ENVIRONMENTAL NOTE NO. 168

ENVIRONMENTAL FACTORS AFFECTING CORAL GROWTH IN THE DAMPIER ARCHIPELAGO, WESTERN AUSTRALIA.

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January 1985

DAMPIER ARCHIPELAGO MARINE STUDY

ENVIRONMENTAL CORRELATES OF CORAL SKELETAL EXTENSION IN THE DAMPIER ARCHIPELAGO, WESTERN AUSTRALIA

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FOREWORD

This Environmental Note is the text and data of a paper presented by the author at the annual scientific meeting of the Australian Coral Reef Society, held in Brisbane on November 3-4, 1984.

The work is part of the Dampier Archipelago marine study being conducted by the Western Australian Department of Conservation and Environment.

This is the first of a series of papers which will discuss aspects of the ecology of corals in the Dampier Archipelago (20°S, 117°E) with special reference to factors influencing growth and survival of coral communities in this region.

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1. ABSTRACT

Linear skeletal extension rates of the scleractinian coral *Acropora formosa* have been determined for three locations in the Dampier Archipelago (20°S, 117°E), Western Australia, between March 1982 and November 1983. Temporal variation in extension rate is significantly correlated with seawater temperatures. Differences in extension rate between sites are significantly negatively correlated with differences in sediment deposition rates.

2. INTRODUCTION

The marine environments of the Dampier Archipelago are described comprehensively by Semeniuk *et al.* (1982). Before 1982 the Western Australian Museum carried out surveys of the corals (Marsh, 1978) and studies on the ecology of the crown of thorns starfish *Acanthaster planci* (Wilson and Marsh, 1974; Wilson *et al*, 1974; Wilson and Marsh, 1975) in the region. Although the coral species occurring in this area have been described, the ecology of the corals and coral reefs of this arid coastline remain largely unknown. Planned large-scale industrialisation in this region necessitates an understanding of the surrounding marine communities and of the natural fluctuations in the environmental parameters that affect their growth and survival, if the effects of environmental perturbations are to be predicted and the possible deterioration of these communities minimised.

This paper describes temporal and spatial variations in linear branch extension of the staghorn coral *Acropora formosa*. The relationships between coral growth and environmental parameters are considered from the Dampier Archipelago, where the intra-annual variation in seawater temperature is high (~14°C) and where river run-off is low.

The effects of high sediment deposition on the growth and survival of *A. formosa* are discussed.

3. MATERIALS AND METHODS

3.1 Study Sites

Three study sites were chosen along an apparent turbidity gradient (Fig. 1). Site 1 is in a shallow depression 4m below mean low water spring datum (MLWS) on the reef flat of the fringing reef at Nelson Rocks. This site is exposed to long period wave action, and the coral community is dominated by tabular acropores and pocilliopores. Site 2 (~2m MLWS) is located on a small patch reef (<1ha.) of relatively large, monospecific stands of arborescent _Acropora_ species on the sheltered south eastern side of Conzinc Island. Site 3 (~2m MLWS), on the eastern side of the No Name Rocks, is relatively well protected from cyclonic wave activity. Arborescent _Acropora_ and massive species (_Porites_ sp., _Goniopora_ sp., _Platygyra_ sp.) are common at this site.

The major hydrographic difference between the sites is between the offshore site (1) and the two inshore sites (2,3). Seasonal extremes of temperature and salinity are less at site 1 due to the proximity of the open ocean. The order of exposure to long period waves of the sites is : site 1> site 3> site 2. In addition, sediment in the vicinity of site 1 is coarser and contains more calcium carbonate and less clay than the two inshore sites.

3.2 Statistical Treatment

To determine whether gross spatial and temporal differences existed in coral growth and environmental variables the study period was divided into two periods, 'winter' (April 1 - August 31) and 'summer' (September 1 - March 31). Data from March 1982 and March/April 1983 were not complete and have been omitted from the spatial analyses. Data for site 1 in both years have been used in the analysis of temporal differences. Growth periods within each season were considered as 'replicates'. Parametric and nonparametic tests of significance were carried out on all data sets with agreement in all cases.

3.3 Coral Growth

Linear skeletal extension of apical corallites was estimated by staining live colonies of *A. formosa in situ* with 10 ppm concentrations of Alizarin Red S (Barnes 1972, Lamberts 1974). Growth rates were determined, on average, from 30-50 branch measurements from 4-5 colonies. From November 1982, colonies at site 1 were tagged and growth measurements were initiated after approximately 40 days. After this period growth was not affected by tagging (Simpson, unpublished data).

3.4 Environmental Parameters

Sediment deposition rates were estimated in sediment traps of plastic tubing 0.3m long and 50 mm internal diameter, suspended 0.5m above the bottom at each site. Total dry weight, organic and carbonate fractions were determined by drying and ashing at 120 °C, 600 °C and 1000 °C respectively. The refractory fraction (non-carbonate, inorganic) was determined by subtraction. Five replicates were used to calculate mean sediment deposition rates. Deployment periods in 'summer' were ~8 days and in 'winter' ~37 days.

Temporal trends in temperature were determined from daily noon temperatures recorded by current meters (Neil Brown Instrument Systems, Inc. Mass. USA) in the Dampier Archipelago throughout the study period. Spatial and vertical differences between the study sites and the mooring locations were determined from temperature survey data, collected at 37 stations throughout the Dampier Archipelago.

