THE DEMISE OF THE FRINGING CORAL REEFS OF BARBADOS AND OF REGIONS IN THE GREAT BARRIER REEF (GBR) LAGOON - IMPACTS OF EUTROPHICATION

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ABSTRACT

The fringing reefs of Barbados are in a very poor state of development when compared with earlier descriptions. The historical data demonstrate a close correspondence between the demise of the coral reefs with increased tourist and industrial development and the resulting degradation in water quality and associated eutrophication. The studies indicate that chronic low levels of eutrophication can restrict coral growth and reproduction and in doing so inhibit the recovery of damaged reefs. The virtual extinction of *A. palmata* in recent times indicates that it could be particularly sensitive to eutrophication. The data suggest a eutrophication threshold of 0.3 mg chlorophyll a m^{-3} if the demise of *A. palmata* is relevant which is low in comparison with the 0.5 mg chlorophyll a m^{-3} previously suggested for the Great Barrier Reef (GBR) lagoon. Data for the GBR lagoon off Townsville show that the status of eutrophication or fertility of the waters (as determined by chlorophyll *a)* is equivalent to or greater than that which was associated with the demise of reefs in Barbados and Hawaii. Recent data show that the fertility (as measured by total diatom counts) of the lagoon water near to LOW Isles is far higher than that measured in 1928-29. The increased fertility in both GBR regions is attributed mainly to agricultural run-off. It is hypothesised that this large scale eutrophication is a significant factor in the demise of corals in the GBR lagoon and in the promotion of outbreaks of *A. p/anti.*

INTRODUCTION

Various descriptions and scientific studies provide a relatively good history of the demise of the once flourishing fringing reefs on the south and west coasts of Barbados. The data indicate that an underlying cause for the demise is eutrophication and associated suspended particulate matter (SPM) and sedimentation (Tomascik and Sander 1985, 1987a and b; Tomascik 1991; Wittenberg and Hunte 1992; Hunte and Wittenberg 1992). The main cause of the eutrophication in Barbados is the increased loads of nutrients that have occurred with the increased development of tourism (see Figure 3) and industry along the coastal fringe (Tomascik and Sander 1985). The effects of the many point sources along the coast are magnified by the impacts of run-off and the seepage of groundwater. The groundwaters are contaminated by industry, agriculture and sewage (much of the sewage from domestic households and tourist resorts is disposed of through cess pits). Run-off, although it only occurs periodically, is usually highly contaminated with sediment, sewage and agricultural wastes. These waters often discharge near to the fringing reefs thus exposing the corals to an immediate high sedimentation load and the toxic effects of the freshwater and its constituents. Examination of the historical data provides useful relationships between water quality and reef health indicators. This data can be used to establish water quality guidelines or eutrophication threshold levels that can be used for the management of coral reef regions. Based mainly on historical data from Barbados (Tomascik and Sander 1985) and Kaneohe Bay (Smith et al 1981; Laws and Redalje 1979 cited by Bell 1991, 1992) Bell (1991, 1992) suggested a eutrophication threshold level for the Great Barrier Reef (GBR) lagoon corals corresponding to an annual mean concentration of chlorophyll $a \leq 0.5$ mg m^{-3} with corresponding concentrations of nutrients $P\text{-}PO_4$ 0.1 -0.2 µM; DIN $(NH_4+NO_3+NO_2)$ 1 µM. These threshold concentrations were used to define the status of eutrophication or fertility of the waters in the GBR lagoon (Bell 1991, 1992). The nutrient threshold concentrations are of the same order as the half-saturation constants of many marine phytoplankton (and probably attached algae) and hence variations around these concentrations will significantly affect the rate of growth of the algae and hence affect the ability of the algae to compete with the corals. A closer examination of the historical data for Barbados is presented below and this indicates that an even lower threshold level is appropriate for that region and possibly the Caribbean as a whole. The low threshold concentrations for the nutrients means that large nutrient discharges (eg. rivers) can lead to large scale eutrophication and thus affect far distant reefs and even very small discharges can affect nearby reefs. Indeed the impacts of local or small scale inputs of nutrients in Barbados could be magnified by the large scale effects which result from the discharges of the rivers of South America, particularly the Amazon but space does not permit further discussion of this aspect.

