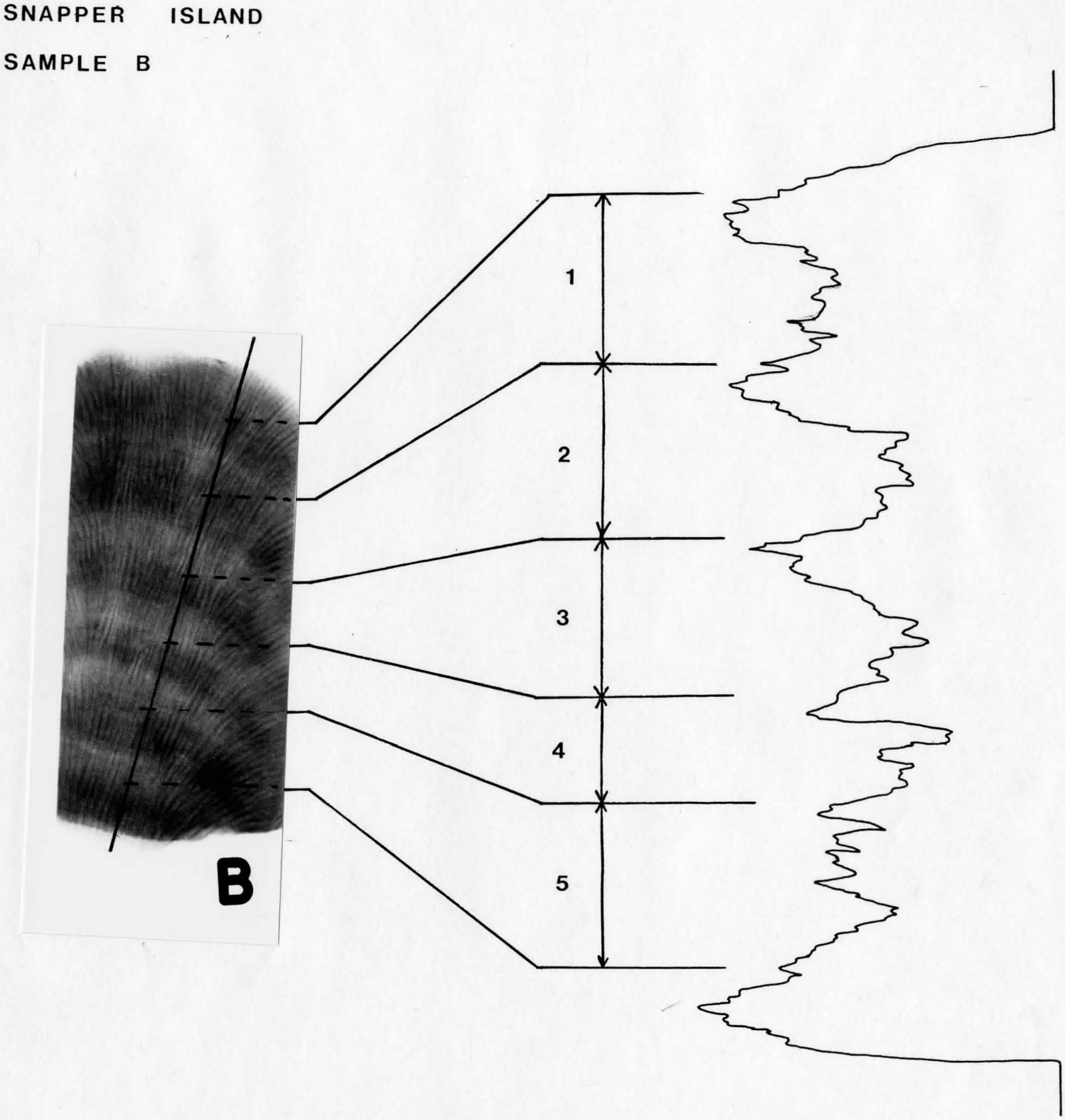


Figure 2 Comparing the x-radiograph positive to the microdensitometer trace obtained from the radiograph. The trace is made on a 2:1 ratio in the densitometer.

blocks were cut, they were immersed in 50% hydrogen peroxide for a period of 24 hours, to dissolve trapped organics. Many samples showed boring algal banding. The samples were then dried in an oven at 110 C for a period of 8 hours, after which they were allowed to cool and were then weighed. Using an initial solution strength of 10% HCl, the samples were kept covered by a minimum of 1 cm of liquid. As the reaction between the carbonate and the acid slowed, concentrated HCl was added in small amounts to maintain a steady rate of reaction. When the sample was completely dissolved, the solution was filtered using 45 um Millepore filters. These filters had earlier been soaked in slightly acidic water, rinsed in distilled water, dried and weighed. After filtering, the filters were again dried and weighed. Initial results seemed excessively high and upon re-filtering using only hot distilled water, reasonable results were obtained. It was determined that calcium chloride had been precipitating and was thus getting trapped on the filter. To avoid continued occurrence, all solutions were heated before filtering as well as rinsing all filters with hot distilled water after filteration of the sample was complete.

SUSPENDED PARTICULATE MATTER DETERMINATIONS

SPM values were measured on site at the time of coral sample collection. 1 l samples were collected and filtered using pre-weighed Nuclopore filters. If the amount of suspended sediment in the sample was high, then only 0.5 l samples were filtered. Filters were then weighed to give SPM values. This process was then repeated and the values averaged.

DISTANCES

Coral sampling sites were noted during the initial cruise on which they were collected. These sites were then re-plotted onto two nautical maps (Aus 831 and Aus 831) which cover the study area. All distances were then measured directly from these maps.

STATISTICAL ANALYSIS

Averages, standard deviations and linear regressions were calculated for the data. The standard deviations calculated were for that of a sample and not a population due to the relatively small sample size.

OBSERVATIONS

Most of the cut coral slabs showed dark and light banding. Some of the slabs showed sharp, narrow, distinct dark bands while others had broad, diffuse, faint bands and still others showed no trace of dark banding whatsoever. Again, variation was common within samples from a specific reef, as well as between the various reefs. There seemed to be a general trend moving across the shelf away from shore for the corals to have better defined and more frequent bands. Samples taken from the offshore reefs of Opal and Norman showed thin, distinct dark bands spaced closely together at fairly regular intervals. Representatives of the midshore reefs showed a change to more diffuse, wider band withe a larger spacing but still seemingly at relatively regular intervals. Both Tongue and Rudder Reef corals clearly showed this banding but the third midshore reef sampled, Low Isles, revealed only very faint dark banding. This was also the case with the two mearshore reefs, Snapper and Korea, whose samples showed faint banding only, if any at all. These bands correlated with bands evident from the radiographs, thus supporting the conclusion of Risk et al.(1987) that the algal banding is annual.

A similiar offshore trend was noticeable when examining density differences as revealed by the x-radiographs. There was a large variation in the clarity and sharpness of all structures found within the sample group as a whole. This variation is not too upsetting, in that a possible explanation may be related to the reef distribution with respect to the shoreline, but large variations were also observed within samples from a specific reef. These latter variations are more difficult to explain. Thus, as a result of these variations and the relatively small sample size used (38), these observations should be considered as general trends only.

Density differences are represented by light and dark bands. Light bands on the radiograph negative represent more dense bands and the dark bands are less dense material. This is reversed when dealing with x-radiograph positives. Variations in definition and width of fine structures were noted for all reefs.

Snapper: Very clear, distinct annual banding with broad light and dark bands. No observance of fine structure.

Korea: Annual banding apparent but not as clear as Snapper samples. Fine structure is poorly developed.

Low: Annual banding clearly developed with dark bands being sharper and narrower than Snapper and Korea samples. Little to no development of fine structure.

Rudder: Annual banding apparent but not well developed. Fine structure visible but not well developed.

Tongue: Annual banding clearly apparent with broad light and dark bands. Fine structure visible but not well developed.

Opal: Annual banding apparent but not distinct. Dark bands thinner relative to other samples. Fine structure becoming sharp and clear.

Norman: Annual banding apparent but not distinct. Fine structure well developed and sharp.

The inshore corals appear to be characterised by clear annual bands accompanied with no development of fine structure. Annual bands are composed of approximately equal thicknesses of low and high density bands with gradational contacts between them.

Samples from midshore reefs have little or no development of fine structure and the degree to which annual bands are developed is quite variable. Annual bands range from sharp, thin and distinct to broad and diffuse.

A marked characteristic of the offshore samples is the good development of fine structure. Annual banding is apparent,but is less defined than the fine structure.

