EFFECTS OF NUTRIENTS CARRIED BY MAINLAND RUNOFF ON REEFS OF THE CAIRNS AREA: A RESEARCH PLAN AND PRELIMINARY RESULTS

Cecily Rasmussen

The ability of corals to record temporal variations in aspects of their environment has been well documented. For example , annual and lunar growth bands, atmospheric ^{14}C and oceanic temperature variations are all recorded in the coral skeleton (Buddemeier & Kinzie, 1976; Druffel, 1982; Schneider & Smith, 1982). Work by Isdale (1984) inferred a strong correlation between summer monsoonal rainfall. and mainland runoff and the intensity, timing and width of yellow-green fluorescent bands contained within the annual growth bands of the coral skeleton.

The ability of mainland runoff to transport large quantities of terrigenous material to nearshore reefs has been adequately described. Increased sedimentation, siltation, turbidity, salinity and temperature fluxes in coral reefs have been linked to anthropogenic changes of the adjacent hinterland (Maragos, 1974; Banner, 1974; Cortes & Risk, 1981). Similarly, inputs of nutrients into the marine environment have been shown to have a deleterious effect on marine communities (Maragos, 1974; Banner, 1974; Smith et al, 1977; Mergner, 1981).

Kinsey & Domm (1974) expressed concern that agricultural nutrients were adversely affecting 'coral reefs. Data from the experiments designed to test this hypothesis were re-examined by Kinsey & Davies in 1979. Calcification and skeletal density of the corals were shown to decrease with the addition of agricultural fertilizers. Kinsey & Davies were unable to differentiate between phosphatic'and nitrogenous influences, but expressed a preference for an inverse relationship between phosphate application and rates of calcification. Evidence from laboratory experiments (Simkiss, 1964; Wilbur & Simkiss, 1968; Yamazato, 1970; Lambert, 1974) suggests calcification in reef corals and molluscs can be markedly suppressed by large increases in phosphate levels in the surrounding water. Reitemeier and Buehrer (1983) studied the development of crystal morpho logy in calcium carbonates following the addition of various amount s of polyphosphates (one of the forms of phosphate present in trace amounts in the marine environment) and

concluded that distorted crystals were formed as the polyphosphate solution increased. Numerous chemical elements are incorporated into the coral skeleton at the time of deposition. Strontium, analyses of skeletal aragonite deposited by reef corals' has been 'conducted by researchers for many and varied reasons (Odum, 1957; Lowens'tam, 1963; Keith & Weber, 1965; Milliman, 1967; Schneider & Smith., 1982; Muir, '1984). Odum (1957) and Goreau (1961) reported the inability of corals to discriminate between strontium and calcium during the process of skeletogenesis. Other studies indicate a slight preference for strontium over calcium in the calcification process (Weber, 1973,).

Kinsman (1969) inferred from experimental evidence that reef coral aragonite is in equilibrium with seawater as far as strontium is concerned Experimentally precipitated aragonite indicated strontium incorporation is temperature dependent (Kitano et al, 1971; Houck et al, 1977). Smith, Buddemeier, Redalje and Houck (1979) subsequently devised a strontium-calcium thermometer for use in coral skeletons. Schneider and Smith (1982) investigated the use of the. strontium thermometer as a means of examining temperature records. preserved in the density bands of massive scleractinian corals. A variable was shown to exist which could not be explained by temperature variations (Schneider & Smith, 1982). Muir (1984) also investigated the suitability of using the strontium:calcium thermometer for seawater temperature interpretation. Results from this study indicated the strontium thermometer lacked a predictable pattern when external influences operated 'on the reef environment. Muir considered that factors, affecting the uptake of strontium could be the influx of periodic water masses from nearshore rivers and/or' inputs of chemical components into the reefal environment from anthropogenically altered coastal environs (Muir, 1984).

Rasmussen (1986) suggested that enhanced levels of nutrients from agricultural fertilizers were being transported to the reefal environment of the northern Great Barri'er Reef as, a component of mainland runoff. This author further suggested that the increased phosphate flux contained in this discharge hindered the ability of coral colonies to operate at equilibrium, thereby resulting in:

a) a decrease in strontium values precipitated into the coral skeleton

b) alterations to the crystal morphology of the coral skeleton

c) a decrease in skeletal density; and

d) an increase in skeletal fragility.

Recent 'research in temperate waters has documented the ability of commercially viable marine products to be reliant on a balanced interplay between mainland runoff and the marine environment. Alterations to the terrestrial regime are reflected in fluctuations in organisms of the marine environment (eg Skreslet, 1986).

Two hypotheses have been proposed that suggest Acanthaster planci outbreaks are a consequence of mainland influences. The larval recruitment hypothesis shows that larvae survivorship improves following lowered salinity and raised temperatures (Lucas, 1973, 1975; Pearson, 1975). While this hypothesis allows for the natural periodicity of monsoonal summer rains of the northern Great Barrier Reef, it also incorporates the proposition that human intervention in the catchments of mainland rivers significantly alters the amount and intensity of runoff delivered to the marine environment.

The second hypothesis, developed by Birkeland (1982) follows the larvae recruitment concept, but emphasises that the marine environment is altered chemically as well as physically by the input of nutrients transferred by terrestrial runoff into. the oceanic waters surrounding nearshore coral reefs. Birkeland suggests larva.1 food sources such as phytoplankton blooms are increased by the addition of mainland derived nutrients, thus promoting survivorship.

Both hypotheses rely on larval survival rates as opposed to a decrease in predator pressure. However, while these hypotheses relate to the direct effect of mainland influences on the Crown-of-Thorns starfish, it is possible that indirect effects are equally important. All organisms, including Acanthaster planci predators will be affected by changes in the chemical and physical conditions resulting from an influx of terrestrial products into the marine environment.

Records of environmental influences contained in the coral skeleton will allow comparisons to be made between known *Acanthaster planci* population fluxes and environmental conditions operating 'at', the same time.

This study, therefore, suggests a number of proposals for' examining the hypothesis that the marine environment of the northern Great Barrier Reef is responding to anthropogenic interference of the nearby mainland.

PROPOSALS

1) Variations in strontium levels,' precipitated into coral skeletons may provide an indication of the chemical factors and mechanisms operating in the marine environment at the time of coral growth.

2) Variations in strontium may provide an indicator of terrestrial' alterations not previously recognized.

3) Phosphate levels in oceanic waters around coral reefs aresufficient to affect the. precipitation of strontium into the coral skeleton. This change may have a deleterious effect on the corals themselves.

4) Other marine organisms may also be adversely affected, either directly or indirectly, by anthropogenically enhanced nutrient levels. Records extracted from the corals should provide the temporal link between terrestrial alterations and artificially induced species adaptations of the marine environment, eg *Acanthaster planci* infestations.