Salinity was measured with a Yeo-Kal Model 602 Salinity-Temperature Meter.

Vertical light attenuation coefficients were calculated from light intensity profiles measured with a LICOR LI-192S underwater quantum sensor and a LICOR LI-188B meter. Mean bottom irradiance values were computed from global radiation, cloud cover, vertical attenuation coefficients, daylight hours and depth.

4. RESULTS

4.1 Coral Growth

The temporal and spatial patterns in branch skeletal extension for *A. formosa* are summarised in Figure 2. Similar seasonal trends occur at all sites, with minimum growth rates during July 1982 and maximum growth rates during November 1982. Minimum growth rates were 52%, 57% and 46% of the maximum values at sites 1, 2 and 3, respectively. Apart from June 1982 growth rates at the offshore site (1) were always higher than for the inshore sites (2 and 3), which had similar growth rates until September 1982. After this, growth rates at sites 2 and 3 diverged sharply. Growth rates at sites 1 and 3 converged in January and April, 1983 following damage, apparently by cyclonic wave activity, to the experimental colonies at site 1.

4.2 Temperature

Mean sea water temperatures for each growth period, for sites 1 and 2, are given in Figure 3. Advection of oceanic water moderates the environment on the outer fringing reefs of the archipelago (site 1) resulting in lower (~1°C) and higher (~1°C) mean temperatures during 'summer' and 'winter', respectively, than at the two inshore sites. Mean temperature differences between sites 2 and 3 were generally less than 0.2°C. High temperatures (>27°C) were maintained from November 1982 to April 1983. Maximum temperatures occurred during February/March, and minima in July.

4.3 Sediment Deposition Rates

Mean sediment deposition rates (refractory fraction) at the offshore site (1) were generally lower and less variable than at the two inshore sites (Fig. 4). Sediment deposition rates at sites 2 and 3 were similar from July to October 1982, but then diverged sharply. High total sediment deposition rates (>250 g m^{-2} d^{-1}) were measured at site 2 during December 1982 and in January and March of 1983.

4.4 Salinity

Maximum differences in mean salinities between the sites were less than 1.5 ^{o}/oo and 0.5 ^{o}/oo in 'summer' and 'winter', respectively. Seasonal differences in mean salinities were 0.5 ^{o}/oo and 1.0 ^{o}/oo at the offshore and inshore sites respectively. Maximum mean salinities occurred from November 1982 to April 1983 (35.9 ^{o}/oo at site 1; 37.0 ^{o}/oo at site 2) and minima in July 1982 and July 1983.

4.5 Bottom Irradiance

Computed mean bottom irradiances were not significantly different during 'winter' (all sites) or during 'summer' between sites 2 and 3 and between sites 1 and 2. Maxima occurred during August/September, 1982 (sites 2 and 3) and October/November 1982 (site 1). During November 1982, computed mean bottom irradiances at sites 2 and 3 declined sharply to minima in January 1983 (site 3, 118 $\mu E\ m^{-2}\ s^{-1}$; site 2, 130 $\mu E\ m^{-2}\ s^{-1}$). Similarly after October/November 1982 computed mean bottom irradiances at site 1 declined to a minimum (200 $\mu E\ m^{-2}\ s^{-1}$) in February 1983. Light loggers (McIlwraith Instrumentation Pty. Ltd., Tas.) were deployed, ~ 0.7m above the bottom, at sites 1 and 2 from November 4 - 14, 1983 to validate the computed bottom irradiances. Mean values during daylight hours at sites 1 and 2 were 420 $\mu E\ m^{-2}\ s^{-1}$ and 400 $\mu E\ m^{-2}\ s^{-1}$ respectively; these means were not significantly different.

5. DISCUSSION

5.1 Temporal Variation

Temporal variation in coral growth rate showed similar trends at all sites. Minimum growth rates coincided with periods of low water temperatures (21-22 ^{o}C) and maximum growth rates occurred during moderate temperatures (27-28 ^{o}C). The low intra-annual variability in bottom irradiance, salinity and sediment deposition at site 1 suggests that temporal variation in coral growth is causally related to temperature variation (21-31 ^{o}C) during the year. However, although mean temperatures increased in December 1982 to a maximum in February 1983, growth rates were lower than in November 1982. In addition, growth rates during August to November 1982 were higher at similar temperatures than during December to April in both years. This suggests that other factors were affecting the growth rates of <u>A. formosa</u>.

The relationship between coral growth rate and temperature is clearly positive at all sites (Fig. 5). This relationship was different between December 1 and April 30 (cyclone season) and the remainder of the year. Significant correlations were obtained for sites 2 and 3 when all data at each site were included and for all sites with data from the precyclone season. Growth rates and temperature were not significantly correlated during the cyclone season (Table 1). Periods of cyclonic wave activity, high temperatures (>30 ^{o}C) and increased turbidity due to local resuspension of sediments by wind waves and the widespread occurrence of the tropical, planktonic alga, <u>Trichodesmium</u> <u>erythraeum</u> all occur in the December to April period.