RESULTS

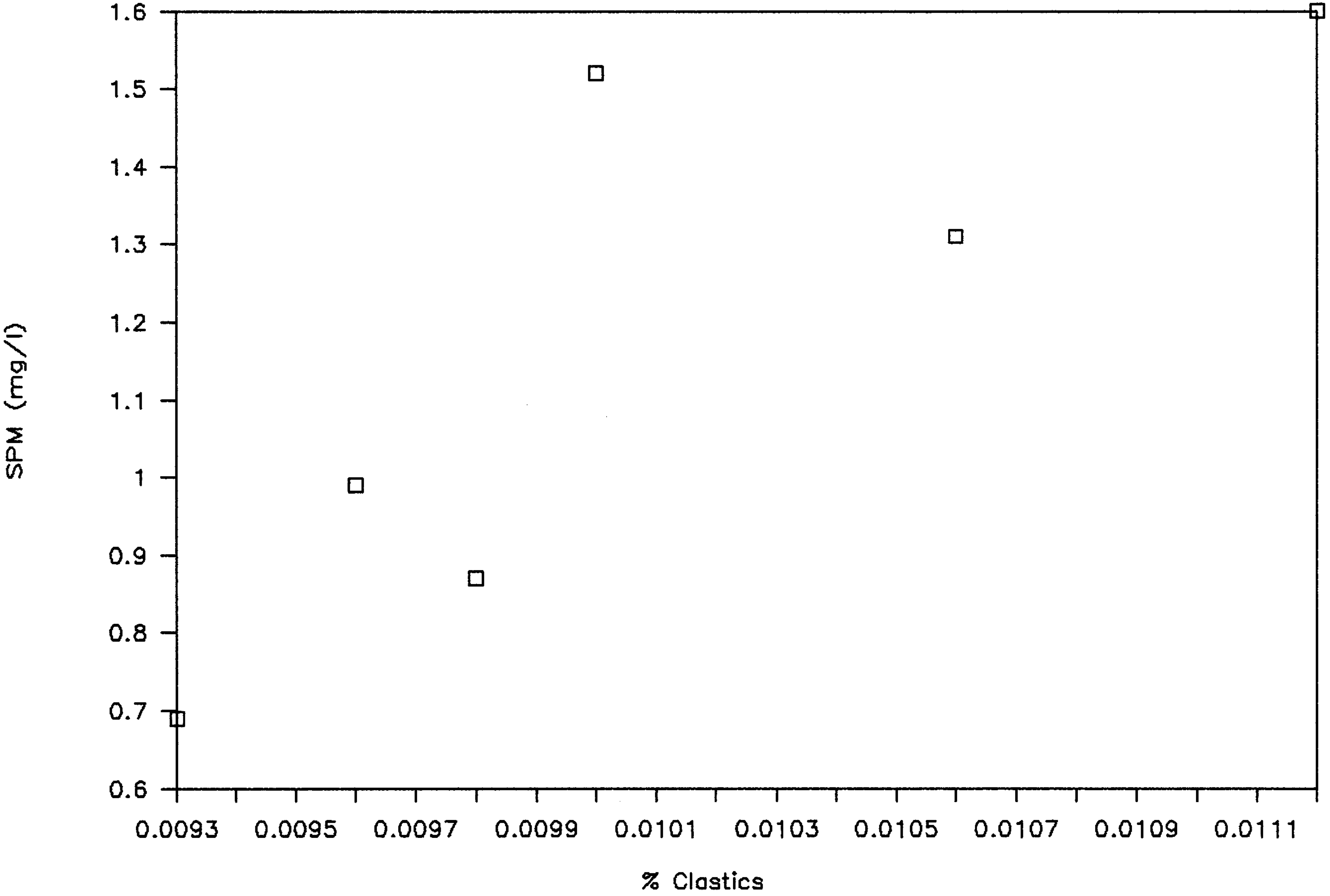
Trapped siliciclastics and growth rate data are presented in in appendices A and B respectively. Every coral slab that was sampled did not necessarily give useable results. In the case of growth rate measurements, some radiographs were unreadable and no growth rate could be measured. When determining values of trapped clastic sediments, unusually high values were noted. Observations made during decalcification were checked, and excessive suspended algae which did not dissolve in the peroxide treatment appeared to be the cause of the heavy filters, in most cases. For those heavy values where algae had not been observed in the filtrate, the original coral slab was then carefully checked. In these remaining cases, borings were readily observable, thus I presumed that unusually high amounts of clastics were introduced into the coral head by means other than incorporation during growth. Samples affected by either of these observations were Rudder C and E, Tongue D and supplementary C, Low supplementary C, Opal G and K, and Snapper E and F.

Upon washing with hot distilled water, some filters lost substantial amounts of weight. Although this treatment was designed to dissolve any trapped calcium chloride, it was determined that some clastic sediments must have been washed off the filter during the washing. Samples affected by this were Rudder D, F and supplementary F, and Korea B.

Various combinations of % trapped clastics, average growth rate, SPM, distance from shore, and distance from the Daintree River were plotted against each other [figures 2-11]. Linear regressions were calculated on all combinations plotted, with this regression information being found in Appendix C. Non-significant ($p > 0.05$) relationships were: % trapped clastics vs growth rate ($n=5, r=0.5968$), and growth rate vs distance to Daintree River ($n=5, r=0.6652$). Significant relationships ($p < 0.05$) were: % trapped clastics vs SPM ($n=4, r=0.8306$), growth rate vs SPM ($n=4, r=0.8432$), growth rate vs distance to shore ($n=5, r=0.8346$), % trapped clastics vs distance to shore ($n=5, r=0.8122$), % trapped clastics vs distance to Daintree River ($n=5, r=0.9758$), distance to shore vs SPM ($n=4, r=0.9866$), and distance to Daintree River vs SPM ($n=4, r=0.9007$). Growth rate vs % trapped clastics was plotted again using all data points, and where one value (either growth rate or % trapped clastics) did not have a corresponding value, reef averages were substituted instead [figure 10]. Also, growth vs year of growth was plotted [figure 11]. Data on regression functions for these two plots can be bound in Appendix D. No significant relationships were found.

Figure 3 Reef averages of trapped clastic sediment vs SPM values. A significant ($p < 0.05$) relationship is shown ($n=4$, $r=0.8306$).

Figure 4 Reef average growth rate vs SPM values. A significant relationship is shown ($n=4$, $r=0.8432$).



