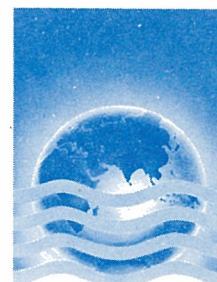


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UNIVERSITY OF NEWCASTLE UPON TYNE  
CENTRE FOR TROPICAL COASTAL  
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**POSSIBLE EFFECTS OF SEA LEVEL RISE ON  
CORALS AND REEF GROWTH**

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Possible effects of sea level rise on corals and reef growth.

by

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## POSSIBLE EFFECTS OF SEA-LEVEL RISE ON CORALS AND REEF GROWTH.

### INTRODUCTION.

The growth of coral reefs is strongly influenced by sea-level. The main reason for this is the coral's dependence on algae (housed in the coral tissues) for continued growth and survival; the algae in turn are dependent on light (for photosynthesis) available in shallow waters. Optimal coral growth, therefore is generally limited to within 30m of the sea water surface, with corals growing right up to the water/air interface where they then become limited by their tolerance to aerial exposure.

During the next 40y it is predicted that global warming will not only cause a potential maximum sea-level rise of 11mm per year (Wigley 1989) but that in addition there will be expected increases of surface seawater temperatures of 0.8 - 1.1°C (Jaeger 1988); increased frequency and intensity of storms (Buddemeier and Hopley in press) and possibly increased cloudiness and rainfall. All these factors have significant implications for the response of coral reefs to an era of sea-level rise. I intend to base my presentation on three themes - the known and predicted response of coral reefs to relative sea-level rise; the tolerances of corals to increased seawater

temperatures and other factors associated with global warming; and finally how low-lying island nations, such as the Maldives, may best protect their reefs so that they have a chance of growing optimally in a changing environment.

**The known and predicted response of coral reefs in an era of sea-level rise.**

As discussed in another presentation at this meeting (Edwards) it is the rate of sea-level rise, rather than the overall rise, which is critical in terms of the response shown by corals and coral reefs. Using the predictions derived from Wigley (1989) shown in Table 1 we can compare known rates of coral reef accretion (or build up) with predicted values of sea-level rise. It is important at this point to distinguish between coral growth and coral reef accretion. Coral reefs are composed of a wide array of different coral species - some are delicate branching varieties, which may show rapid linear growth in excess of 10cm per year ; others are slow-growing massive species which extend linearly by less than 2cm per year.

Considering the response of corals and coral reefs to sea-level rise, we are concerned not only with how fast individual corals may grow in a linear dimension but more importantly with how the whole reef builds up material vertically ie accretion. On a reef dominated by fast growing , branching species, growth of such corals would have to be accompanied by infilling from a source of sediment for this growth to be translated into the accretion of a 'solid' reef. Apart from corals there are many other organisms which build up the reef

structure - they include coralline algae, molluscs, echinoderms, foraminiferans - often their importance is underestimated though Grigg (1982) calculated that these organisms were responsible for 40-70% of total carbonate production of reefs in the Hawaiian Archipelago.

The power of reef fauna and flora to erode the structure of coral reefs is another factor which must not be underestimated. The rates of boring are comparable with the maximum rates of coral reef accretion (about 10mm per year) so where there are several surfaces of bioerosion within a reef framework, their combined action may be removing  $\text{CaCO}_3$  from the frame faster than the single growth surface of the corals can add it. In such cases the level of the reef surface will fall, even though it may support a flourishing cover of healthy corals. The effects of bioerosion may be much more significant on those reefs at high latitudes where coral growth is more limited (Scoffin 1987) and also on reefs which are affected by eutrophication. It should also be remembered that although vertical reef accretion is the net result of input of  $\text{CaCO}_3$  minus output (effected by physical and biological erosion and dissolution), sediments produced during biological erosion are an important contribution to the build-up of the 'solid' reef.

Considering the rates of vertical accretion which have been recorded for coral reefs ( Table 2 ) it is obvious that there is a wide variation in reported values - a range which varies between 1-12 mm per year even within a single geographic region. Such variation is attributable to at least two major causes. The first is due to the variable choice of regions on the

reef where the measurements were taken in each study; the second is the result of the use of different methodologies to obtain values for vertical reef accretion.