Moss *et al.* (1992, cited by Gabric and Bell 1993) estimate that the annual loads of sediment and nutrients discharged to the GBR lagoon are 3-5 times that prior to European settlement. Their data show that only 11% of the total coastal catchment area is pristine with over 85% under agricultural development. Given the limited flushing of the GBR lagoon and the low eutrophication threshold level for coral reef regions it is quite likely that little if any of the GBR lagoon could be classed as pristine. Indeed historical data for the GBR lagoon indicate that some regions exhibit signs of large scale eutrophication (Bell 1991,1992). In particular it is noted that areas once renowned for their coral growth are now dominated by other benthos eg algae, soft corals and seagrasses (eg Magnetic Island and Low Isles). There is evidence that small scale discharges of run-off, groundwater and sewage have also impacted upon GBR coral reef ecosystems (eg Green Island, Hamilton Island). In the results section below historical data from studies done in Barbados and from studies done at Magnetic Island and Low Isles in the GBR lagoon are summarised. The reader should refer to the original work for the methods used. The 1993 algal cover transect study for Barbados followed the method of Tomascik and Sander (1987a).

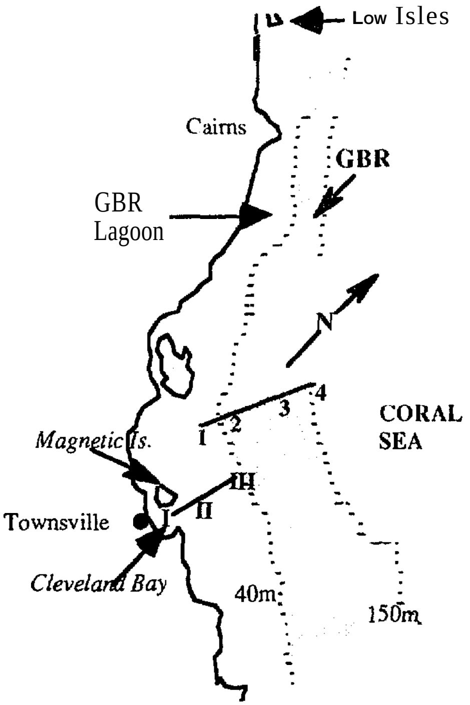

Figure 1. GBR locations. I, 11, and 111 denote cross-lagoon sampling stations and 1-4 show outer shelf sampling **stations.**

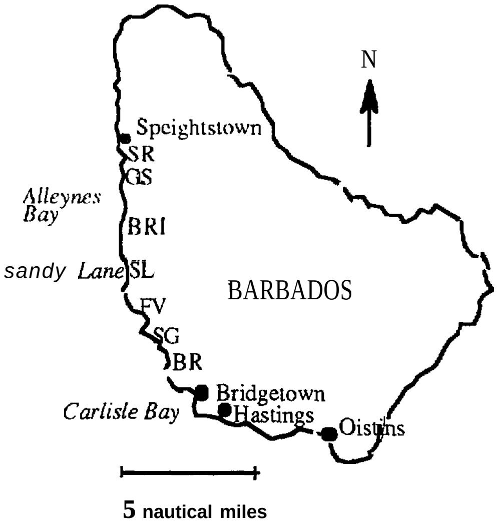

Figure 2. **Location of** fringing reef sampling stations SR, SG, BRI, SL, FV, SG, BR, in Barbados.

RESULTS

Observations of Demise of Barbados's Fringing Reefs and Water Quality. -- The abundant "good thriving reefs" as described by Nutting (1919) which existed "for miles in the immediate neighbourhood" of Pelican Island (ie. close 10 Bridgetown) and those off Hastings where there were "acres of bottom crowded with immense fronds of *Isopora (Acropora) palmata* " exist no more. The demise of the south coast fringing reefs coincided with the rapid development of tourism (see Figure 3) and degradation of water quality that has occurred along the south coast since 1950 (Light 1974 cited by Lewsey 1978; Vezina 1974 cited by Tomascik and Sander 1985; Turnbull 1979). Lewsey (1978) demonstrates the extent of the degradation of the reefs, coralline algal and sea-grass beds since 1950 using aerial photographs. The demise is attributed to a combination of anthropogenic activities (eg reef mining, coral collecting, dynamite fishing), natural occurrences (eg hurricanes) and the effects of water pollution and in particular eutrophication.

The extensive *A.palmata* beds were gone by the time of the work of Lewis (1960). By the time of Macintyre (1967) even some of the west coast reefs appeared to be in decline. He notes that the prolific coral growth (>75% cover; also see Lewis 1960) was restricted to the reefs lying between Speightstown and Lower Carlton and between Alleynes Bay and Sandy Lane. The other west coast fringing reefs consisted of reef-rock and coral debris covered with pink coralline algae with only sparse growths of corals. He notes *A.palmata* was still relatively common on the surface of the spurs of some reefs in the mid 1960s. Ott (1971) recorded 28 colonies in a 100 metre square area on the Bellairs Research Institute (BRI) reef. The work of Steam et al.(1977, as cited by Tomascik and Sander 1985) shows prolific coral growth on the northern section of the BRI reef, the mean cover for the outer half of the reef, which included the spur and groove region and part of the coalesced spur zone, was over 50% live coral and some *A.palmata was still* present, Hurricane Allen in 1980 caused severe damage to the northern BRI reef (Mah 1984 as cited by Tomascik and Sander 1987a) and probably to other west coast reefs.