% Clastics vs SPM

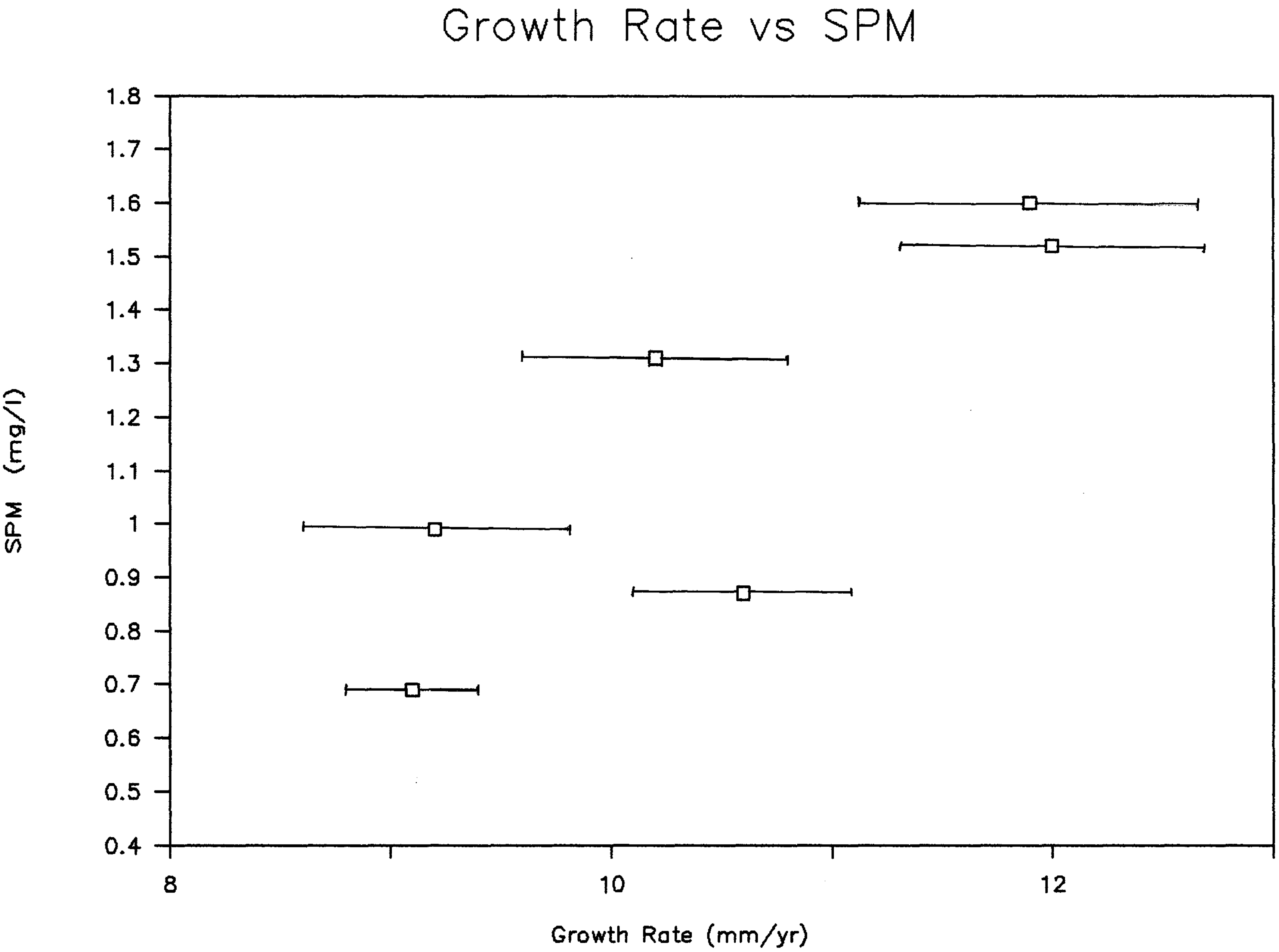
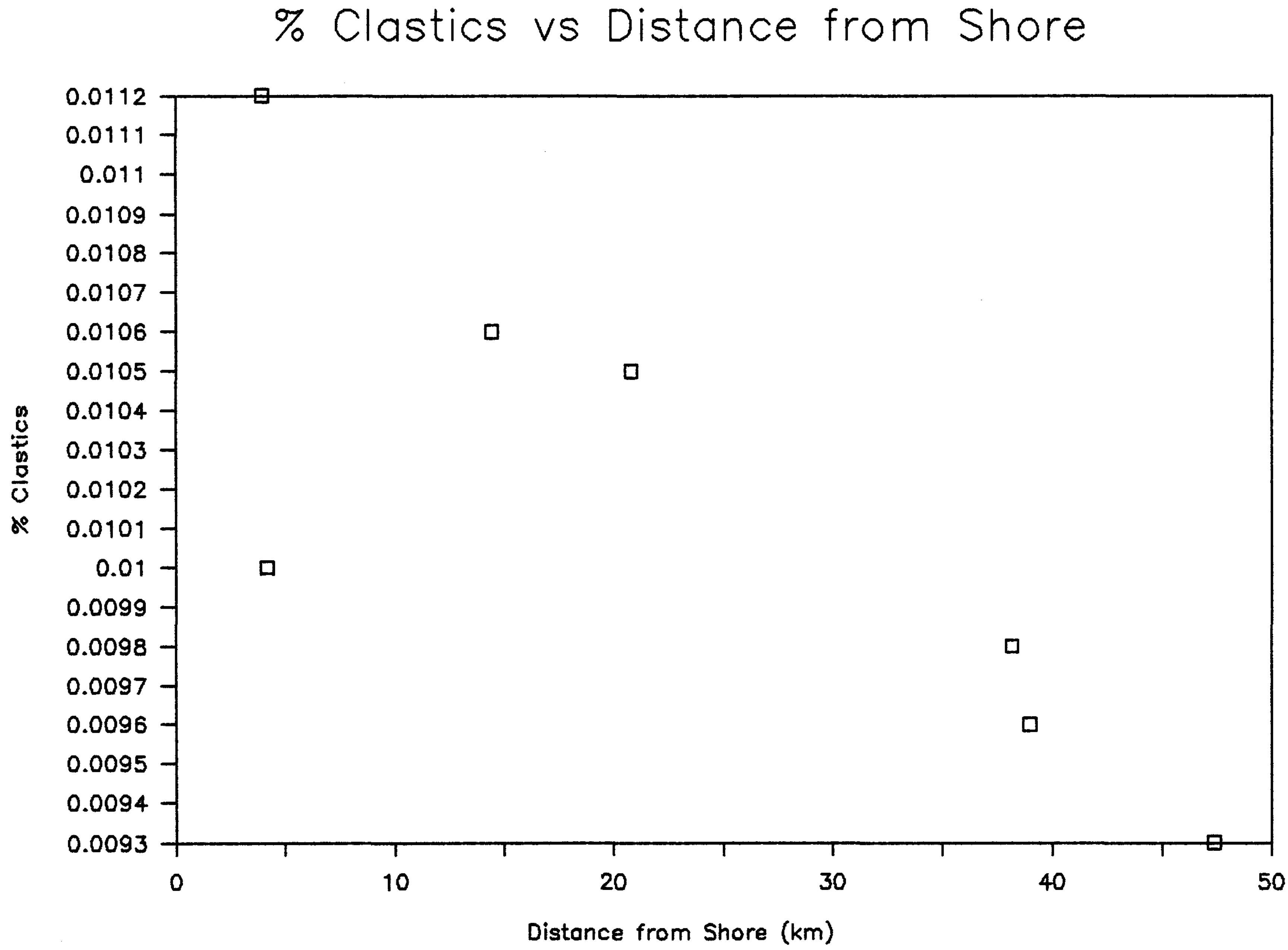

Growth Rate vs SPM
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
SPM (mg/l)
8
10
12
Growth Rate (mm/yr)

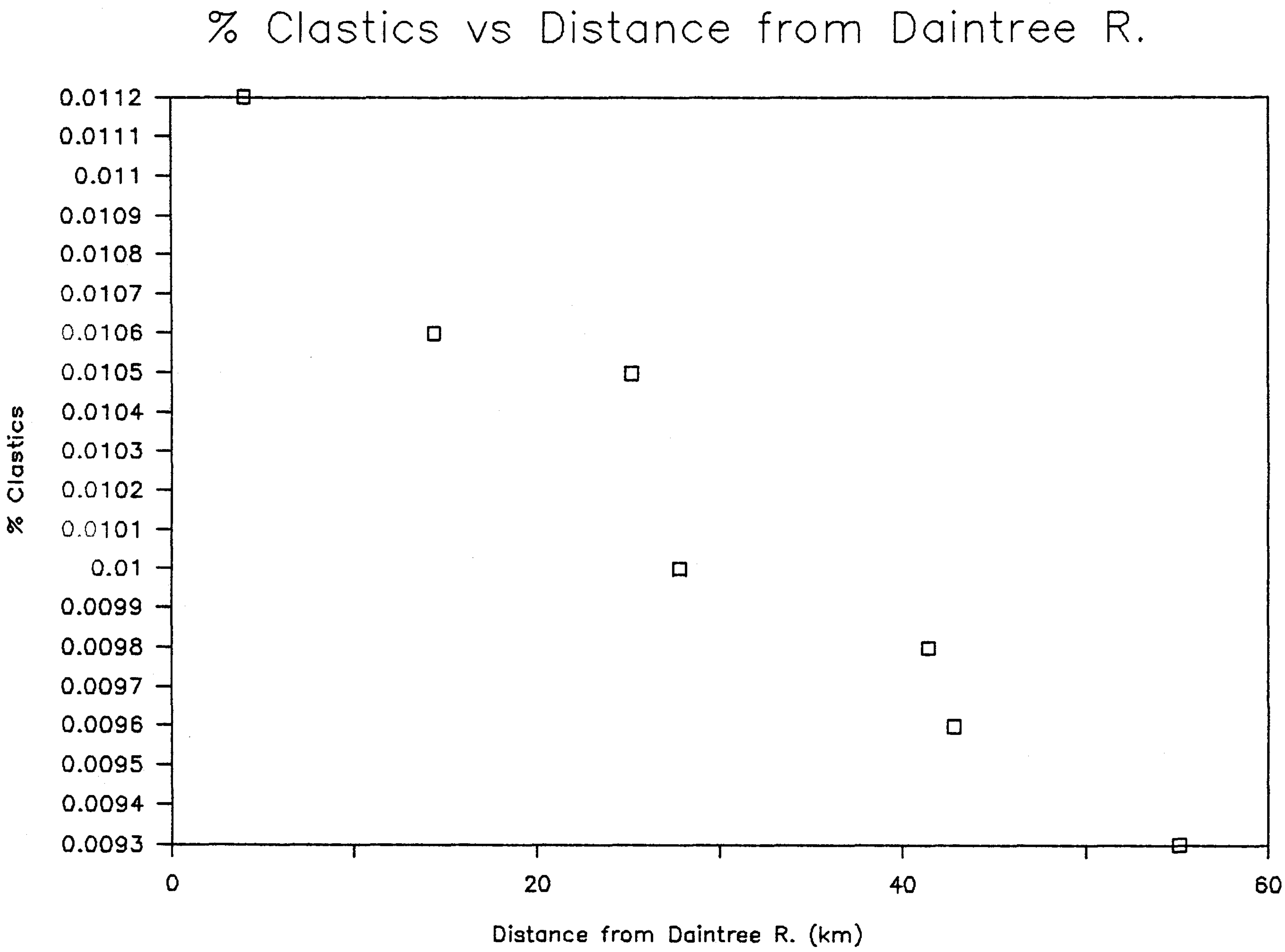
Figure 5 Reef averages pf trapped clastics vs distance from shore. A significant ($p < 0.05$) relationship is shown ($n=5$, $r=0.8122$).