It therefore seems possible that mechanical damage, supra-optimal temperatures, reduced light and the metabolic cost of sediment rejection are all possible explanations for the reduced growth rates observed during this period. Mechanical damage, presumably by cyclonic wave activity occurred in March 1982 (site 1, site 3), January 1983 (site 1) and in April 1983 (site 1). Growth rates were markedly reduced during these periods and appeared to be reduced in the periods following extensive damage to the experimental corals (site 1, April 1982, February 1983; site 3, April 1982). These observations are supported by the growth rates of _Pocilliopora damicornis_ which appeared undamaged at site 1 during the same periods. This species maintained relatively constant growth rates during December 1982 to April 1983. Correlations of growth rates between these two species increased (from r=0.74, n=12, to r=0.96, n=8) when 'damaged' coral growth rates, from December to April in each year, were excluded.

Isolated incidences of bleaching (expulsion of zooxanthellae) were observed at all sites in February/March of 1982, 1983 and at site 2 in March 1984. Maximum temperatures for this period in 1983 were 31.2°C, 31.9°C and 32.7°C for sites 1, 2 and 3 respectively. Expulsion of zooxanthellae can be triggered by stress (Goreau, 1964; Bak, 1978) and Yap and Gomez (1981) attributed reduced growth rates of _Acropora pulchra_, in the Philippines, to the effect of supra-optimal (>30°C) temperatures.

Maximum growth rates at site 1 in November 1982 coincided with maximum computed mean bottom irradiance at this site. From December 1982, light levels declined, to a minimum in February 1983, again coinciding with reduced growth rates. Similar, but more marked, decreases occurred at the two inshore sites. At site 2 high sediment deposition rates were recorded from December 1982 to March 1983 and coincided with a decline in growth rates.

There are insufficient data to explain the apparent reduction in growth rates over the December to April period of 1982 and 1983, although mechanical damage by cyclonic wave activity at site 1 and site 3 and the effects (reduced light and/or inundation) of high levels of sediment deposition at site 2 are the most obvious explanations. However, reduced light levels at sites 1 and 3 and supra-optimal temperatures at all sites cannot be excluded. The temporal trends in coral growth at these sites are consistent with published seasonal variations observed in staghorn corals, in locations where minimum temperatures are below $\sim 26^{\circ}$C (Shinn, 1966; Oliver, 1983; Crossland, 1981).

5.2 Spatial Variation

Spatial differences in coral growth rate and in the environmental parameters were minimal during April to August 1982. During 'winter' mean coral growth rates at site 2 and site 3 were not significantly different and at these two sites there was no significant difference in any of the physical parameters measured. During 'winter' growth rates at site 1 were generally higher than at the two inshore sites. Mean temperatures and computed mean bottom irradiances were not significantly different but the mean sediment deposition rate at site 1 was significantly lower than at the two inshore sites. In 'summer' mean growth rates were significantly different between all sites with site 1> site 3> site 2. Again water temperature and bottom irradiance between sites 1 and 2 and 2 and 3 were not significantly different but sediment deposition rates were significantly different with site 1< site 3< site 2. Hence, the difference in growth rates between the offshore site and the two inshore sites in 'winter', and between all the sites in 'summer', may be due to the effects of different sediment deposition rates. Past studies elsewhere have shown that high rates of sediment resuspension and sedimentation reduce coral growth (Hudson, 1981; Dodge *et al*, 1974; Dodge and Vaisnys, 1976), especially that of branching, foliose and tabular species (Hudson, 1982; Kendall *et al*, 1984; Endean, 1973). To examine the relationship between spatial variation in coral growth and physical parameters, correlations were sought between differences in coral growth, between the sites, and differences in the environmental variables, for 6 growth periods between June 30, 1982 and March 10, 1983. Significant negative correlations were obtained between coral growth and total and refractory (inorganic, non-carbonate) sediment deposition rate (Table 2). The relationship between difference in coral growth and difference in refractory sediment deposition rate has been approximated by a TYPE I linear regression model, but there is some indication that the relationship is curvilinear (Fig. 6). The refractory fraction was used as an index of the medium term ($\sim$40 days) sediment deposition environment rather than the total amount trapped which, at site 1, occasionally included large fragments of coral rubble resuspended by long period wave activity.

The effects of sediment resuspension and sedimentation on reef corals are mainly associated with removal of sediment from the surface of the live coral, and reduced photosynthesis caused by lowered light levels. Differences, between sites 1 and 2, in computed mean bottom irradiances were not significantly different during October 1982 ($330 \mu E\ m^{-2}\ s^{-1}$ and $305 \mu E\ m^{-2}\ s^{-1}$ respectively) whereas differences in sediment deposition rate of the refractory fraction and differences in coral growth were significantly different. The recorded bottom irradiances from instruments deployed at sites 1 and 2 during November 1983 and the computed bottom irradiances support the conclusion that, due to a combination of higher light attenuation and shallower depths at sites 2 and 3, the differences in mean bottom irradiance between the inshore and the offshore sites were not significantly different from June to October 1982. It is unlikely that light at these levels is limiting growth of <u>A. formosa</u> (Chalker and Dunlap, 1983). These data suggest that the difference in growth rates between sites 1 and 2 in October 1982 may have been caused by the metabolic cost of sediment rejection rather than by reduced photosynthesis.