There are three ways by which a reef accretion measurement has been obtained to date. The first is by a detailed  $\text{CaCO}_3$  budget of all organisms on the modern reef. This method has only been carried out in detail at one location namely Barbados in the Caribbean (Stearn and Scoffin 1977). The second is by a method known as the alkalinity depression technique, which is based on changes in the carbon dioxide concentration of seawater necessary to precipitate  $\text{CaCO}_3$  over an area on a modern reef (Smith and Kinsey 1978). This method has highlighted 3 modal rates of vertical accretion equivalent to three areas on the reef. These were 0.4mm per year for sand and rubble shallow flats; 3mm per year for many present seaward reef flats and 7.0mm per year for areas with a high coral cover dominated by branching corals. The third method involves measurement of the growth of the reef since the last glaciation, over 10,000 years ago. This approach directly estimates retention and accumulation of sedimentary material rather than evaluating production of material. It involves coring into the reef, aging the corals in the core and deriving a rate of vertical accretion. Using this method in the Caribbean, three types of reef have been described; these have been termed 'keep-up', 'catch-up' and 'give up' reefs (Neumann and Macintyre 1985). 'Keep-up' reefs have been able to maintain shallow frame-building communities during rapid sea-level rise which followed the last glaciation, generally by the growth of the branching coral Acropora palmata. 'Catch-up' reefs are described as those which after an initial lag ( due in part

to increased sedimentation from inundated inshore areas following sea-level rise) rapidly grew upwards to catch up with sealevel. The most spectacular growth of this sort was shown at Alacran reef in Yucatan (Macintyre et al 1977) where growth rates of 12mm per year were recorded. This 'sprint' to catch up with sea-level was due to the rapidly growing, branching coral Acropora cervicornis. The third type of reef response - 'give-up' reefs are deep reefs where reef growth lagged behind sea-level rise until they were stranded at depths below the limit of active accretion.

In the Pacific most of the data refers to the Great Barrier Reef where the majority of reefs fall into the 'catch-up' category. 'Keep-up' reefs are rare and 'give-up' reefs have only recently been identified (Harris and Davies 1989). In the Indian Ocean there is insufficient information to identify growth responses of reefs though Montaggioni (1976) has provided data for reef accretion rates of 10mm per year in Mauritius.

By comparing values in Tables 1 with data collected on vertical reef accretion it should be possible to estimate the response of coral reefs to projected sea-level rise figures. Considering reef flats, for which accretion rates are well documented by the alkalinity depression method, it seems unlikely that vertical accretion of these areas dominated by branching corals (estimated as 7-8mm per year) would match a 11mm per year rise in sea-level, though higher rates of reef accretion have been obtained from dating geological cores (see Table 2). At lower estimates of sea level rise (ie 3.7 - 6mm per year) reef flats dominated by mixed communities of branching and massive corals should be able to keep pace with a sea-level rise of this

magnitude.

**The tolerances of corals to increased seawater temperatures and other factors associated with global warming.**

It is now becoming more widely acknowledged that the critical response of coral reefs to sea-level rise may lie not in the ability of reefs to keep pace with increasing water depth above them but their ability (or otherwise) to adapt to increasing seawater temperatures associated with global warming. For the majority of corals, the optimal temperature for their growth is 29°C. Corals in both tropical and sub-tropical locations therefore live precariously close (within 1-2°C) of their upper lethal temperature during the summer months (Jokiel and Coles - in press).

When corals are exposed to an increased seawater temperature of 1-2°C above ambient for several weeks, they will begin to bleach or lose their zooxanthellae (Glynn 1983). Such loss is not irreversible and if environmental conditions improve, the corals will regain their zooxanthellae complement. If however the temperature stress is prolonged the bleached corals will ultimately die. Over the last 5y there have been recurring bouts of coral bleaching on a world-wide scale (Brown 1987). One of the most dramatic events occurred in 1983 when seawater warming, as a result of the 1982-3 El Nino, caused coral bleaching at locations that spanned the Pacific from Panama to Indonesia. Results of studies carried out at that time indicate



that branching corals were much more susceptible to bleaching than massive coral species, a factor which cannot be lightly dismissed when rapid reef accretion depends on the good 'health' of rapidly growing, branching species. Following the bleaching, reefs in the East Pacific showed long-term coral community alterations, failures of corals to recover and recolonise and in some cases a shift to a net erosional environment (Glynn -in press; Glynn et al in press). Subsequently in 1987, widespread coral bleaching was observed in the Caribbean (Williams et al 1987) and currently coral bleaching is reported as severe at locations such as Jamaica in the Caribbean where temperatures are reported as 31°C - some 1-2°C above ambient (Goreau -in press).

The loss of zooxanthellae may prove critical to corals for corals which survive bleaching events have been shown to exhibit a reduction in growth rate and also an inability to reproduce - both critical factors in assessing the response of a reef to keep pace with sea-level rise. The impact of increasing seawater temperatures on corals is therefore of paramount importance and there is a growing feeling among biologists that the mass coral bleaching which has been witnessed over the last 5y could be a signal of climatic change. Given the predicted temperature increase in surface waters of the tropics over the next 40y we must ask can corals adapt to a 1°C increase in temperature, bearing in mind that existing reef fauna and flora have evolved in conditions where the rate of temperature change never exceeded that predicted over the next 40y?