Figure 6 Reef averages of trapped clastics vs distance from the Daintree River. A significant relationship is shown ($n=5$, $r=0.9758$).

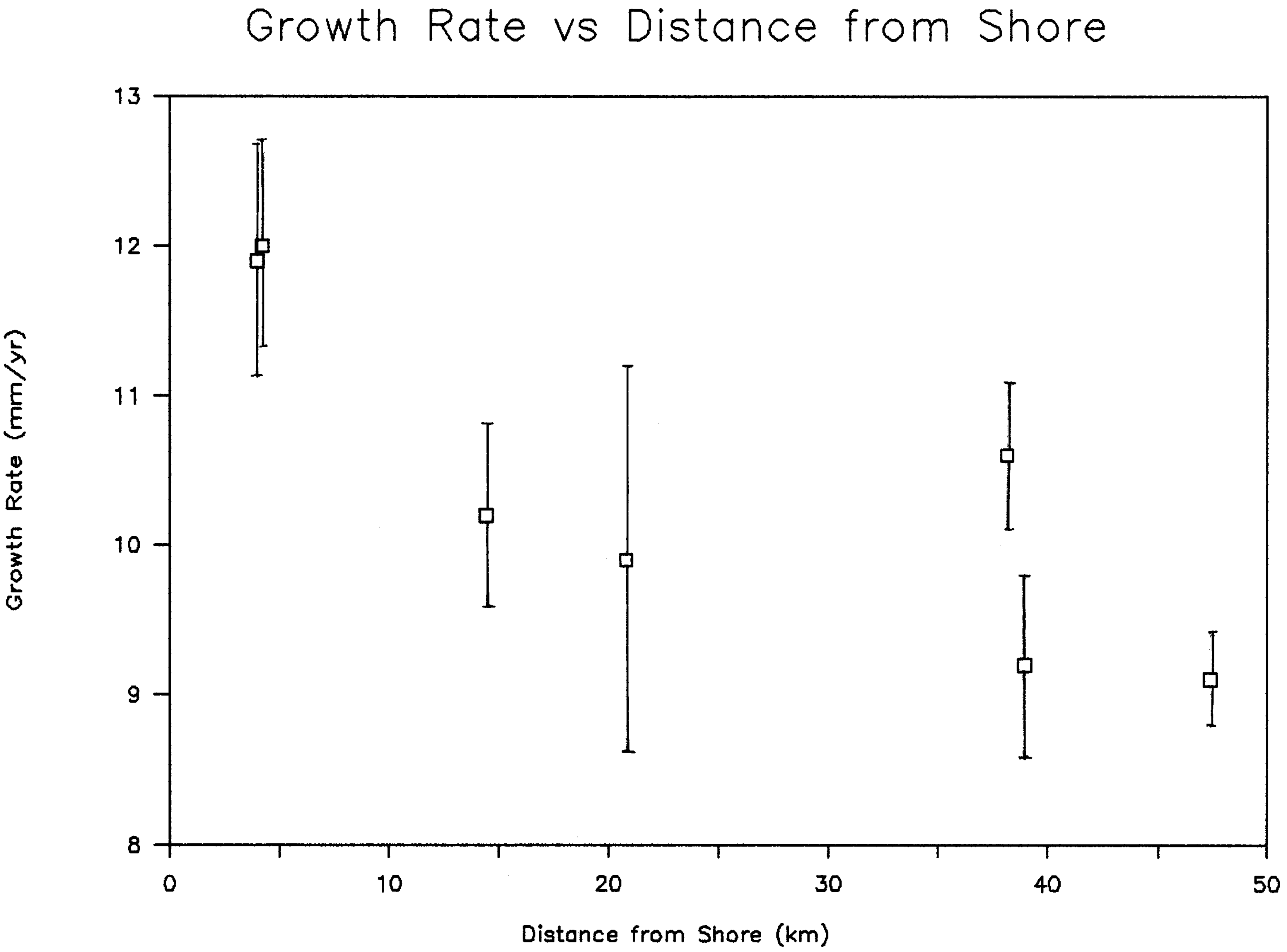
Figure 7 Reef average growth rate vs distance from shore. A significant relationship is shown ($n=5$, $r=0.8346$).

Figure 8 Reef average growth rate vs distance from the Daintree River. An insignificant ($p > 0.05$) relationship is shown ($n=5$, $r=0.6652$).


% Clastics vs Distance from Shore
0.0112
0.0111
0.011
0.0109
0.0108
0.0107
0.0106
0.0105
0.0104
0.0103
0.0102
0.0101
0.01
0.0099
0.0098
0.0097
0.0096
0.0095
0.0094
0.0093
% Clastics
0
10
20
30
40
50
Distance from Shore (km)



% Clastics vs Distance from Daintree R.


Growth Rate vs Distance from Shore
Growth Rate (mm/yr)
13
12
11
10
9
8
0
10
20
30
40
50
Distance from Shore (km)