Table 1. Correlations between coral health indicators (reef mean) (H: Brillouin's diversity index; %CC: % coral cover; GR: growth rate of *M.annularis* cm yr^{-1}) and annual mean water quality parameters (SPM mg 1^{-1}; Chl *a* mg m^{-3}; P-PO_4 uM; DIN uM)

Correlation	r^2
H = 1.361- 1.350 Log(SPM)	0.86
H = 0.792 - 1.950 Log(Chl *a* +1)	0.83
H = 0.545 - 5.088 Log(P-PO_4 +1)	0.70
H = 0.533 - 0.459 Log(DIN+1)	0.66
$Sin^{-1}(\%CC)^{0.5}$ = 30.25- 64.82 Log(Chl *a* +1)	0.65
$Sin^{-1}(\%CC)^{0.5}$ = 47.95- 43.29 Log(SPM)	0.63
$Sin^{-1}(\%CC)^{0.5}$ = 21.25- 150.15 Log(PO_4+1)	0.43
Log(1+GR) = 0.866- 0.729 Log(SPM+1)	0.99
Log(1+GR) = 0.467- 0.877 Log(Chl *a* +1)	0.92
Log(1+GR) = 0.321- 1.957 Log(PO_4+ 1)	0.57

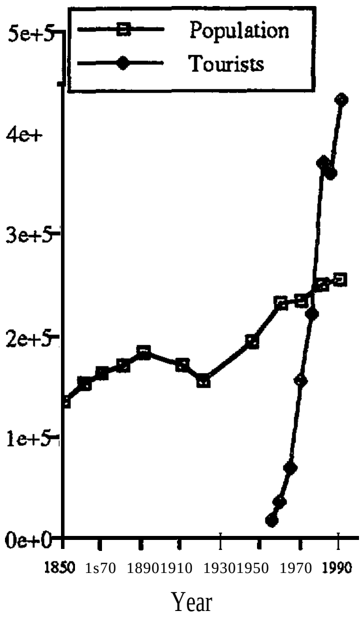

Figure 3. Total general population and and tourist arrivals - Barbados.

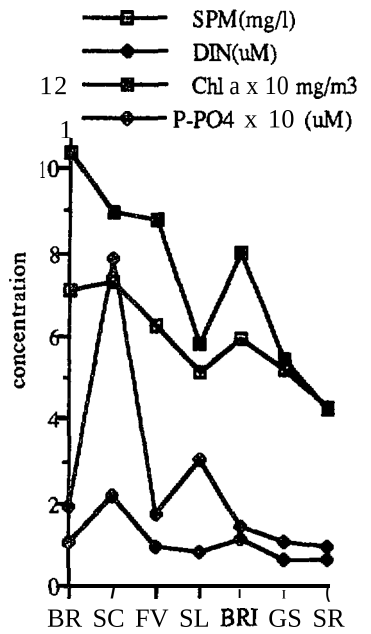

Figure 4. Variation in water quality (annual mean values) along the west coast of Barbados.

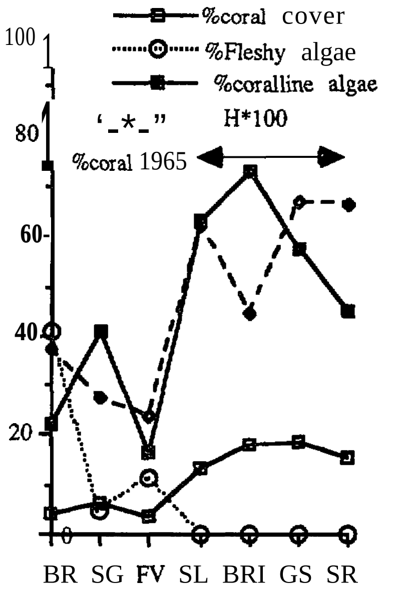

Figure 5. Variation in mean coral health indicators along the west coast.

In 1982 Tomascik and Sander (1987a) found the southern portion of the BRI reef in a relatively poor state of development with live coral cover of only 18% in the spur and groove zone. They-found live coral cover ranging from 3%-19% in the spur and groove zones of the seven reefs surveyed which illustrates a general decline in the west coast fringing reefs when compared with the earlier descriptions. Their data show *A. Palmata* was quite rare. Tomascik and Sander (1985, 1987a) showed that the water quality of the west coast waters had declined over the preceding decade and hypothesised that the increased eutrophication resulted from the tourist and industrial developments along the coast. They concluded that eutrophication is a principal cause of the demise of the west coast reefs. In a more recent study Wittenberg and Hunte (1992) found that the reefs on the west coast are still in a poor state of development with higher fleshy algae cover than measured by Tomascik and Sander (1987a) and coral cover in the spur and groove zone ranging from 2.0-24.9%. A recent survey (by PRFB) in 1993 showed a fleshy algal cover for BRI of >70% (mean of six 20m transects).