A programme of research was subsequently devised .to test the above proposals. Selection of Cairns and environs (Fig 1) as a suitable study site was dictated by three parameters:

1) proximity of the reef to a significantly developed coastal environment

2) the influence of a large drainage basin'anthropogenically altered for agricultural purposes

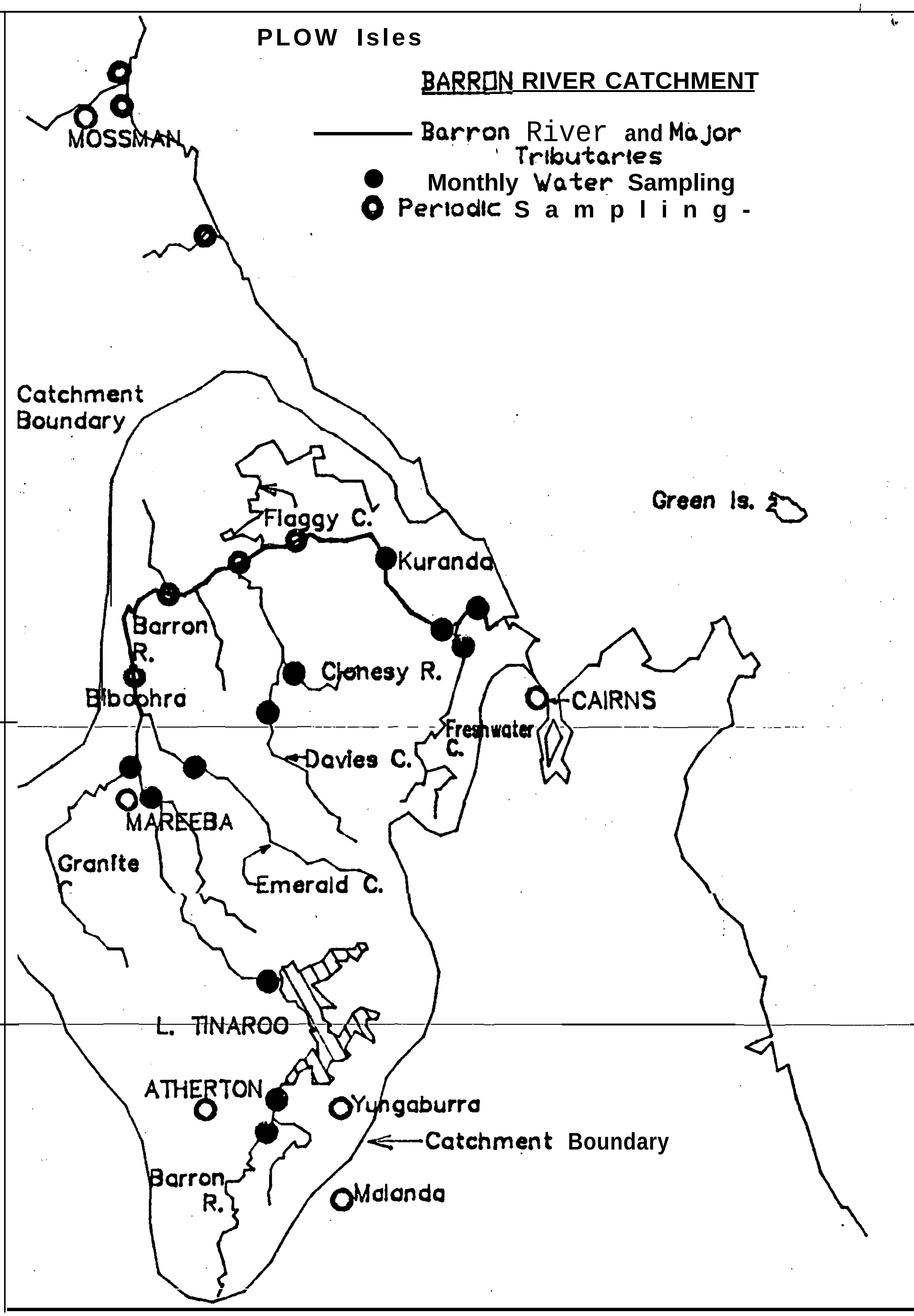


Figure 1. **Barron** River Catchment. Water sampling on a-monthly basis began from sites marked • in February 1986, and from site marked o in November 1986.

3) the location of Green Island, suggested as the possible location of initial Acanthaster planci infestations.

PROGRAMME OF RESEARCH

The nature of the problem indicated two main fields of research were required. Hence, a marine and a terrestrial programme were instigated.

Terrestrial Environments

If enhanced nutrient levels in the marine environment are the result of agricultural practices, then source and method of transport need investigation. Research methodology, therefore, should incorporate a number of components:

1) Collection of water samples on a monthly basis from the Barron River and its tributaries, as well as from short flowing streams of the nearby coastal hinterland (Fig '1). To determine whether variations in stream nutrient levels can be ascribed to agricultural fertilizers, these will be analysed for PO_4, NO_3, NO_2, NH_4 and dissolved silica.

2) Collection of sediment samples from the water sampling sites. These will be analysed to *determine the ability of particular dissolved chemical species to adsorb to clay and oxy-hydroxide particles carried as bed load.

3) pH readings at water sampling sites. Accurate interpretation of chemical equilibria in the water column is necessary if agriculturally induced nutrient levels are to be separated from biological and geological alterations.'

4) Collection of rainfall data. These will be correlated with stream nutrient data as a simple means of estimating method of nutrient' introduction to the stream channel, ie overland flow; ground water discharge; or combinations' of both.

5) Collection of landuse, and land management information. This would be analysed in conjunction with other 'data to determine spatial and temporal' influences on stream nutrient 'levels.

6) Intensive collection of water samples for a one monthly period from two agriculturally diverse locations. These will be collected using Garnet Automatic Water. Samplers placed at strategic locations - one in the pastoral area of the Atherton Tablelands, and one in the sugar cane growing coastal hinterland. These will be analysed in the same manner as other water samples, but specifically to determine whether a dual input of nutrients suggested by Rasmussen (1 9 8Fig ;2) *can* be isolated and allocated to particular land use practices. Timing of this water sampling programme will be determined by the indications 'from Figure 3, ie nutrients are reaching the marine environment twice yearly, mid-year (suggested as a response to sugar cane planting and associated fertilization) and early summer (suggested as a response to the land management practice of fertilizing dairy pastures in preparation for the monsoons).