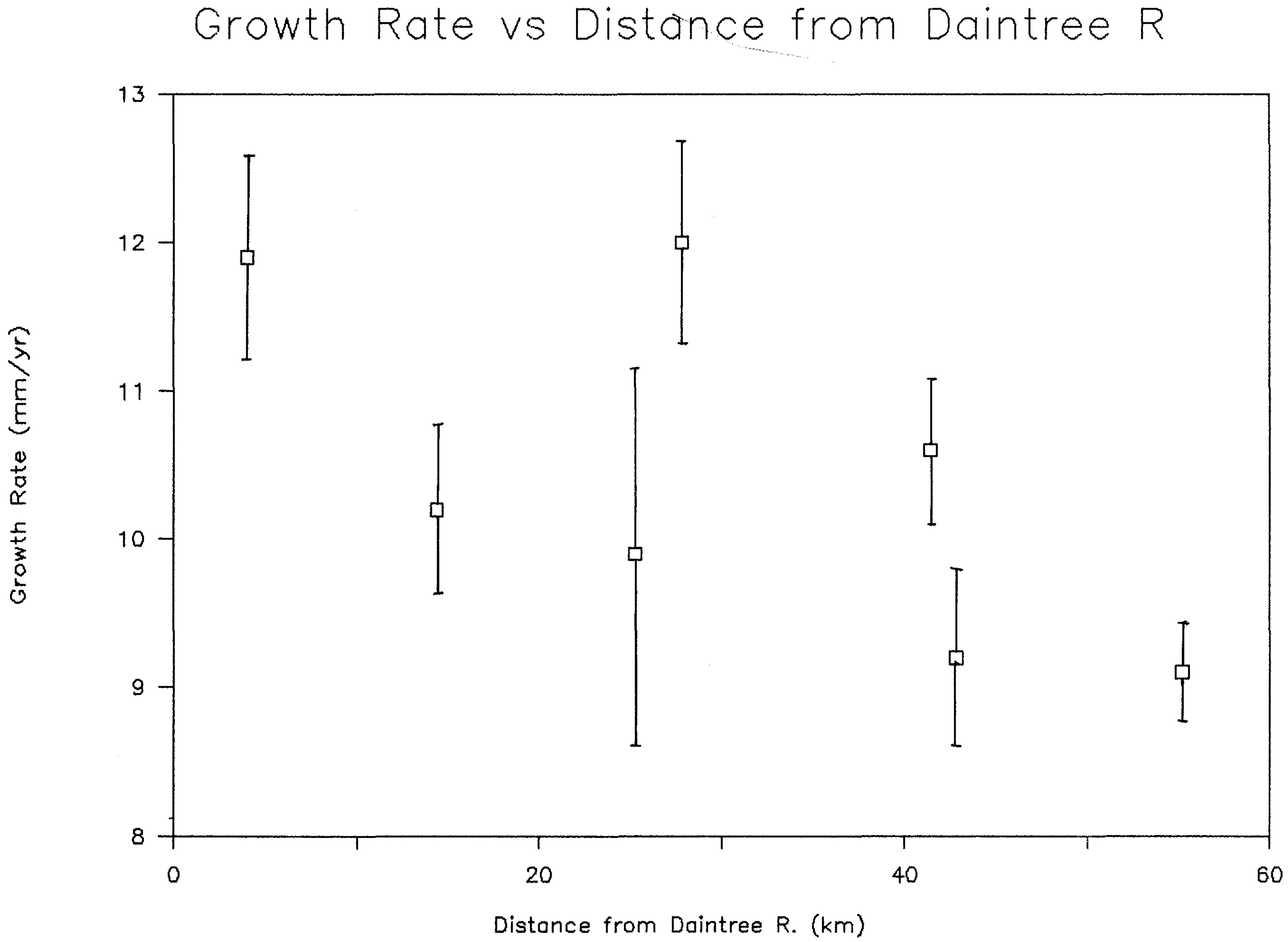
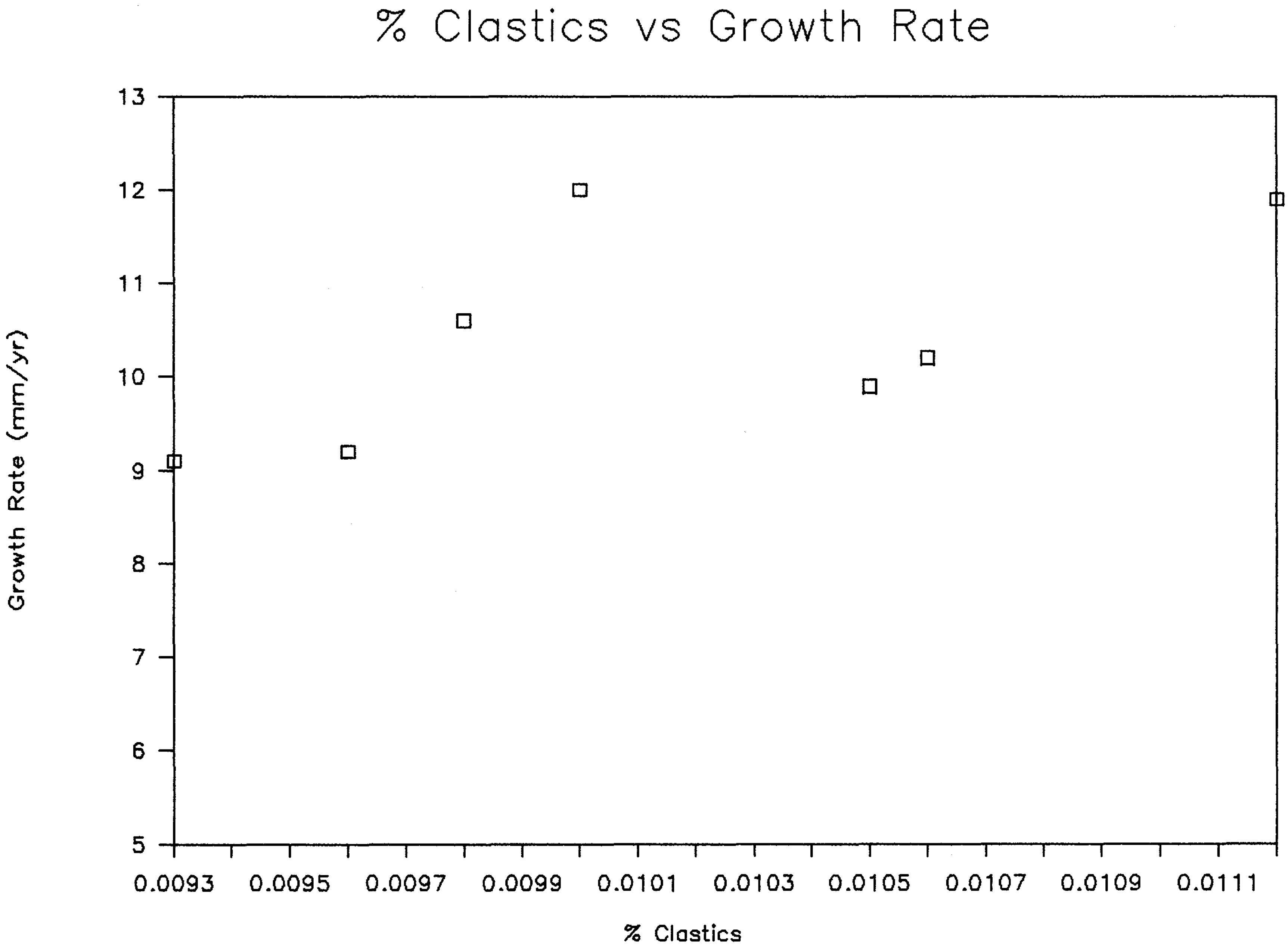

Growth Rate vs Distance from Daintree R
Growth Rate (mm/yr)
13
12
11
10
9
8
0
20
40
60
Distance from Daintree R. (km)

Figure 9 Reef average of trapped clastic sediment vs growth rate. An insignificant ($p > 0.05$) relationship is shown ($n=5$, $r=0.5968$).

Figure 10 Individual sample values of trapped clastic sediments vs growth rate. An insignificant relationship is shown ($n=50$, $r=0.0050$).


% Clastics vs Growth Rate
Growth Rate (mm/yr)
13
12
11
10
9
8
7
6
5
0.0093
0.0095
0.0097
0.0099
0.0101
0.0103
0.0105
0.0107
0.0109
0.0111
% Clastics