Water Quality, Coral Health and Reproduction-Barbados. -- Tomascik and Sander (1985, 1987a) measured various coral reef health indicators and water quality parameters along the west coast of Barbados and analysed for correlations between the health indicators and the water quality parameters. Detailed statistical analysis to test for the significance of the results was performed. Figures 4 and 5 summarise the spatial variation of some water quality (annual mean) and the coral health indicators (reef mean) along the west coast. Some of correlations between the health indicators and the water quality parameters are given in Table 1. Additional studies by Tomascik and Sander (1987b) showed that the reproduction output of *Porites porites* was reduced in the more eutrophic regions. Also Tomascik (1991), Wittenberg and Hunte (1992) and Hunte and Wittenberg (1992) found that coral recruitment was significantly reduced in the more eutrophic regions. In particular these studies showed that in the more eutrophic regions juvenile settlement rates were lower, juvenile mortality was higher and juvenile abundance was lower than in the less eutrophic regions.

Observations of the Demise of Corals on the Reefs of Magnetic Island. -- The demise of the reefs at Nelly Bay and the nearby Geoffrey, Arthur and Florence Bays on Magnetic Island have been attributed to increased sedimentation which results from the dumping of spoil from harbour dredging and also to effects of cyclone “Althea” (Collins, 1978; Endean, 1976 cited by Bell, 1992). Nelly Bay, Magnetic Island, was once renowned for its coral reef platform of *Acropora, Turbinaria* and *Montipora*, much of which emerged at low tide and was known to many as the “coral gardens” (eg see Johannes, 1972 ; Collins, 1978; Endean, 1976, cited by Bell, 1992). “As recently as the latter half of the 1960s the island still possessed coral gardens that were equal, and in fact often superior, to anything on the Great Barrier Reef... the diversity and form and delicate colouring of the corals painted an exquisite picture of unequaled beauty” (T. Brown cited by Bell, 1992). T. Brown noted that seaweed growth invaded the silt-saturated environment which effectively eliminated many of the remaining corals (cited by Bell, 1992). Endean reports (1976, cited by Bell 1992) that algae invaded many areas after destruction of part of the coral cover and this precipitated further destruction by trapping sediment.

Water Quality Data for Townsville Magnetic Island Region. -- The most comprehensive study on nutrients and water column productivity for the GBR lagoon is that of Revelante and Gilmartin (1982) for the region off Townsville (see Figure 1). Figures 6 and

7 compare the results obtained by Revelante and Gilmartin (1982) for chlorophyll *a* and P-PO$_4$ (in surface waters) with the suggested eutrophication threshold concentrations. Figure 8 compares the P-P04 data for the mid-lagoon Station II with those collected by Marshall at Low Isles in 1928-29 (Bell 1991). Some data for the outer regions of the GBR lagoon are also available (see Figures 6 and 7). These results are probably biased towards the high side because these data were mostly collected during the upwelling periods.

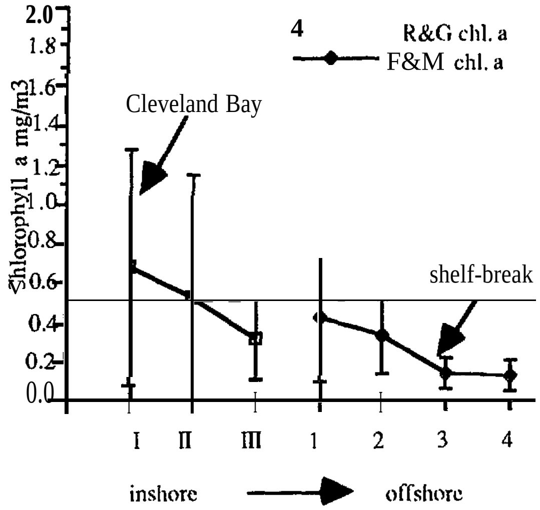

Figure 6. Cross-shell variation of chlorophyll a as recorded by Revelante and Gilmartin (1982), Ikeda et al, (1980) (R&G); Furnas & Mitchell (1984) (F&M) cited by Bell (1992) (see Fig. 1 for sampling station locations)