Marine Environment

The concept that anthropogenically derived enhanced nutrient levels are adversely affecting the marine environment requires the programme of research be divided into five major sectors:

1) The attainment of corals from previous experimental areas such as the One Tree Reef project undertaken by Kinsey and Domm in 1974.

2) The collection of corals from areas of known anthropogenically derived elevated nutrient levels. For example, Kaneohe Bay and the Gulf of Aquaba.

3) The introduction of elevated levels of commercial superphosphate to Acropora and Porites species of corals grown under laboratory conditions.

4) To determine whether a decay or cumulative effect operates geographically within the marine environment (effects which may be related to distance from input, marine vegetation, eddies, or sewerage outfall), the removal of coral cores from Porites species of

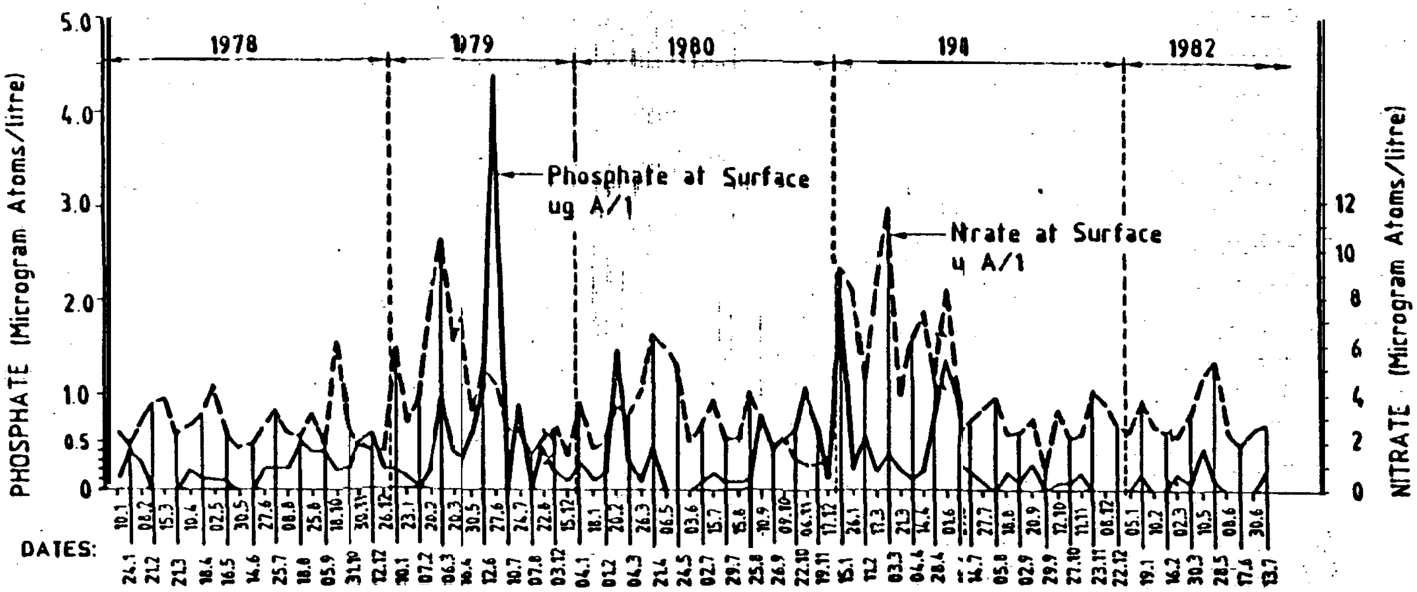


Fig 2. OCEANIC PHOSPHATE AND NITRATE LEVELS
Source : C.S.I.R.O. Dvision of Oceanography

LOW ISLES, NORHERN GREAT BARRIER REEF

Corals in a grid pattern radiating out from the mouth of the Barron River and extending as far north and south as financially possible will be undertaken (Fig 3). A control sample will, be removed from a reefal area sufficiently distant from mainland influences to be considered uncontaminated by anthropogenic interference (eg Myrmidon Reef).

5) Collection of samples of oceanic water will be undertaken by the Queensland National Parks and Wildlife Service' on a monthly basis from the entrance to Cairns Harbour across to the Green Island reef. Further samples will be collected on an intermittent basis from other reefs visited by Queensland National Parks and Wildlife Service. Fortnightly water samples will be collected from Low Isles by the Head Lighthouse Keeper. A further programme of collection has recently been planned for Agincourt Reef.

All oceanic water samples will be analysed for similar chemical species as the terrestrial samples. Correlations will subsequently be sought with events on the nearby mainland, weather regimes, tourism influx and dredging.

Corals obtained by the four methods listed above will be analysed temporally and spatially for variations in chemistry, crystal morphology, density, calcification, fragility, growth patterns and internal morphological characteristics.

Results obtained from this section of the programme will be analysed in conjunction with the terrestrial programme. The anticipated understanding of environmental records located in the coral skeleton will then be available for interpretation in conjunction with known *Acanthaster planci* biology, ecology, history and geographical distribution.

RESULTS

Water Samples

Results presently to hand indicate a strong correlation between raised stream nutrient levels and rainfall in associated areas with a lag of approximately one month (Figs 4 & 5). A further correlation exists