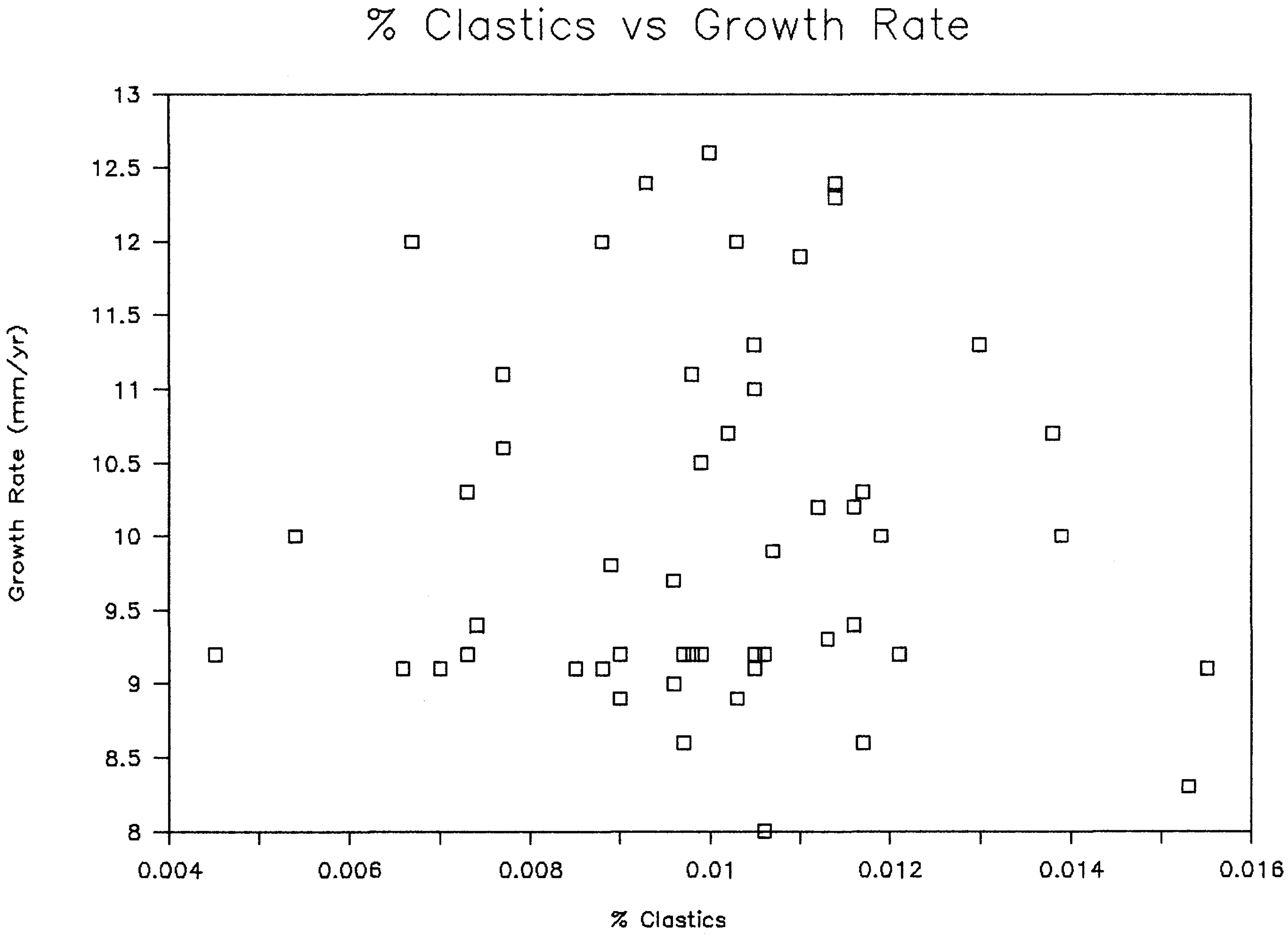
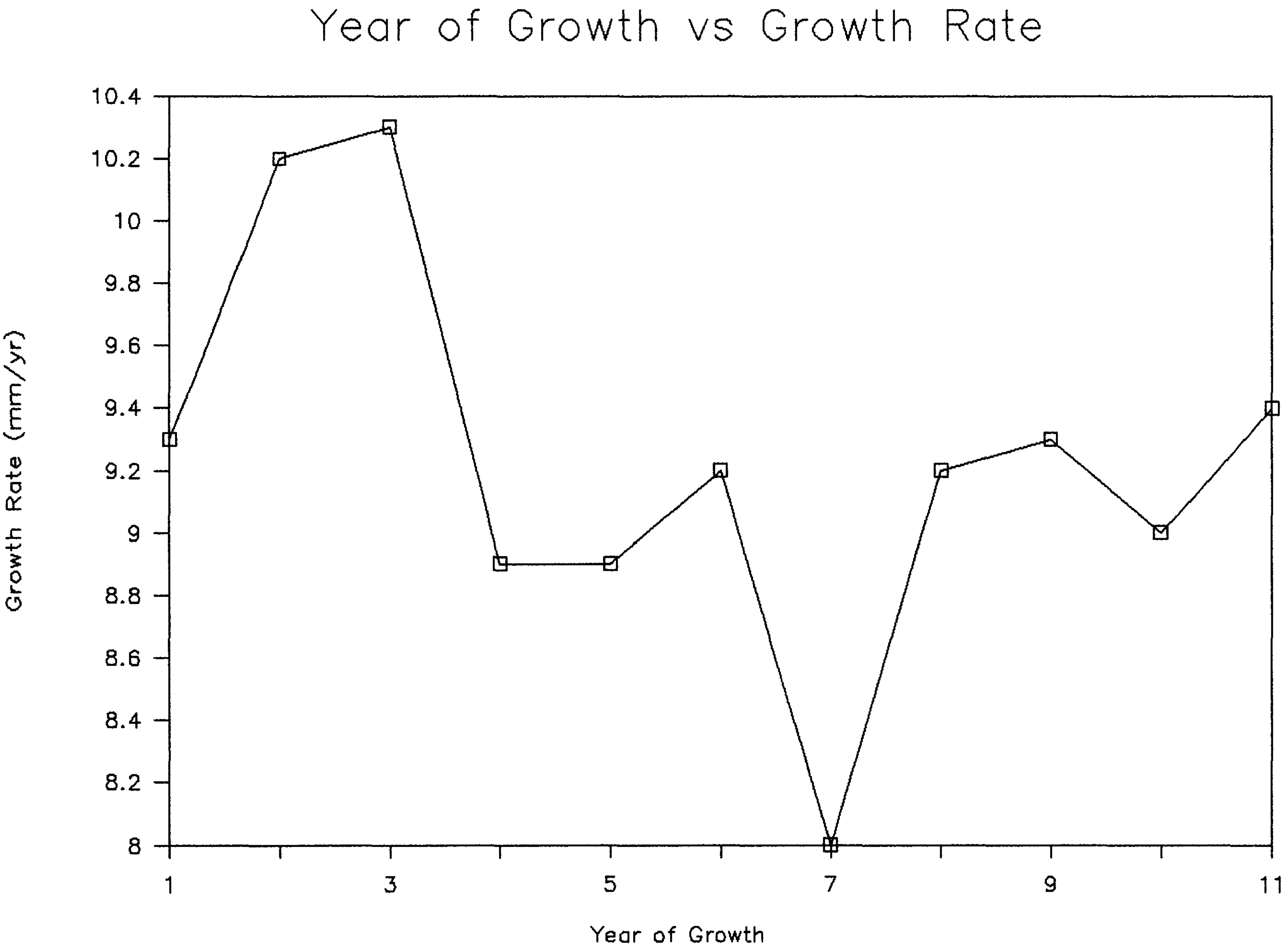

% Clastics vs Growth Rate
Growth Rate (mm/yr)
13
12.5
12
11.5
11
10.5
10
9.5
9
8.5
8
0.004
0.006
0.008
0.01
0.012
0.014
0.016
% Clastics

Figure 11 Year of growth, starting with the present, vs average growth rate. An insignificant ($p > 0.05$) relationship is shown ($n=9$, $r=0.3666$).


Year of Growth vs Growth Rate
Growth Rate (mm/yr)
10.4
10.2
10
9.8
9.6
9.4
9.2
9
8.8
8.6
8.4
8.2
8
1
3
5
7
9
11
Year of Growth

DISCUSSION

The results of the study support one of the original hypotheses while contradicting the second. I initially believed that high SPM values would be reflected in higher values of trapped siliciclastics, and since SPM values decreased moving offshore, then the amount of siliciclastics trapped within the coral skeleton would also decrease. This relationship is shown in figure 3. My second hypothesis also involved SPM values, but in this case, I believed that high amounts of suspended sediment would be detrimental to coral growth rates (Cortes and Risk,1985). Our study did not support this hypothesis: as growth rate increased with increasing SPM, and increased inshore [figures 19,23 and 24]. This suggests that siltation stress is not the only factor involved, and that the other factors operating are the dominant processes in this particular study. Work done by Isdale (1987) on corals in the GBR in the general vicinity of our study showed the same trend, where growth rate was greatest in inner shelf positions and decreased moving towards the outer shelf. He attributed this to elevated nutrient levels stimulating growth rate of coral on inshore reefs. Increased nutrient levels occur with increased suspended sediment as a result of increased river discharge from continental rainfall runoff. Thus, with the distinct seasonality of the area, these elevated nutrient and SPM levels are also distinctly seasonal. The study by Isdale (1987) and that by Cortes and Risk (1985) appear to represent the two extremes when dealing with the two factors of high suspended sediment and elevated nutrient levels. Risk proposes (personal comm.) that there will be some middle ground where high sedimentation rates inshore will be deleterious to coral growth, as will low nutrient levels found offshore, but an optimum combination of maximum nutrients and minimum siltation will result in maximum growth somewhere in between. In this study, it is clear that increased nutrient levels is the key factor, but if Risk's proposal is correct then it is possible that the amount of suspended sediment was not high enough to cause siltation stress.

For this study, we were taking the Daintree River to be our major source of sediment. It is the largest river in the study area and carries much of the runoff. We assumed this to be a point source of sediment, from which currents distributed the sediment up and down the coast and across the shelf. A problem with the assumed pattern of distribution of the sediment is that no detailed work of current patterns has been completed (Pickard,1977). Whatever the specific pattern is, there appears to be a clear relationship found between the percent of trapped siliciclastics and SPM values to both the distance from shore and from the Daintree River [figures 3,5 and 6].