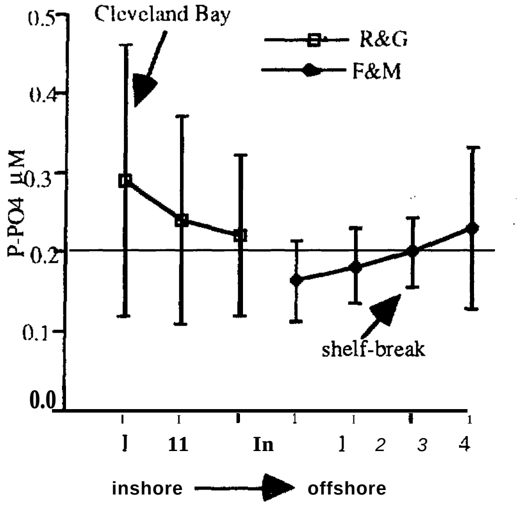

Figure 7. Cross-shelf variation of chlorophyll *a* as recorded by Revelante and Gil martin (1982), Ikeda et al. (1980) (R&G); Furnas and Mitchell (1984) (F&M) cited by Bell (1992) (see Fig, 1 for sampling station locations)

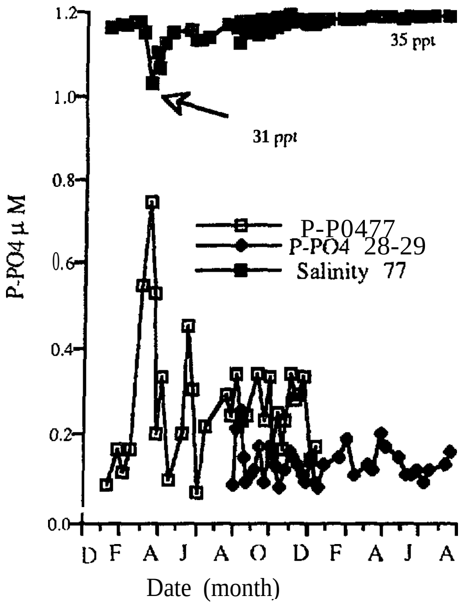

Figure 8. Comparison of seasonal variation of P-PO$_4$ at Station II (see Fig. 1) in 1977 with that measured in 1928-29 at Low Isles. Salinity is for Station II 1977.

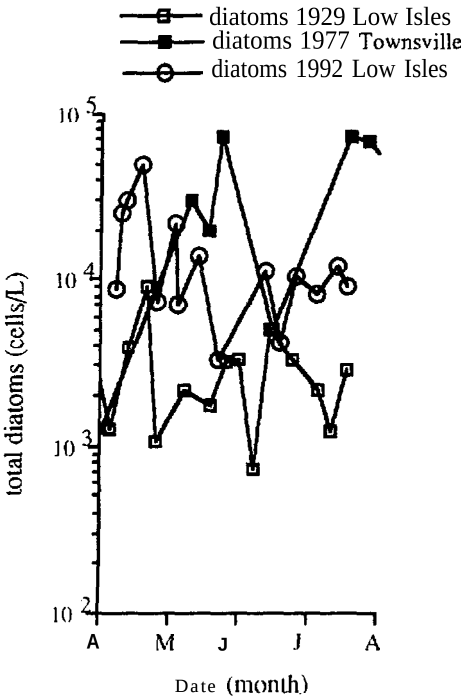

Figure 9. Comparison of variation of total diatom concentrations at mid- GBR lagoon stations 3ME Low Isles in 1929, 3ME Low Isles in 1992 and Station II (see Fig. 1) off Townsville 1977.

Observations of Demise of Coral Cover an Water Quality at Low isles--- Our personal observations and a comparison of photographic and descriptive records (eg see GBR 1933) demonstrates that a large portion of the reported flourishing hard coral cover in the shallower waters at Low Isles has been replaced since 1928-29 by soft corals, algae and sea grasses. Since the 1928-29 British Expedition to Low Isles, the corals have been subjected to the destructive forces of cyclones and to attacks by the crown of thorns starfish (*A. planci*). Results for $P\text{-}PO_4$ and diatom (>20µm) concentrations of samples collected at a station located 3 miles east (3ME) of Low Isles during the 1928-29 study are summarised in Figures 8 and 9. Figure 9 compares the total diatoms concentrations measured in 1992 at 3ME (Elmetri 1993) with those measured in 1929 at 3ME and those measured at Station II (Fig. 1) off Townsville in 1977.