During November 1982 to March 1983 high total sediment deposition rates (>250 $g\ m^{-2}\ d^{-1}$) were recorded at site 2; by May 1983 these levels had declined, and by August 1983 were approximately the level of August, 1982. These high levels coincided with increased dredging activities, in the vicinity of sites 2 and 3. From November 1, 1982 to November 27, 1982 140,000 m^3 of dredge spoil from the Materials Offloading Facility (MOF) (Figure 1) was dumped approximately 1.5 km north of the MOF jetty. From December 1, 1982 to February 21, 1983 a further 400,000 m^3 of dredge spoil from the Product Berth (Figure 1) was dumped in the upper area of No Name Creek (Woodside Offshore Petroleum Pty. Ltd, 1983). In December 1982 a sediment plume was observed to extend from the MOF jetty to Conzinc Island (~8 km). In January 1983 and in early March 1983 sediment plumes were observed to extend from No Name Creek northwards to Conzinc Island (~7.5 km). In addition to these dredging activities, backfilling for the pipeline trench commenced on November 13, 1982 and was completed on June 30, 1983. Approximately 940,000 m^3 of crushed rock was used along the pipeline route from 0.1 km to 22.0 km (Woodside Offshore Petroleum Pty. Ltd, 1984). Before November 1, 1982 mean sediment deposition rates at site 3 were significantly correlated with site 1 ($r=0.82$, $n=7$) and site 2 ($r=0.88$, $n=6$) for simultaneous deployments. Between November 1982 and April 1983 site 3 was significantly correlated with site 1 ($r=0.94$, $n=5$) but not with site 2 ($r=0.31$, $n=3$). These data and field observations suggest that the high rates of sediment deposition at site 2 were influenced by dredging activities. By April 19, 1983 (the last collection date) coral colonies at this site were recorded as "appearing unhealthy" (patchy loss of zooxanthellae throughout the colony). By March 1984 high mortality of the corals was observed *in situ*. From approximate maximum colony size (2m diameter) and growth rates ($0.1m\ y^{-1}$) it is concluded that these colonies had survived at least 10 years. This supports the conclusion that the observed coral mortality was caused by a rare (>10y) event, which, in the

Dampier Archipelago, could be the dredging that occurred in the vicinity of sites 2 and 3 from November 1982 to February 1983.

6. CONCLUSIONS

1. Temporal variation in growth rate of the staghorn coral, *Acropora formosa*, in the Dampier Archipelago, was correlated to seawater temperature. Maximum growth rates occur at moderate temperatures (27^{o}C) and at maximum computed bottom irradiances at site 1.
2. Growth rates appear to be reduced following extensive damage by cyclonic wave activity.
3. The effects of light and high temperatures may be modifying influences on the temporal patterns of growth in *Acropora formosa* in the Dampier Archipelago.
4. Spatial variation in the growth rate of *Acropora formosa* was correlated with differences in sediment deposition rate. In this study the separate effects of sediment settling on live corals and reduced light availability could not be separated. Some evidence, however, supports the assumption that reduction in coral growth was due to metabolic costs of sediment rejection.
5. Circumstantial evidence suggests that high sediment deposition rates at site 2 between December 1982 and March 1983, may have been due to dredging activities, and that high mortality of corals (mainly branching acroporids) was a result of these dredging activities.

7. ACKNOWLEDGEMENTS

I thank Mr Mike Forde for valuable assistance in the field work and for the analysis of the sediment trap data, Dr D A Mills for the use of temperature data, and Associate Professor A J McComb and Dr J R Ottaway for critical reviews of the manuscript. This work was carried out as part of the Dampier Archipelago marine study being conducted by the Western Australian Department of Conservation and Environment.