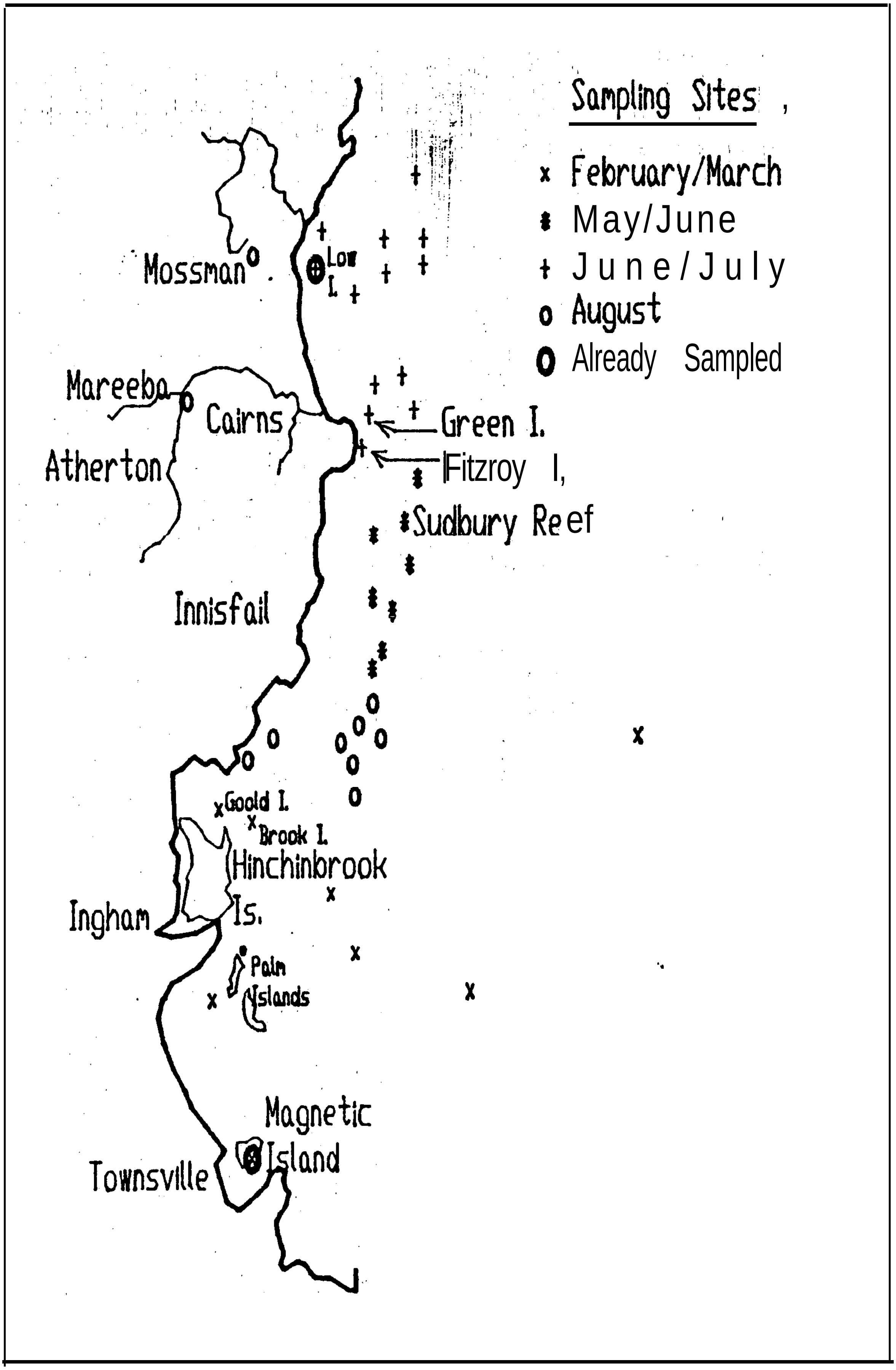


Figure 3. Proposed coral coring programme - northern Great Barrier Reef

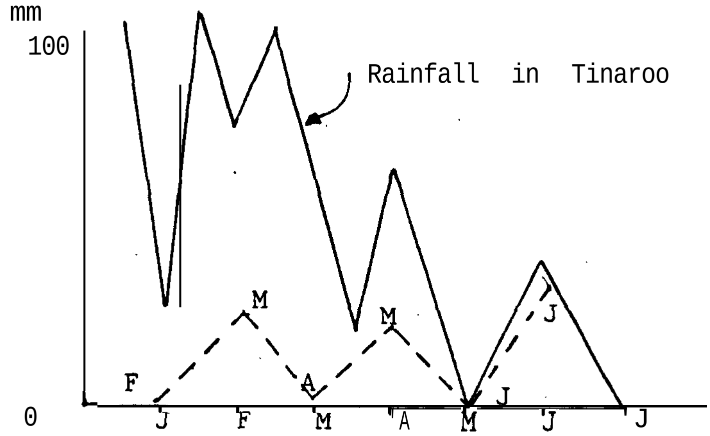


Figure 4. Rainfall data superimposed over NO_2 stream concentrations in the Tinaroo area - lag time = 1 month

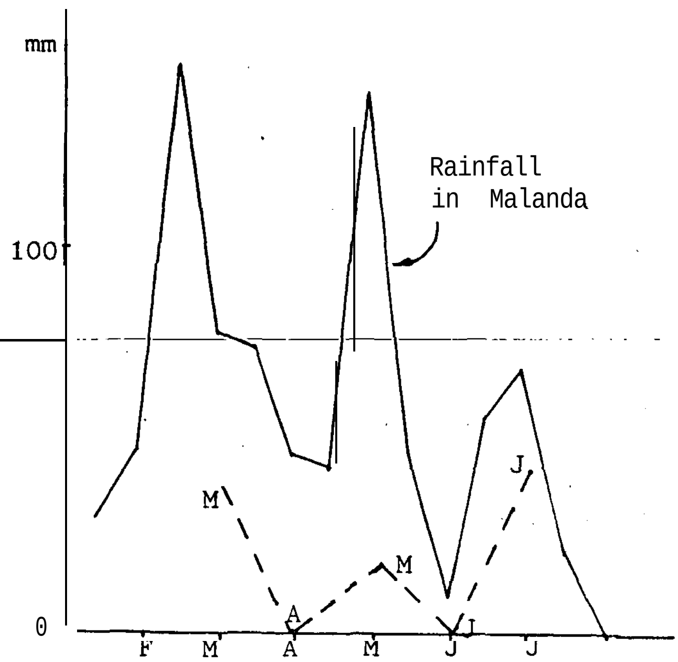


Figure 5. Malanda rainfall data superimposed over NO_2 stream concentrations in the Upper Barron River - Lag time = 1 month

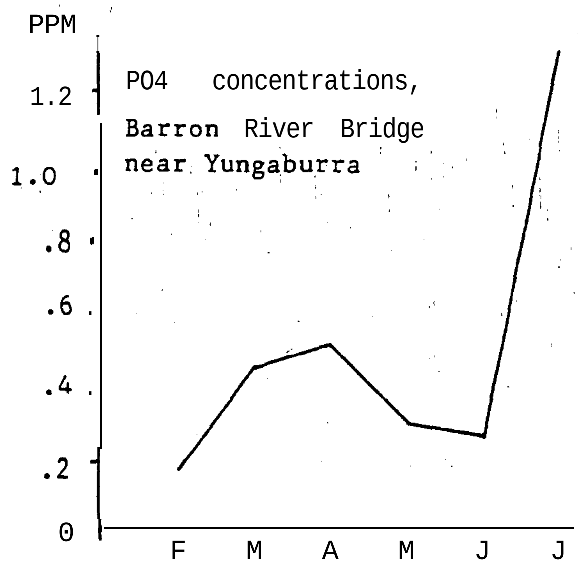


Figure 6. Increased PO4 concentrations corresponding with decreased rainfall and use of irrigation as the major source of farm water supply (see rainfall pattern Fig 4)