DISCUSSION

Barbados. -- The early work demonstrates a significant demise of the coral reefs on both the south and west coasts of Barbados since 1950 which coincides with the increase in pollution of the coastal waters by sewage outfalls, storm drainage outlets, contaminated groundwaters and industrial discharges. Macintyre (1967) noted the more southern reefs on the west coast ie. those located closer to Bridgetown, had less coral cover than most of the reefs to the north, however all the substrate not covered by coral was covered by pink coralline algae. The results in Figure 5 indicate that the coralline algal cover of these reefs had been replaced to some extent by fleshy algae (eg turf and filamentous) by 1982. The impact of the rum factory and power plant discharges between BR and SG on DIN concentration is clearly discernible in Figure 4. The results in Figure 5 show a trend towards healthier reefs as one moves from south to north down the eutrophication gradient, with increases in the following reef characteristics: coral diversity, coral cover and coralline algal cover (at the expense of fleshy algal cover). Coralline and fleshy algal cover are included as health indicators because (i) live coralline algae are the preferred substrate for settlement of many corals, some species will not settle on fleshy algae (ii) fleshy algae have been identified as a competitor for space for both adult corals and juvenile corals and (iii) fleshy algae may promote disease (eg see review by Van Moorsel, 1989; Bell, 1992). Also the coral and coralline algal fragments are the main source of sediment to replenish beaches and to maintain and build the coral reefs themselves (Lewsey 1978; Scoffin et al. 1980 cited by Tomascik and Sander 1985). Eutrophication, by promoting fleshy algae and preventing the growth of corals and coralline algae, could therefore be a significant factor in the reef and beach erosion that is occurring on the west and south coasts of Barbados.

Figure 5 shows no fleshy algal cover in the spur and groove zone for the less eutrophic reefs in 1982. Today the coral rock areas of all of these reefs have significant cover of fleshy algae. A recent survey (6 transects 1993) of BRI showed over 70% of the spur and groove is covered with fleshy algae. Also Wittenberg and Hunte (1992) recorded significant increases in fleshy algal cover over that shown in Figure 5 for the spur and grove zones for SG (60.7%) and FV (50.2'%). The increased fleshy algal growth is attributed to both eutrophication and reduction of grazing pressure brought about by the die-off of *Diadema antillarum* in 1983 (Wittenberg and Hunte 1992). However it is important to note Tomascik and Sander's (1987a) results pre-date the 1983 die-off and these results did show far higher fleshy algae, lower coral diversity and lower coral cover in the more eutrophic region than in the less eutrophic region. A confounding factor is that Tomascik and Sander (1987a) found lower numbers of *D. antillarum* on the more eutrophic reefs. However there is evidence that eutrophication may decrease the recruitment of *D. antillarum (see* Wittenberg and Hunte 1992) which supports Tomascik and Sander's (1987a) conclusion that the primary cause for increased fleshy algal growth on the more southern reefs was eutrophication and not a reduction in grazing pressure. Wittenberg and Hunte (1992) also found fewer *D. antillarum* on the more eutrophic reefs. This finding following the severe die-off of *D. antillarum* supports the hypothesis that recruitment of *D. antillarum is* inhibited by eutrophication. It is concluded that the impact of the eutrophication has been magnified on all reefs by the reduction in grazing pressure that resulted from the *D. antillarum die-off.*

The results of correlation analyses between water quality parameters and coral health indicators are summarised in Table 1. These results show that both growth rate (GR) of *Montastrea annularis* and Brillouin's species diversity index (H) are highly correlated with chlorophyll *a* and SPM. This simple analysis supports Tomascik and Sander's (1987a) conclusion that the species diversity is the key community index in delineating the impacts of eutrophication. Of the water quality parameters that are specific measures of eutrophication, namely concentrations of nutrients and chlorophyll *a*, chlorophyll *a* exhibited the highest (negative) correlation with the coral health indicators. This indicates that chlorophyll *a is the* best water quality parameter for measuring the status of eutrophication. Laws and Redalje (1979) (cited by Bell, 1992) came to the same conclusion for their work in Kaneohe Bay. It is noted that because the water column would usually be well mixed in the shallow fringing reef areas the chlorophyll *a* of surface water samples reflects the fertility of not only the water column but also the substrata as well. In particular the sediment could be a source of nutrients and some components contributing to the chlorophyll *a* could originate from the substrata eg. dislodged attached algae and pennate diatoms. Pennate diatoms are a major contributor to the phytoplankton biomass in the coastal waters of Barbados (Partlo, 1975). The observed sensitivity of coral diversity to small changes in chlorophyll *a (ie.* eutrophication) is supported by the results of Maragos et al. (1985) and the analysis of Bell (1991, 1992) which show significant coral recovery of some rarer coral species in the northern (least polluted) region of Kaneohe Bay for a decrease in annual mean chlorophyll *a* concentration from 0.68 to 0.55 mg m^{-3}.