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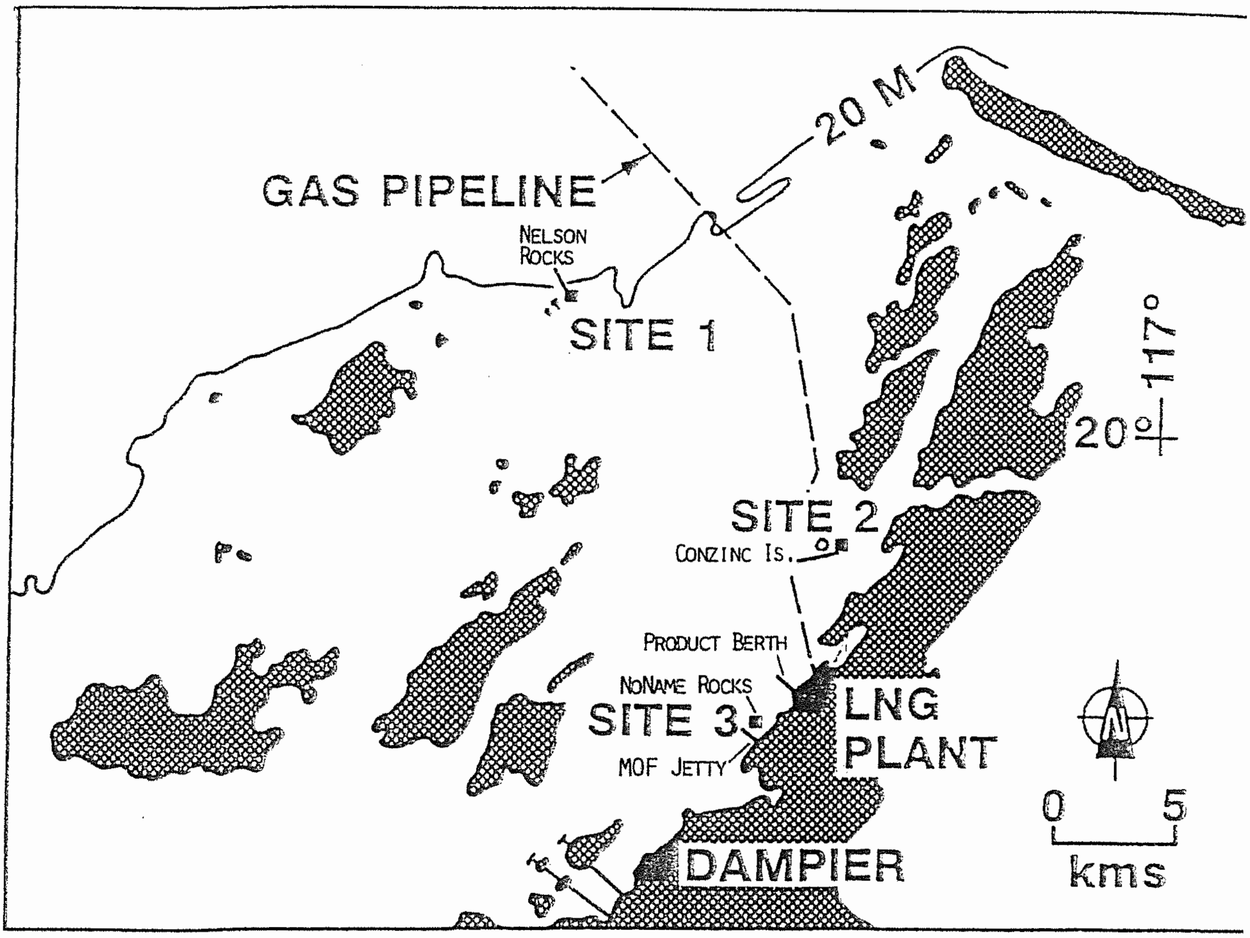

FIGURE 1. Map of the Dampier Archipelago showing the location of study sites.

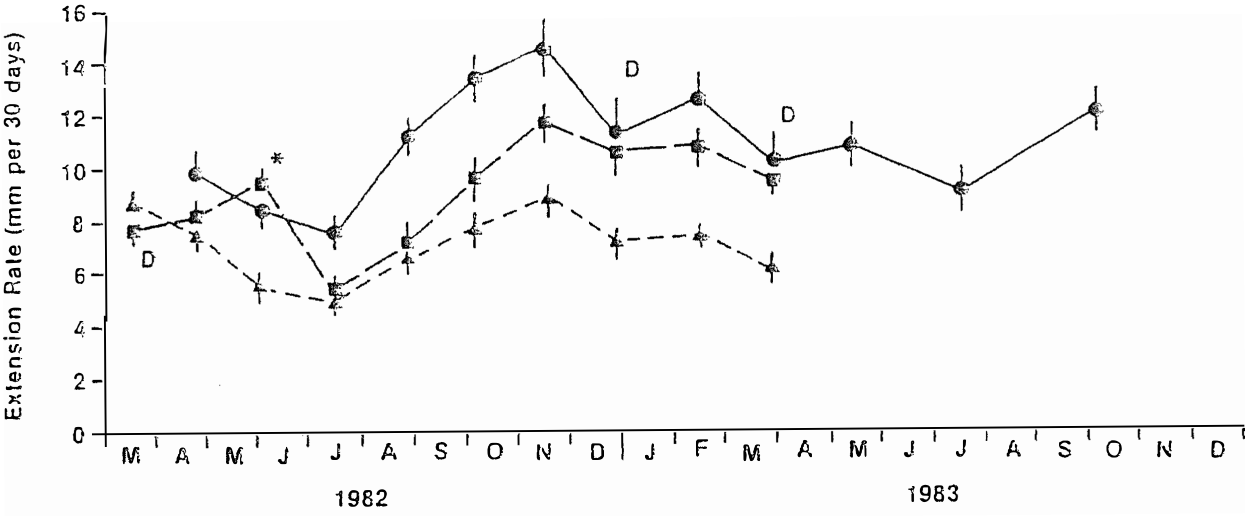

FIGURE 2. Mean skeletal extension rates at the three study sites (●, site 1; ▲, site 2; ■, site 3). D, damage to experimental colonies (cyclones occurred during these periods); all colonies at site 1 were destroyed in March, 1982; *, 4 out of 5 colonies destroyed at site 3; sample sizes vary from 30 - 50 branch measurements from an average of 4 - 5 colonies; error bars are 95% confidence intervals.