There is surprisingly little information available to help us answer this question. Work currently in progress in

Hawaii suggests that there are genetic differences between corals of the same species - some genotypes being extremely sensitive to higher temperatures while others are less vulnerable to temperature stresses ( Hunter and Kinzie in Jokiel and Coles - in press). It is also suspected that both corals and zooxanthellae may be able to manufacture heat-shock proteins in response to temperature increases which could allow the development of tolerance of both corals and algae to a 1°C temperature increase. Although not yet observed in corals these responses appear to be universal in all other organisms studied (Craig et al 1982). Should they be found in corals they could provide the means for understanding the scope these animals have for adapting to temperature changes. The best evidence that corals can adapt to higher temperatures must be the existence of relatively diverse and luxuriant reefs in the northern Arabian Gulf where summer temperatures of 32°C are regularly recorded on the reef.

Other changes associated with global climate change include increased CO<sub>2</sub> uptake by oceans and increased intensity and frequency of storms. The short term effects of chemical changes are expected to be minor relative to the calcium carbonate supersaturation of tropical surface waters while on a longer time scale the accretion and destruction of marine carbonates are important aspects of the global carbon cycle. With higher seasurface temperatures it has been suggested that the frequency and intensity of tropical storms may increase ( Emanuel 1987). Changes in storm activity could have a very important long-term influence on reef development. Disturbance by storm damage has been seen as a way of maintaining diversity on reefs - given adequate time for recovery between storms, However when the

frequency and intensity of storms increase the result may be the rapid demise of the reef system as seen in Jamaica where Hurricane Allen in 1980 caused high mortality of the branching coral Acropora palmata with little subsequent recovery - the coral rubble being remobilised over the reef by Hurricane Gilbert eight years later ( Woodley -in press). For Jamaica the effects of recent storms and bleaching events are causing considerable concern to scientists working there who believe that the combination of environmental circumstances could convert these reefs into algal habitats with severe economic losses from deteriorating reef fisheries, tourism and shore protection. At the same time it must be appreciated that algal dominated areas may return to coral dominated communities within a 5y time span given improved environmental conditions ( Maragos et al 1985), and that reefs are always recovering from a hurricane ( Kaufman 1986). Analysis of the history of severe hurricane impacts over 120 years on the north coast of Jamaica suggest that their median interval has been about seven years. The storm-free period 1944-1980 when Acropora flourished and when classic descriptions of the reef were written seem to have been exceptional.

#### **Protective measures for coral reefs under threat.**

We have shown that scientific evidence suggests that coral reefs do have the potential to keep up with moderate predictions of sea-level rise, provided that they have the ability to adapt to increasing seawater temperatures over the next 40y. At the same time many reef scientists are fearful that

the apparently accelerating demise of reefs worldwide place them as extremely threatened habitats. Strict conservation methods are therefore required to protect reefs so that they are in a position to repond optimally to global climate changes.

For small, low-lying islands developments which are most likely to cause disturbance to reefs ( eg coral mining, dredging and tourist activities) must be strictly controlled. For countries such as the Maldives, where the major man-made influence on the reefs is coral mining, alternatives to mining the living reef must be found soon. Removal of the shingle ramparts on exposed reef flats for infill and use in concrete aggregate must also be banned, for this material has an important role to play in the build up of the reef and the protection of the land behind it. The urgency for conservation action is inescapable especially as scarcity of both living and dead material drives the miners to the reef flats of the outer reefs of the atoll - the ultimate defence against storm surge and sea-level rise.

The scope of reef flats which have been completely mined to recover and to play a significant role in vertical accretion is very limited. Living coral cover on reef flats mined over 16y ago has been recorded as less than 5% ; the substrate of the reef consisting of loose coral rubble which is very mobile and which , under the prevailing strong current regime, crushes and smothers juvenile corals attempting recolonisation (Brown and Dunne 1988). For these reefs sea-level has effectively risen by between 0.5-1.0m in the last 16y; mining having lowered the surface of active

accretion by this amount. Such damaged reefs are then in a very poor position to respond rapidly and effectively to sea-level rise. It is therefore imperative that policies and legislation to protect the reef environment are put in place if coral reefs are to play their natural role in protecting the land behind them.

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Table 1

**Projected Sea Level Rise (mm per year) 1985-2030 (after Wigley 1989)**

High level	11mm
Best estimate (high)	6mm
Best estimate (low)	3.7mm
Low level	1.0mm

Table 2

Rates of coral reef accretion in the Atlantic, Pacific and Indian Ocean (after Grigg and Epp 1989). \* denotes accretion by sedimentation

Area	Rate (mm per year)
<b>ATLANTIC OCEAN</b>	
St. Croix, US Virgin Islands	9-15
Alacran, Mexico	up to 12
Caribbean	1-12
St. Croix, US Virgin Islands	4-10
Bermuda	1-3*
Jamaica	1.3
<b>PACIFIC</b>	
Hawaii	1-10
Eastern Pacific	approx. 10
Hawaii and Johnson Island	up to 9
Australia	up to 8
Australia	2.6-7.3
Australia	1.5*
<b>INDIAN OCEAN</b>	
Mauritius	up to 10