Suspended sediment plays a direct and indirect role in coral growth. Directly, it is the cause of siltation stress. Indirectly, it affects light availability (Bak,1974;Rogers,1979), which has been shown to be one of the key factors in the development of annual density banding in corals (Buddemeier and Kinzie,1975; Highsmith,1979). In our study area, the suspended sediment is introduced as runoff from thunderstorms and cyclones occurring during the rainy season. Thus a coupling effect is seen, where extreme cloud cover and runoff both, reduce light availibility. This may help to explain the observed offshore trend of radiograph-revealed banding variations. As was previously noted, annual banding became less distinct mobing offshore but fine structure became more apparent. The whole area is subjected to decreased light during the rainy season, but only inshore and, to some degree, midshelf reefs have the additional decrease in light due to suspended sediment. This may be the reason for the marked seasonal (annual) banding. The better definition of fine structure may have a similiar explanation in that the factors generating the structures have only subtle influences and thus are erased or overpowered when a strong factor, such as sedimentation, is operating.

A portion of this study dealt with the determination of the amount of trapped siliciclastics. The idea was to use this information as an indicator of SPM values on the sampled reefs. One serious problem with this is that only siliciclastic sediments are left after decalcification. SPM is composed of both siliciclastics and carbonates, and thus the carbonate fraction goes unaccounted for. The importance or predominance of the carbonate fraction is shown in the study by Marshall and Orr (1931) on Low Isles Reef (also one of our sampled reefs), where carbonate sediments of varying origins composed approximately 65 % of the total suspended sediments collected. The problem then becomes, how do you determine the amount of suspended carbonate sediment? Risk (in review) has suggested that, using petrographic methods, the occurrence of any calcite within modern corals can be attributed to suspended sediments which have been incorporated into the skeleton. This can be used only for modern corals that have not been weathered or recrystallized.

To determine growth rates we used x-radiographs and microdensitometer traces of those radiographs. It was thought that the microdensitometer traces would take some of the subjectivity out of measuring the annual bands. In some cases where banding was distinct and obvious on the radiograph, this was supported by the microdensitometer trace, but where it was most needed for samples whose radiographs were unclear, the microdensitometer traces were just as unclear. These traces were extremely spikey and as a result proved very difficult to interpret. As an afterthought, we discussed the possibility of smoothing the trace by using a wider beam on the microdensitometer. Thus only the large scale density differences (annual banding) would be recorded, while smaller scale differences would be ignored. A wider beam may have been especially useful on the outershelf corals, where fine structure was much more evident.

CONCLUSIONS

As an introductory study, this project was very effective in pointing out general trends. Significant relationships were found for the combinations: % trapped clastics vs SPM, average growth rate vs SPM, average growth rate vs distance to shore, % trapped clastics vs distance to shore, % trapped clastics vs distance to the Daintree River, distance to shore vs SPM, and distance to the Daintree River vs SPM. I believe the key findings of this study are that the amount of clastics trapped in the coral skeleton does increase with increasing SPM, and that growth rate also increased with increasing SPM, contrary to our oringinal hypothesis, but in support of Isdale's findings (1987).

The study could have been improved by having a larger coral sample size, more SPM values, and more information on currents and nutrients.

In agreement with Buddemeier et al. (1974), intra-reef and inter-reef variation in linear growth rates, as observed on radiographs, was quite high and appeared to show only general trends. Although absolute values for growth rates were obtained, "linear growth rates do not appear to be a particularly informative parameter" (Buddemeier et al.,1974).

Another and final finding of this study was the agreement found between density banding on the radiographs and the observed algal banding on the corals. This supports the conclusions of Risk et al. (1987), that algal bands are annual.

APPENDIX A

% TRAPPED SEDIMENTS

Sample	Trapped Sediment	Sample Weight	% Trapped Sediment	Reef Average	Standard Deviation
Rudder A	0.0016	15.7201	0.0102		
B	0.0018	16.9226	0.0106		
sup D	0.0028	26.1149	0.0107	0.0105	0.0003
Tongue A	0.0018	15.3286	0.0117		
B	0.0011	14.2205	0.0077		
D	0.0017	14.2810	0.0119		
E	0.0010	10.0774	0.0099		
sup B	0.0025	33.3235	0.0075	0.0098	0.0021
Korea A	0.0016	14.0451	0.0114		
C	0.0022	16.8830	0.0130		
D	0.0016	18.1663	0.0088		
sup C	0.0016	23.8400	0.0067	0.0100	0.0028
Low A	0.0010	13.7571	0.0073		
B	0.0018	20.1149	0.0089		
C	0.0030	21.5734	0.0139		
D	0.0016	14.3408	0.0112		
sup B	0.0031	26.8039	0.0116	0.0106	0.0025
Opal A	0.0023	25.8505	0.0089		
B	0.0036	33.8490	0.0106		
C	0.0047	30.3840	0.0155		
D	0.0039	39.8661	0.0098		
E	0.0022	33.4400	0.0066		
F	0.0030	33.4571	0.0090		
H	0.0030	31.0605	0.0097		
I	0.0012	22.2514	0.0054		
J	0.0035	22.8484	0.0153		
sup C	0.0021	28.6524	0.0073		
sup D	0.0036	36.2084	0.0099		
sup E	0.0013	29.0253	0.0045		
sup J	0.0046	38.0651	0.0121	0.0096	0.0033
Norman A	0.0015	17.5816	0.0085		
B	0.0020	20.6642	0.0097		
C	0.0016	21.7267	0.0074		
D	0.0020	17.6367	0.0113		
E	0.0012	17.0250	0.0070		
F	0.0019	21.5374	0.0088		
G	0.0015	16.6215	0.0090		
H	0.0026	22.3313	0.0116		
I	0.0016	24.0905	0.0066		
sup B	0.0029	24.8118	0.0117		
sup G	0.0015	14.5939	0.0103	0.0093	0.0018

Sample		Trapped Sediment	Sample Weight	% Trapped Sediment	Reef Average	Standard Deviation
Snapper	A	0.0016	13.9944	0.0114		
	B	0.0021	22.5705	0.0093		
	C	0.0027	19.5032	0.0138		
	D	0.0016	15.4813	0.0103		
	G	0.0020	18.2514	0.0110	0.0112	0.0017

Note: samples having the "sup" descriptor refers to supplementary samples taken from the same coral slab

APPENDIX B

Sample			Growth per year				
	1	2	3	4	5	6	7
Rudder A	12.0	10.5	9.5				
B	8.0	8.0	8.0	7.0	8.0	10.0	7.0
C	13.5	12.5	8.0				
D	12.0	12.5	10.0	13.5	12.5	10.0	8.0
E	9.0	9.0	10.0	9.0	8.5		
F	10.0	10.5	8.0	9.0	8.0	8.0	9.0
Tongue A	8.5	8.0	9.0	12.0	14.0		
B	13.0	15.0	11.5	10.0	8.5	8.5	
C	11.5	12.0	11.5	11.0	12.0	10.0	9.5
D	7.0	12.5	8.0	11.0	11.5	10.0	
E	11.5	9.5	9.0	8.0	13.5	11.5	11.0
Korea A	15.0	15.0	14.0	13.0	14.0	15.0	
B	14.0	12.0	12.0	12.0	13.0	13.0	12.0
C	12.0	14.0	14.0	13.0	13.0	13.0	
Low AI	7.0	9.5	12.0	10.5			
AII	8.5	10.5	14.5	9.5			
B	7.5	10.0	13.0	9.0	8.5	11.0	10.5
CI	9.0	9.0	9.5	10.0	11.0	9.0	
CII	11.0	12.5	13.0	9.0	11.0	9.0	
Opal C	10.5	8.0	8.0	8.0	7.5	11.0	8.0
E	9.0	11.5	8.0	7.0	7.0	8.5	11.0
G	10.5	11.0	9.0	10.0	9.0	8.5	
I	12.0	12.0	9.0	10.0	11.0	9.5	8.5
J	8.5	7.0	7.5	9.5	9.0		
KI	10.5	8.0	11.5	7.5	7.5	7.0	11.0
KII	13.0	8.5	12.0	7.5	7.5		
Norman B	8.0	9.0	9.0	7.5	8.0	8.0	9.0
C	9.0	11.0	11.0	9.0	9.0	9.0	10.0
D	8.0	10.0	9.5	9.0	8.5	10.0	10.0
G	8.0	8.0	8.0	9.5	8.5	10.0	9.0
H	8.0	10.0	9.5	9.0	9.0	9.0	10.0
Snapper A	11.0	15.0	13.0	11.0	12.0		
B	14.0	14.0	11.0	11.0	12.0		
C	11.0	12.0	11.0	11.0	10.0	10.0	9.5
D	10.0	11.0	13.0	14.0			
Average	9.3	10.2	10.3	8.9	8.9	9.2	8.0
Standard Deviation	2.0	2.3	1.8	1.2	1.5	0.8	3.9