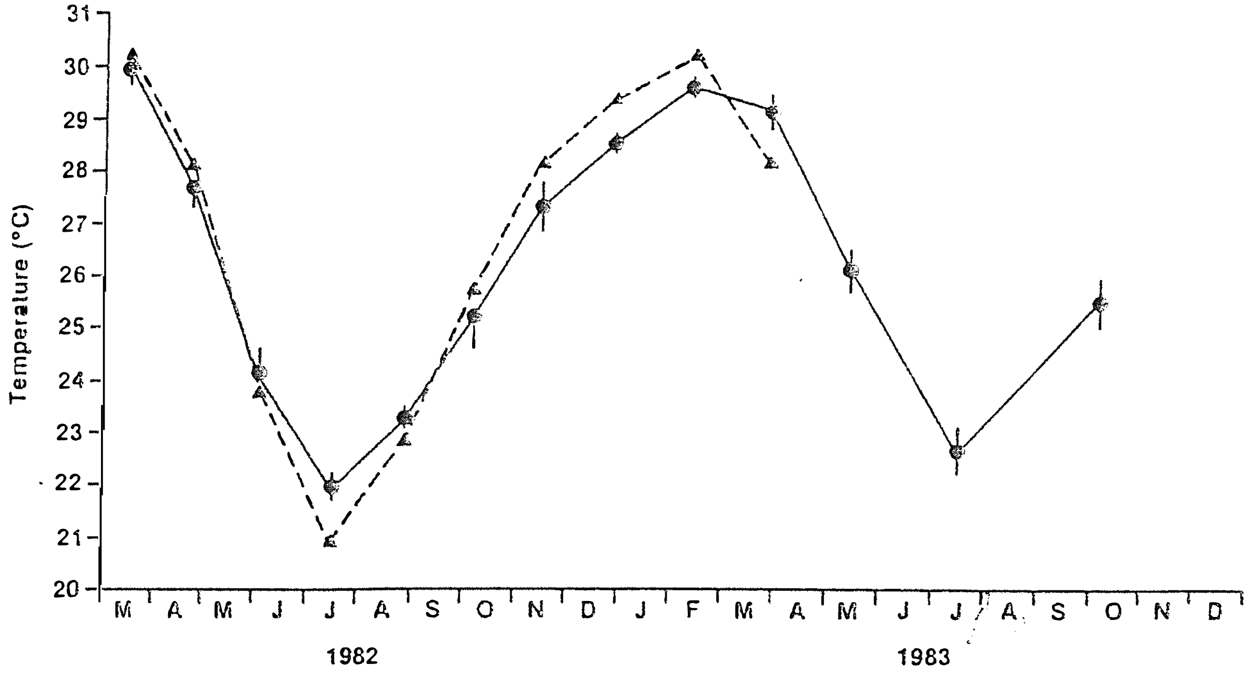

FIGURE 3. Mean bottom temperatures for growth periods (●, site 1; ▲, site 2); mean temperatures for site 3 are within 0.2°C of site 2; error bars are 95% confidence intervals.