Tomascik and Sander's (1985 and 1987a) statistical analyses show that a significant reduction in the growth rates of *Montastrea annularis* (when compared with the growth rate at SR) occurs at stations with annual mean chlorophyll *a* concentrations ≥ 0.5 mg m^{-3} and that a significant reduction in Brillouin's diversity index occurs at stations with an annual mean chlorophyll *a* concentration ≥ 0.6 mg m^{-3}. Both of these values are in general agreement with the threshold concentration of 0.5 mg m^{-3} suggested by Bell (1991, 1992). However other data suggest that a lower threshold level maybe relevant for Barbados. Firstly the more southern reefs were in a poor state of development in the mid 1960s (Macintyre, 1967) and these were characterised by an annual mean chlorophyll *a* concentration of around 0,4 mg m^{-3} in 1972-73 (source Vezina, 1974 cited by Tomascik and Sander 1985). Second] y in 1970 the outer region of B-RI was characterised by a mean chlorophyll *a* concentration of 0.23 tng m^{-3} (Sander 1971, cited by Tomascik and Sander 1985). At this time *A. palmata was* relatively plentiful on BRI (Ott, 1971) yet was becoming a rarity in other regions. If it is assumed that the demise of *A. palmata was* due to eutrophication then these data suggest a threshold concentration of between 0.23 and 0.4 mg chlorophyll *a* m^{-3}. A value of *0.3* mg chlorophyll *a* m^{-3} is chosen. This threshold concentration may appear low but is in fact twice the open water background level (Kidd 1978, cited by Tomascik and Sander 1987a). The hypothesis that the recent demise of *A. palmata was* due to eutrophication seems reasonable when one considers (i) its sensitivity to sedimentation (ii) its susceptibility to physical damage by storms and predators and hence to overgrowth by algae (eg see Pastorok and Bilyard 1985 cited by Tomascik and Sander 1987a). Tomascik and Sander's (1987a) data also show that significant fleshy algal growth only occurred in the spur and groove zone of regions characterised by a mean chlorophyll *a* concentration >0.8 mg m^{-3}. It is hypothesised that beyond this second threshold level grazers cannot cope with the pressures of increased fleshy algal growth.

The effect of Hurricane Allen on BRI reef suggests that many of the other fringing reefs were probably severely damaged. The poor development of all the reefs along the west coast to-day in comparison with the earlier descriptions is attributed to their recovery being inhibited by eutrophication and in particular through its ability to restrict coral growth and reproduction. Tomascik and Sander (1 985; 1987b), Tomascik (1991), Wittenberg and Hunte (1992) and Hunte and Wittenberg (1992) found that coral growth, reproduction potential and recruitment (settlement and survival of spats) were significantly reduced in the more eutrophic regions. Other workers have observed that attached algae inhibits recolonisation of damaged corals (eg Ott 1971, Endean, 1976 cited by Bell 1992). Also Wittenberg and Hunte (1992) found that both fleshy algae and sediment were directly responsible for the mortality of some of the settled spats. These latter observations confirm the work of other workers (eg see Van Moorsel 1989). While a reduction in growth and reproduction ability of the adult corals may be important in the more eutrophic regions of Barbados, the lack of coral recovery in the less eutrophic regions is attributed largely to a reduction in recruitment and recolonisation which would have resulted from the increase in fleshy algal cover. As noted above the increase in fleshy algal growth due to eutrophication and hence its impact on coral recruitment and recolonisation would have been magnified by the reduction in grazing pressure due to the *D. antillarum* die-off. It is interesting to note that Van Moorsel (1989) found that coralline algae was an important competitor for settled spats and hence it is hypothesised that in the early stages of eutrophication that increased growth rate of coralline algae could reduce the survival of spats. This could explain the lack of coral development on the fringing reefs described by Macintyre (1967).