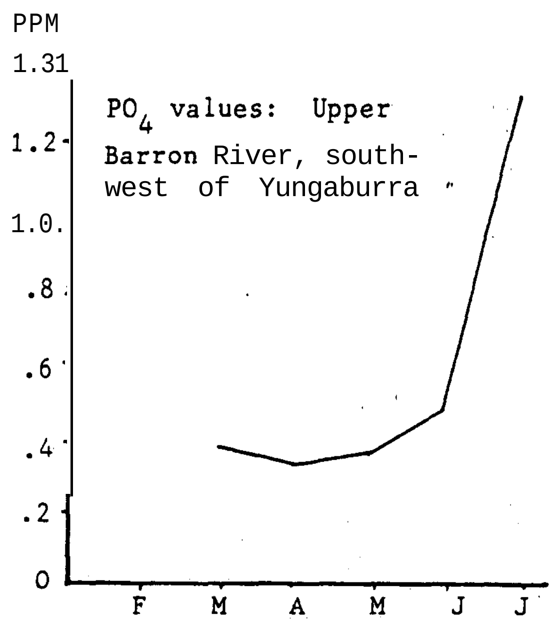


Figure 7, Increased PO concentrations corresponding with onset o4 irrigation **following** the decline in natural precipitation (see rainfall pattern Fig 5)

between land management practices and enhanced nutrient levels of the streams. For example, in the Yungaburra, Kairi and Tinaroo areas, irrigation began as rainfall decreased. This is reflected in the sudden flushing of nutrients into the associated streams draining these particular areas (Figs 6 & 7). Similarities are also suggested between stream nutrient levels, geographical location and landuse patterns. For instance, Davies Creek and Clohesy River (Figs 8 & 9) share similar nutrient -peaks, landuse patterns and geographical locations. These signatures are quite distinct to the dairying area of the Atherton Tablelands (eg Figs 6 & 7).

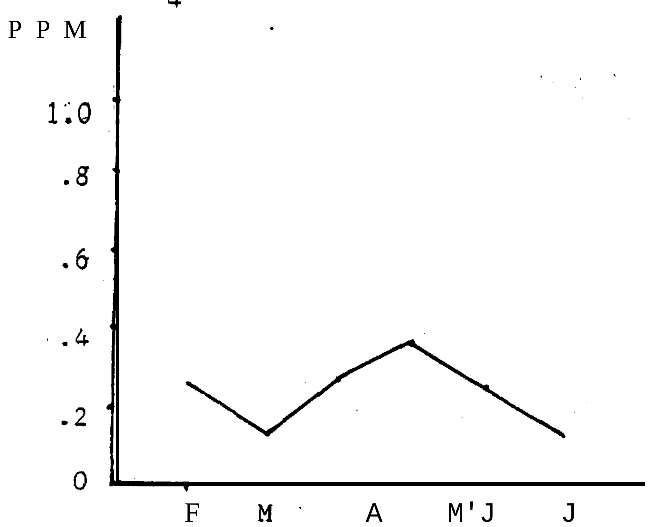
Experimental Corals

Two species of corals, Acropora formosa and Porites, were selected for experimentation. The ability to use the same Porites sample under a variety of geomechanical and geochemical techniques has provided researchers with an invaluable tool for unravelling the complexities of coral records. However , Acropora species of corals provide large -quantities. of coral shingle to the reefal environment. It is also considered aesthetically pleasing by tourists, hence its commercial value must not be overlooked. The rapid growth habits of Acropora formosa determined its experimental suitability.

Acropora formosa and Porites species of corals were grown in aquaria at the Orpheus Island Research Station. To mimic the marine environment as near as possible, unfiltered seawater was pumped into the tanks direct from the reef flat at a rate designed to provide an hourly turnover of marine water. Shade cloth covered the top and sides of the tanks to replicate oceanic conditions at a depth of approximately two metres. Commercial superphosphate of the composition described in Table 1 was dissolved in filtered seawater and added to the tanks by a drip system designed to maintain concentration within individual tanks of 2, 4 and 8 ugA/L P04. Two tanks remained free of fertilizer as controls. Alizarin was used as a marker stain to provide a time basis for the experiment.

Figure 8. Davies Creek

a) PO_4 concentrations



b) NO_2 concentrations

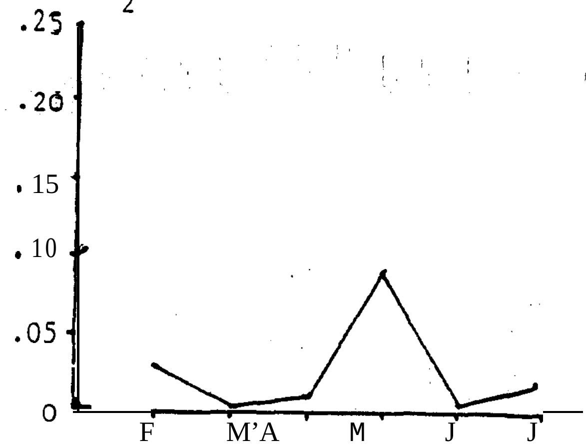
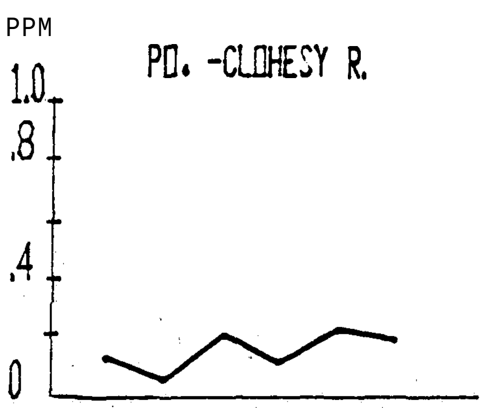


Figure 9. Clohesy River

a) PO_4 concentrations



b) NO_2

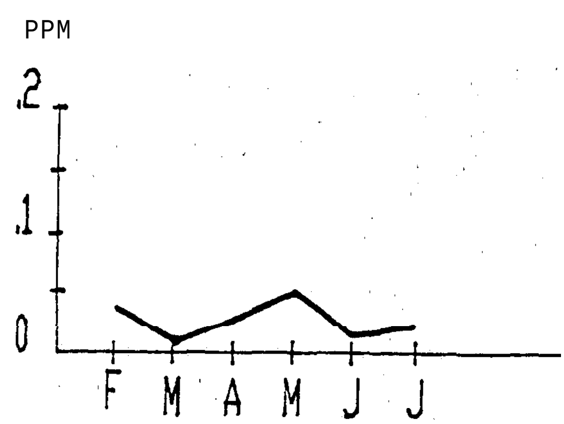


Table 1. Superphosphate Analysis (weight percent)

Phosphorus 'P' (water soluble)	7.0%
Phosphorus 'P' (Citrate soluble)	1.5%
Phosphorus 'P' (Citrate insoluble)	0.5%
	9.0%
Sulphur 'S' as Sulfates	10.0%
Calcium 'Ca' as Superphosphate	20.0%

Porites species proved difficult to grow in experimental conditions. *Acropora formosa*, previously understood to be difficult to maintain experimentally (pers comm R Babcock; J Oliver) has proven extremely successful.