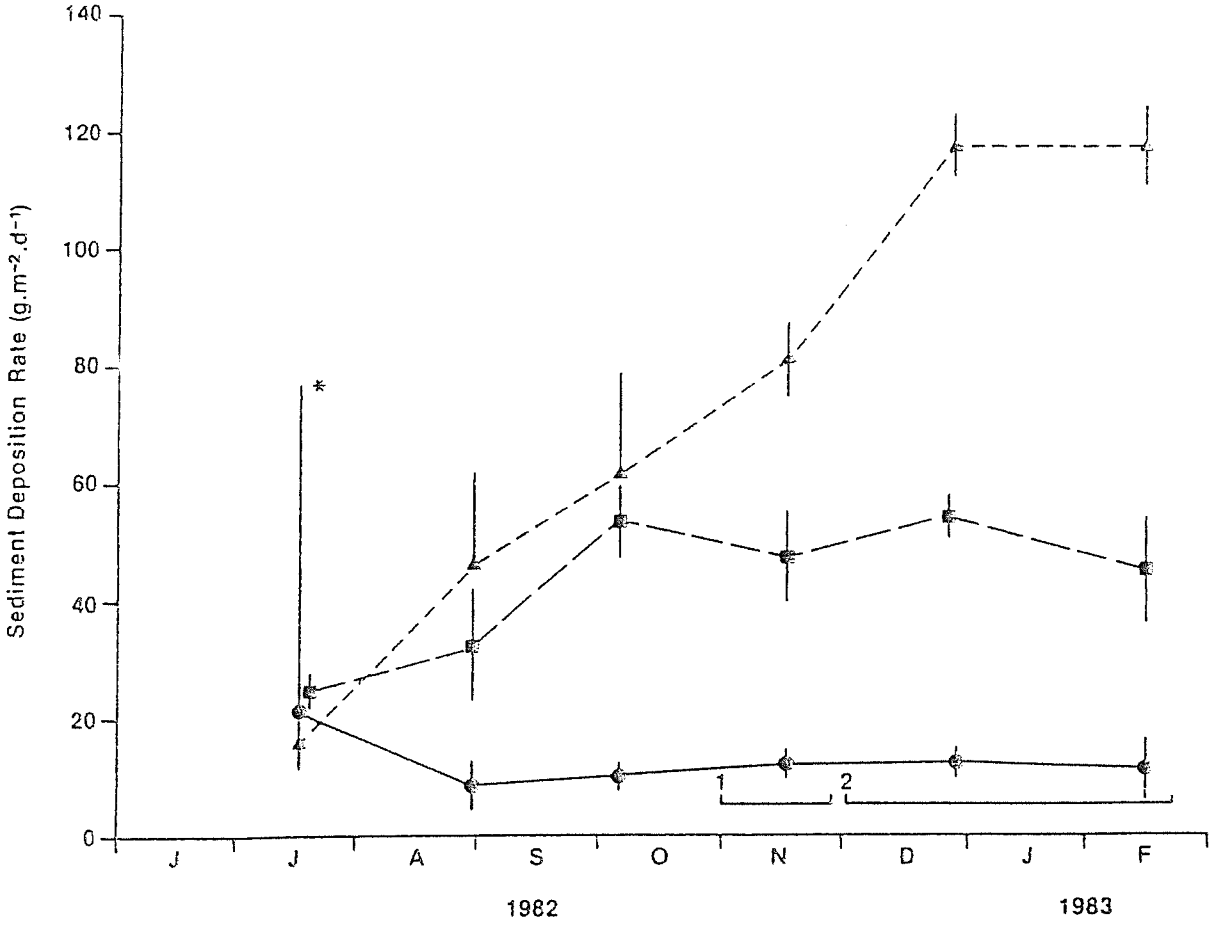

FIGURE 4. Mean sediment deposition rates (refractory fraction) for 6 growth periods (●, site 1; ▲, site 2; ■, site 3); error bars are 95% confidence intervals; data are means of 5 replicates; *, 6 out of 8 sediment traps lost in this period; periods of dredging are shown (1, 1-11-82 to 27-11-82; 2, 1-12-82 to 21-2-83).

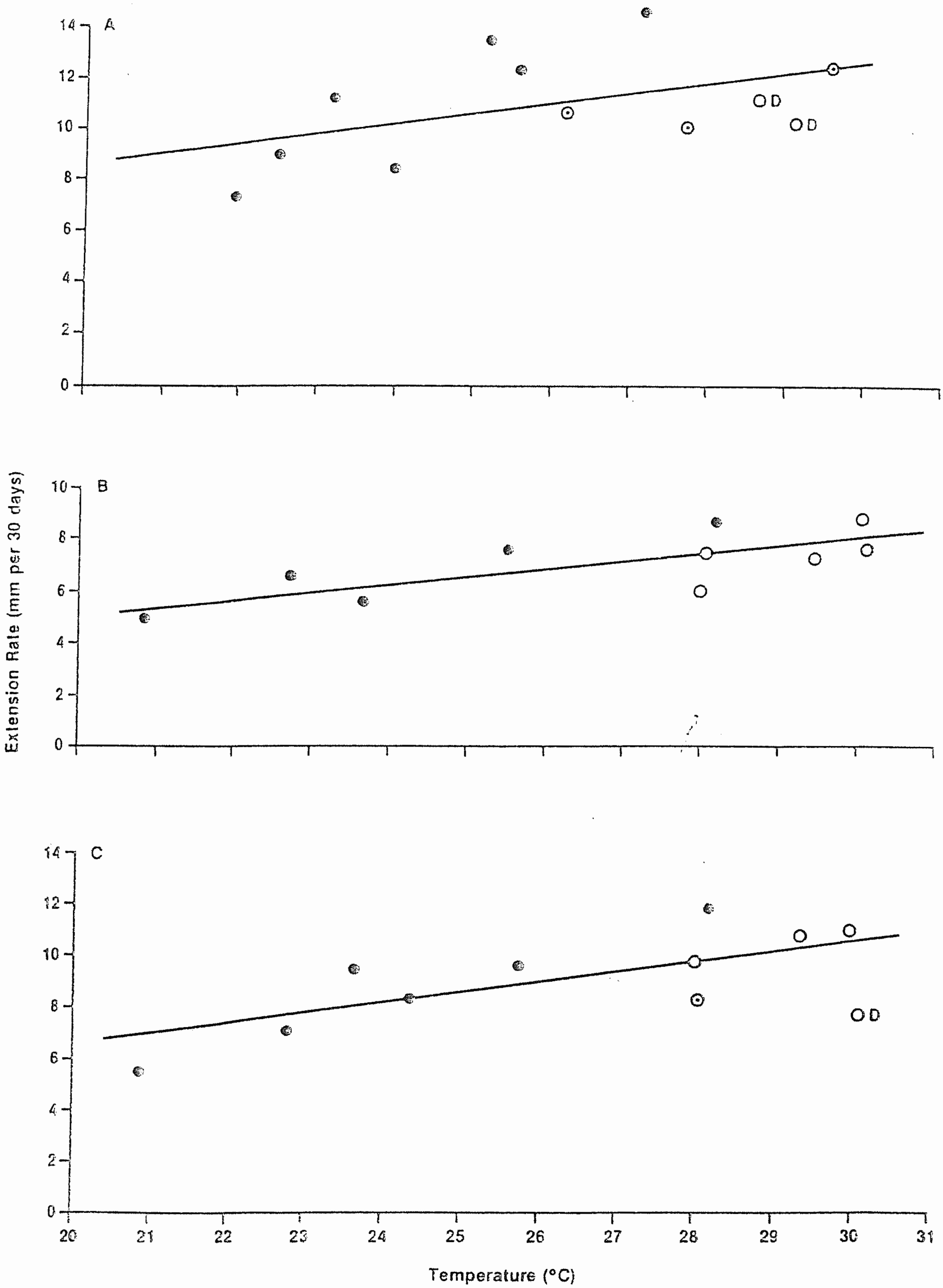

FIGURE 5. Relationships between mean branch extension rate and mean temperature (A, site 1; B, site 2; C, site 3); ● data from May 1 to November 30; O, data from December to April 30 (cyclone season); O^D, damage to experimental colonies, ⊙, data from growth period after damaged occurred.