Townsville and Magnetic Island. -- The demise of the reefs at Nelly Bay and the invasion by macrophytes of nearby Geoffrey, Arthur and Florence Bays on Magnetic Island are consistent with the region being eutrophic. After cyclone "Althea" no recruitment of *Acropora* spats was observed in the following 15 months (Collins 1978 cited by Bell 1992). Collins noted that both increased sedimentation and algal growth make the conditions unsuitable for such settlement and also eludes to the possibility that eutrophication was causing the increased algal growth. The results of Revelante and Gilmartin (1982) (see Figures 6-8) show elevated concentrations of nutrients and phytoplankton for Cleveland Bay and for the mid-lagoon in the late 1970s. If the eutrophication threshold criteria are valid for the GBR lagoon then these results suggest that coral reefs in this region would have been experiencing stress through the effects of eutrophication (Bell 1991; 1992). It is important to note that, in the vicinity of the fringing reefs, mean concentrations of nutrients and chlorophyll *a* would probably be significantly higher than those given in Figures 6 and 7 due to the effects of local discharges and "island mass" effects. Revelante and Gilmartin (1982) concluded that riverine discharge is the principal source of the elevated nutrient concentrations for the near shore region. The results do indeed demonstrate a close correspondence between P-P04, silicate and lowered salinity which indicates they are river derived (eg see Figure 8). However decaying antecedent algal blooms and wind driven resuspension could be important factors contributing to the DIN flux (see review by Bell 1992). The results in Figure 8 suggest that the concentrations of P-P04 may have more than doubled in the inner lagoon since 1928 (Bell, 1991), which is consistent with the increased loads of phosphorus suggested Moss et al (1992; cited by Gabric and Bell 1993). The data of Revelante and Gilmartin (1982) also show the concentration of micro-phytoplankton (ie. phytoplankton > 20μm) in the mid-lagoon is some 1-2 orders of magnitude greater than that recorded by Marshall at Low Isles in 1928-29 (Bell 1992 eg see Figure 9). Bell (1992) notes that the mean concentration of nanoplankton (<20μm) is quite high and is in fact greater than the critical level suggested by Lucas(1974; 1982 cited by Bell 1992) for promotion of the growth of *Acanthaster planci*. Thus eutrophication of the inner GBR lagoon could be a significant factor in the outbreaks of *A. planci* (cf. Birkeland's hypothesis see Bell, 1992). The high concentrations of nutrients in the outer regions are attributed to upwellings and in the case of DIN, also to nitrogen fixing algae and bacteria which inhabit the sub-strata of the coral reefs. In addition to the large scale impact of river discharge on Cleveland Bay there are a number of local or small scale impacts. The harbour channel is dredged regularly and the spoil is dumped into Cleveland Bay. Sewage effluent (35,000 $m^3 d^{-1}$) and sludge from the city of Townsville flows to Cleveland Bay. A recent tourist development at Nelly Bay has not only destroyed much of the existing buffering capacity of the foreshores for the septic seepage from the existing local population but will atso increase run-off to the tinging reefs. A most beautiful headland dotted with large granite boulders and majestic pines was literally blasted apart and dumped into Nelly Bay to reclaim land and to construct a marina. The entrance to the marina requires the mining of the fringing coral reef. This development ensures that the "coral gardens" will never reestablish in Nelly Bay.

Low Isles. -- The observed reduction in coral cover at Low Isles, although not conclusive evidence, is consistent with the region being eutrophic. The principal cause of the eutrophication is surmised to be due to river discharges transporting nutrients from agricultural areas. The fact that the Low Isle-s region is impacted by river run-off has be recognised by various workers. Fairbridge and Teichert (Johannes, 1972 cited by Bell 1992) note that many of the corals in the vicinity of Low Isles had apparently been killed by sedimentation which they attribute to "colossal soil erosion due to unplanned agriculture". Yonge came essentially to the same conclusion on revisiting Low Isles, 50 years after the 1928 British expedition (Brown and Howard 1985 cited by Bell 1992). The CSIRO data summarised by Bell (1992) certainly show significant freshwater influence at Low Isles and the nitrate concentrations are of similar a magnitude to that measured by Revelante and Gilmartin (1 982) for the river-affected inner lagoon off Townsville. A repeat of the 1928-29 study is underway. Preliminary results (see Figure 9) indicate that the diatom concentrations were much higher (-x 10) in 1992 than they were in 1928-29 (Elmer" 1993). Preliminary results for the concentrations of *Trichodesmium* indicate that they are also far higher now than they were in *1928-29*. These results suggest that the GBR lagoon in the Low Isles region is far more fertile now than in 1928-29 which supporta the hypothesis that GBR lagoon in this region is eutrophic. It is recognised that there could be a year to year variation in the phytoplankton concentrations and hence it is important that a monitoring programme be maintained.

CONCLUSIONS

The data demonstrate a close correspondence between the demise of the coral reefs in Barbados with increased development and the resulting degradation in water quality and associated eutrophication. The studies indicate that chronic eutrophication is inhibiting the reproduction of the corals and in doing so is inhibiting the recovery of darnaged reefs. The effect of the eutrophication is magnified by the reduction in grazing pressure brought about by the *D. antillarum* die-off. Eutrophication, by promoting fleshy algal growth at the expense of coralline algal growth and reducing coral growth, could be a significant factor in the reef and beach erosion that is occurring on the west and south coasts of Barbados. The virtual extinction of *A. palmata* in recent times indicates that it could be particularly sensitive to eutrophication and if so the data suggest a relatively low eutrophication threshold of 0.3 mg chlorophyll *a* m^{-3}. Data for the GBR lagoon indicate that some river impacted regions exhibit signs of large scale eutrophication. There is some evidence that discharges of sewage are also impacting upon GBR coral reef ecosystems. The large scale eutrophication, which is attributed to agricultural run-off, could well be a factor in the demise of corals in the GBR lagoon and in the promotion of outbreaks of *A. planci.*

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