The *Acropora formosa* colonies were harvested on the night of coral spawning (9 November 1987) at Orpheus Island. Small sections were removed from each colony for examination of variance of spawning ability.

Growth-tips from the remaining colonies were removed using _ _n_ _ d_ _ tipped saw, and examined under the Scanning Electron Microscope for morphological and chemical variations. Plates 1, 2 and 3 indicate substantial alteration to the internal morphological structure of the skeleton has occurred. Skeletal walls have thinned and voids enlarged considerably with increased-addition of P04.

At present little is known of standard levels of strontium within *Acorpora* species of corals. However, although data are only preliminary, variation exists within the three samples indicating decreased levels of strontium following increased additions of PO4 (Table 2).

Coral Cores

Sections from two cores from Low Isles and Magnetic Island were made available by Dr Peter Isdale, Australian Institute of Marine Science. These samples were examined using x-radiography to determine annual growth bands and selected bands analysed using Atomic Absorption Spectometry, X-ray Diffraction and Scanning Electron, Probes to determine possible spatial and temporal variations in mineralogical and chemical precipitation into the coral cores..

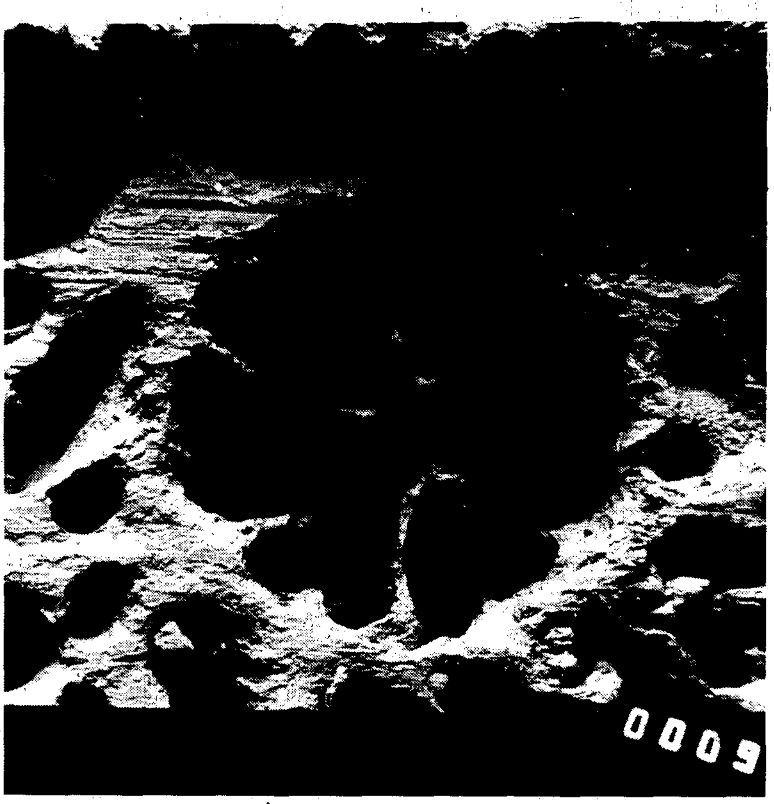


Plate 1. Growth tip, Acropora formosa. Control (Magnification x 40)

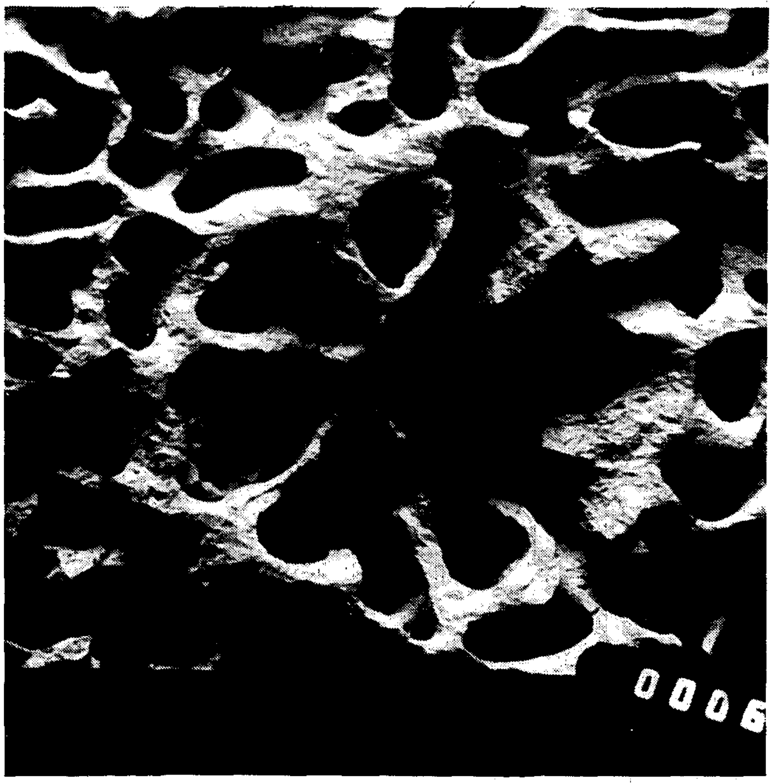


Plate 2. Growth **tip, Acropora** formosa, following the **addition** of 4 **ugA/L** PO_4 (Magnification, x '40). NB **walls** beginning **to** thin

Plate 3. Growth tip, Acropora formosa, following the addition of 8 ugA/L PO_4. (Magnification x 40) NB Considerable alteration to skeleton morphology; a) -excessive thinning of internal walls; and b) increase in size and number of voids

Table 2. *Strontium* values, Acropora formosa, following the addition of controlled levels of PO_4 to experimental aquaria, Orpheus Island. Values taken mid-way across tip using Electron Probe Analysis

PO4 CONCENTRATION	Sr VALUE
Control	7215
4 ugA/L	6820
8 ugA/L	6835

Preliminary data only

Strontium levels from both cores show a general decline over time, correlating with use of phosphatic type fertilizers in nearby terrestrial environments. Of particular interest is the different signature emanating from each coral core, thus establishing the individualteration of the marine environment surrounding each coral colony rather than an overall steady decline in strontium availability. Further, the different signatures apparent in each core relate to known environmental histories of the different geographical locations of the two coral colonies.