TABLE 1. Correlation coefficients for mean growth rate of *A. formosa* and mean temperature; pre-cyclone period from May 1 to November 30 for each year; cyclone period from December 1 to 30 April of each year.

SITE	n	r	p	DATA TYPE
1	12	0.481	0.12	all
1	8	0.810	<0.02 *	pre-cyclone
1	4	0.645	>0.20	cyclone
2	10	0.690	<0.03 *	all
2	5	0.937	<0.02 *	pre-cyclone
2	5	0.668	>0.20	cyclone
3	10	0.641	<0.05 *	all
3	5	0.948	<0.02 *	pre-cyclone
3	5	0.220	>0.50	cyclone

* : significant at the 0.05 probability level

TABLE 2. Correlation coefficients for differences in coral growth and corresponding differences in the environmental variables between the 3 sites from June 1982 to March 1983.

VARIABLE	n	r	p
Sediment Deposition (Total)	18	-0.613	<0.008 *
Sediment Deposition (Refractory)	18	-0.660	<0.004 *
Temperature	18	0.062	0.805
Salinity	18	-0.436	0.070
Bottom Irradiance	18	0.287	0.249

*: significant at the 0.05 probability level

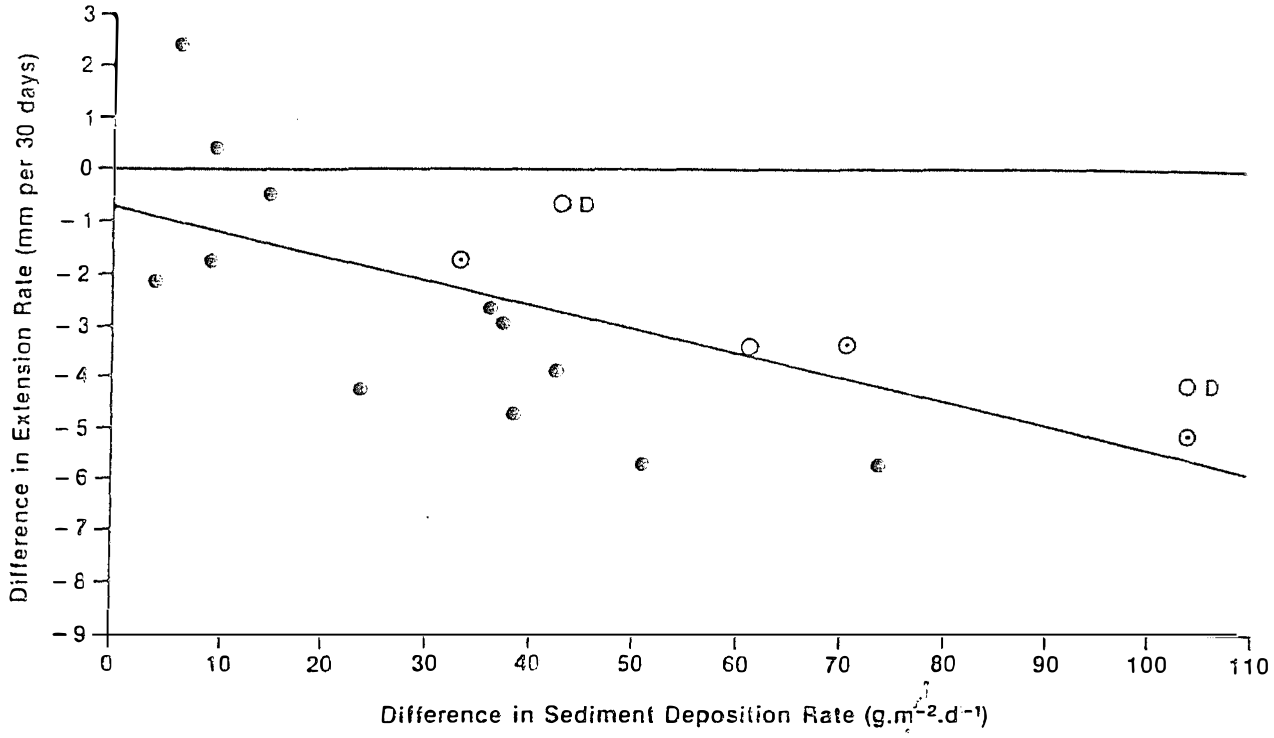

FIGURE 6. Relationship between differences in coral growth between the sites and the corresponding differences in sediment deposition rate (refractory fraction); ●, data from 30-6-82 to 6-12-82; O, data from 6-12-82 to 9-3-83 (cyclone season); O^D, damaged occurred to experimental colonies; ⊙, data from growth period after damaged occurred.