Sample	Growth per year				Sample Average	Reef Average	Standard Deviation
	8	9	10	11			
Rudder A					10.7		
B					8.0		
C					11.3		
D	11.0	9.5			11.0		
E					9.1		
F	11.0				9.2	9.9	1.3
Tongue A					10.3		
B					11.1		
C					11.1		
D					10.0		
E	10.0				10.5	10.6	0.5
Korea A					12.3		
B					12.6		
C					11.3	12.0	0.7
Low AI					9.8		
AII					10.8		
B	9.0				9.8		
CI					9.6		
CII					10.9	10.2	0.6
Opal C	12.0	9.0			9.1		
E	10.0	9.0	8.5	11.5	9.2		
G					9.7		
I	11.0	6.5	9.0	11.0	10.0		
J					8.3		
KI	11.5	6.0	8.5	6.0	8.6		
KII					9.7	9.2	0.6
Norman B	9.0	10.0	8.0	9.5	8.6		
C	8.0	9.0	9.0	9.0	9.4		
D	9.0				9.3		
G	10.0	9.0	9.0	9.0	8.9		
H	10.0	9.0	10.0	10.0	9.4	9.1	0.3
Snapper A					12.4		
B					12.4		
C	11.0				10.7		
D					12.0	11.9	0.8
Average	9.2	9.3	9.0	9.4			
Standard Deviation	0.8	0.5	0.8	0.5			

Note: Roman numerals refer to supplementary strips cut from the same coral slab.

APPENDIX C

Reef	% Clastics	Growth Rate	SPM	Distance From Shore	Distance From Daintree
Rudder	0.0105	9.9		20.8	25.2
Tongue	0.0098	10.6	0.87	38.2	41.4
Korea	0.0100	12.0	1.52	4.2	27.8
Low	0.0106	10.2	1.31	14.4	14.4
Opal	0.0096	9.2	0.99	39.0	42.8
Norman	0.0093	9.1	0.69	47.4	55.2
Snapper	0.0112	11.9	1.60	4.0	4.0

```
% Clastic  0.0105      9.9              Regression Output:
   vs      0.0098     10.6          Constant                        -0.3869
Growth     0.0100     12.0          Std Err of Y Est                 1.0318
           0.0106     10.2          R Squared                        0.3562
           0.0096      9.2          No. of Observations              7.0000
           0.0093      9.1          Degrees of Freedom               5.0000
           0.0112     11.9
                                    X Coefficient(s)   *********
                                    Std Err of Coef.   640.2644
                                    r                    0.5968
```

```
% Clastic  0.0098     0.87              Regression Output:
vs         0.0100     1.52          Constant                        -3.2489
SPM        0.0106     1.31          Std Err of Y Est                 0.2295
           0.0096     0.99          R Squared                        0.6899
           0.0093     0.69          No. of Observations              6.0000
           0.0112     1.60          Degrees of Freedom               4.0000

                                    X Coefficient(s)   437.5766
                                    Std Err of Coef.   146.6936
                                    r                    0.8306
```

```
Growth       10.6     0.87              Regression Output:
rate         12.0     1.52          Constant                        -1.4234
vs           10.2     1.31          Std Err of Y Est                 0.2216
SPM           9.2     0.99          R Squared                        0.7109
              9.1     0.69          No. of Observations              6.0000
             11.9     1.60          Degrees of Freedom               4.0000

                                    X Coefficient(s)     0.2464
                                    Std Err of Coef.     0.0785
                                    r                    0.8432
```

```
Growth        9.9      20.8                  Regression Output:
Rate         10.6      38.2         Constant                          154.6608
vs           12.0       4.2         Std Err of Y Est                   10.6498
Distance     10.2      14.4         R Squared                           0.6965
to            9.2      39.0         No. of Observations                 7.0000
shore         9.1      47.4         Degrees of Freedom                  5.0000
             11.9       4.0
                                    X Coefficient(s)   -12.5463
                                    Std Err of Coef.     3.7036
                                    r                    0.8346
```

```
growth        9.9      25.2                  Regression Output:
rate         10.6      41.4         Constant                          134.4659
vs           12.0      27.8         Std Err of Y Est                   14.4625
distance     10.2      14.4         R Squared                           0.4425
to            9.2      42.8         No. of Observations                 7.0000
daintree      9.1      55.2         Degrees of Freedom                  5.0000
             11.9       4.0
                                    X Coefficient(s)   -10.0200
                                    Std Err of Coef.     5.0295
                                    r                    0.6652
```

```
% Clastic  0.0105      20.8                  Regression Output:
vs         0.0098      38.2         Constant                          244.9670
distance   0.0100       4.2         Std Err of Y Est                   11.2785
to         0.0106      14.4         R Squared                           0.6596
shore      0.0096      39.0         No. of Observations                 7.0000
           0.0093      47.4         Degrees of Freedom                  5.0000
           0.0112       4.0
                                    X Coefficient(s)   *********
                                    Std Err of Coef.   *********
                                    r                    0.8122
```

```
% clastic  0.0105      25.2                  Regression Output:
vs         0.0098      41.4         Constant                          296.1272
distance   0.0100      27.8         Std Err of Y Est                    4.2328
to         0.0106      14.4         R Squared                           0.9522
daintree   0.0096      42.8         No. of Observations                 7.0000
           0.0093      55.2         Degrees of Freedom                  5.0000
           0.0112       4.0
                                    X Coefficient(s)   *********
                                    Std Err of Coef.   *********
                                    r                    0.9758
```

```
distance     38.2     0.87                   Regression Output:
to            4.2     1.52          Constant                     1.6264
shore        14.4     1.31          Std Err of Y Est             0.0672
vs           39.0     0.99          R Squared                    0.9734
SPM          47.4     0.69          No. of Observations          6.0000
              4.0     1.60          Degrees of Freedom           4.0000

                                    X Coefficient(s)   -0.0189
                                    Std Err of Coef.    0.0016
                                    r                   0.9866
```

```
distance     41.4     0.87                   Regression Output:
to           27.8     1.52          Constant                     1.6976
daintree     14.4     1.31          Std Err of Y Est             0.1791
vs           42.8     0.99          R Squared                    0.8113
SPM          55.2     0.69          No. of Observations          6.0000
              4.0     1.60          Degrees of Freedom           4.0000

                                    X Coefficient(s)   -0.0173
                                    Std Err of Coef.    0.0042
                                    r                   0.9007
```

```
         ***** represents values > 999.9999
```

APPENDIX D

year of growth	average growth rate
1	9.3
2	10.2
3	10.3
4	8.9
5	8.9
6	9.2
7	8.0
8	9.2
9	9.3
10	9.0
11	9.4

% Clastics	growth rate
0.0102	10.7
0.0106	8.0
0.0105	11.3
0.0105	11.0
0.0105	9.1
0.0105	9.2
0.0107	9.9
0.0117	10.3
0.0077	11.1
0.0098	11.1
0.0119	10.0
0.0099	10.5
0.0077	10.6
0.0114	12.3
0.0100	12.6
0.0130	11.3
0.0088	12.0
0.0067	12.0
0.0073	10.3
0.0089	9.8
0.0139	10.0
0.0112	10.2
0.0116	10.2
0.0106	9.2
0.0155	9.1
0.0098	9.2
0.0090	9.2
0.0096	9.7
0.0097	9.2
0.0054	10.0
0.0153	8.3
0.0096	9.0
0.0073	9.2
0.0099	9.2
0.0045	9.2
0.0121	9.2
0.0085	9.1
0.0097	8.6
0.0074	9.4
0.0113	9.3
0.0070	9.1
0.0088	9.1
0.0090	8.9
0.0116	9.4
0.0066	9.1
0.0117	8.6
0.0103	8.9
0.0114	12.4
0.0093	12.4
0.0138	10.7
0.0103	12.0
0.0110	11.9

```
% Clastics                 Regression Output:
   vs             Constant                           10.0676
 Growth           Std Err of Y Est                    1.2161
  Rate            R Squared                           0.0000
                  No. of Observations                52.0000
                  Degrees of Freedom                 50.0000

                  X Coefficient(s)    -2.7152
                  Std Err of Coef.    76.8229
                      r                0.0050
```

```
 Year of                   Regression Output:
 Growth           Constant                            9.6600
   vs             Std Err of Y Est                    0.6130
 Growth           R Squared                           0.1344
  Rate            No. of Observations                11.0000
                  Degrees of Freedom                  9.0000

                  X Coefficient(s)    -0.0691
                  Std Err of Coef.     0.0584
                      r                0.3666
```

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