Geographical variation, hydrological regime and landuse practices of the nearby terrestrial environment plays a significant role in determining the chemical composition of the corals. For example , it has been argued within this paper that the increased use of superphosphate is primarily responsible for a decrease in the amount of strontium precipitated into the coral skeleton.' 'Thus, when PO4 is added to the marine. environment via short runoff streams on a small is land draining pineapple farms (eg Magnetic Island) it would be 'anticipated s'keletal precipitation would be subjected to different variables than PO4 entering' the marine environment via a major river draining a large catchment substantially altered for agricultural purposes (eg Barron River). This geographical and environmental variation is recorded in coral skeletal material. As is evident in Fig 10 Townsville's 1946 flood served to dilute the amount of PO4 normally entering the marine environment only via a very few short runoff streams or through groundwater seepage, resulting in a strontium peak during this period,. Sewerage discharge from Ross River (Townsville) which replaced, fertilizer as the main source of PO4 in the Magnetic Island region following the decease of pineapple production, is similarly diluted by the heavy 1974 wet season, leading to 'a further strontium, peak at this time. In contrast, the Barron River catchment responded to the 1974 heavy wet 'by injecting large quantities of agricultural fertilizers into the marine environment around Low Isles. The substantial increase in PO4 led to a corresponding decrease in strontium precipitated into the coral skeleton during this period (Fig 11). It is significant to note that superphosphate is added to pastures in the Barron River catchment around October specifically in anticipation of the wet season. That superphosphate is reaching the rivers -following rainfall has been demonstrated above.

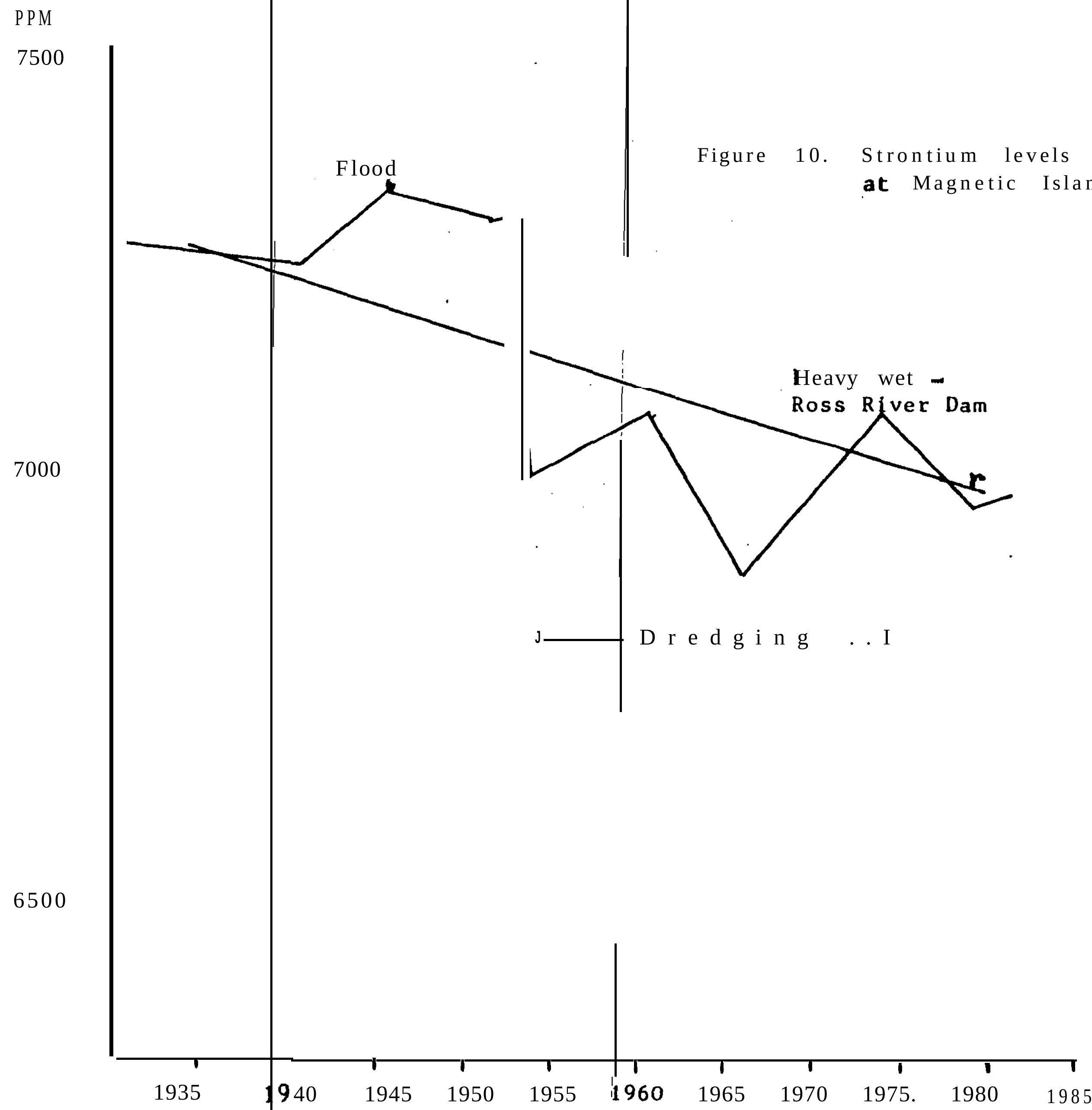


Figure 10. Strontium levels – Porites spp at Magnetic Island

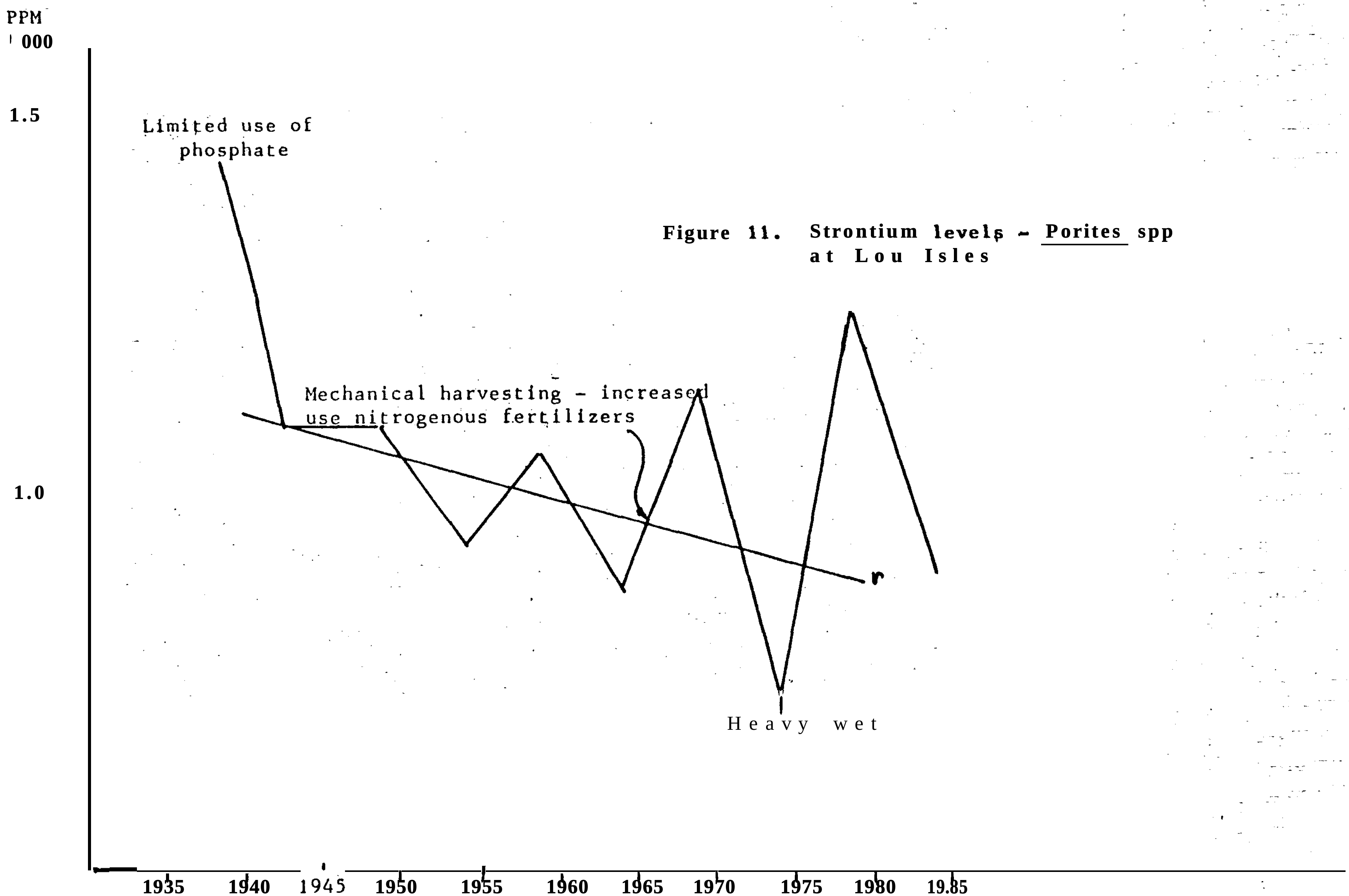


Figure 11. Strontium levels - Porites spp at Lou Isles

It would appear that strontium levels (interpreted here as the result of anthropdgenically introduced PO4 into the marine environment) provide an accurate interpretation of past environmental changes. From an examination of the Low Isles cores and the known history of sugarcane farming in the nearby terrestrial hinterland, it is possible to correlate the environmental history of the area with variations in the coral cores. The limited use of phosphatic type fertilizers prior to 1939 corresponds to the anticipated levels' of strontium expected in Porites species of corals as interpreted by Frazer Muir (1984). However, strontium levels drop with the introduction of phosphatic type fertilizers. At present it has only been possible to examine. the Low Isles core at selected temporal intervals. It is considered that examination on an annual basis will indicate a break in the regression line shown in Figure 11, corresponding to the introduction of mechanical harvesting and the subsequent ability to substitute phosphatic-type fertilizers with increasing amounts of the nitrogen enhancing fertilizers, subsequently leading to a decrease in PO4 entering the marine environment and a relative increase of strontium precipitated into the coral skeleton. Continued and expanding useage of phosphatic type fertilizers for other agricultural purposes on the Atherton Tablelands will tend to mar this upward trend, a point which is emphasised by the effects of the 1974 and 1979 wet seasons on the strontium values of the corals.

The drop in Strontium content in 1985 from the Magnetic Island coral colony is presently unaccountable. However; this was the outer limit of the sample and it may be a peculiarity of the corals. This peculiarity has also been noted in the Acropora formosa samples grown experimentally at Orpheus Island, but no explanation is presently possible.

CONCLUSIONS

1) From the results to hand a direct correlation exists between enhanced levels of PO4 in the marine environment and strontium concentrations precipitated into the coral skeleton.

2) Increased nutrient levels in streams of the Barron River catchment are closely linked to precipitation, landuse and land management practices.

3) A link, therefore, is suggested between land. management, practices, enhanced levels of nutrients transported via mainland runoff into the marine environment, and strontium levels precipitated into the coral skeleton.

4) Experiments conducted on Acropora formosa at Orpheus Island indicate phosphatic type fertilizers have a deleterious effect on the skeletal deposition of the coral colony. At high levels, calcification is hindered, altering both the internal and external morphology of the coral structure. Thinning of the skeletal walls occurs, theoretically leading to increased fragility of the coral colony.

5) Data extrapolated from the coral cores suggsts the use of strontium levels precipitated into the corals. to (a) indicate historical anthropogenic influences, and (b) as a monitor of the present health and condition of the reef for future management planning.

6) The combined results from the above studies should ultimately provide an accurate spatial and temporal record of anthropogenically altered environments within the Great Barrier Reef. This will subsequently provide a scale against which Acanthaster planci data may be plotted.

OTHER VARIABLES

It is possible there are other sources of nutrient enhancement not being examined in this study, eg nutrient upwelling from oceanic currents; sewerage discharge into the marine environment. However it is anticipated that examination of coral cores from a variety of environments will eliminate many of the confounding variables.

PROPOSED FUTURE RESEARCH

1) Acropora formosa samples removed from the experimental tanks on Orpheus Island during the period of coral spawning are presently being examined by Dr B Willis to assess the effects of increased levels of PO4 on the reproductive cycle of coral colonies.

2) Acropora formosa samples collected from various cross-shelf locations, . northern Great Barrier Reef, have been obtained from Dr J Oliver. These corals will be analysed to determine the relationship between coral fragility and proximity to the mainland.

3) Experimental corals will again be grown on Orpheus Island. Rates of PO4 injection will be altered to include 1.0, 0.6 and 0.4 ugA/L PO4. Intermittent injection at spasmodic controlled level5 will also be included in the experimental programme. Availability of previous research on Porites species of corals dictate the suitability of using this species of coral for experimental research. Thus, for comparative purposes, every effort will be made to grow Porites species of corals under experimental conditions. Should this prove possible, Porites and Acropora species will share experimental tanks.

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