

# GLOBAL WARMING AND CORAL REEFS

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## Abstract

Ever increasing global warming trend is predicted to cause within the next 100 years an accelerated sea level rise, increase in sea surface temperature and enhanced ultraviolet radiation to a significant enough extent to affect drastically the marine communities. Among the latter, the coral reefs are the most vulnerable because of their occurrence near the shoreline and close to the sea surface, and also because of their sessile nature. Besides, coral reefs respond quantitatively and qualitatively to sea level changes, and the reef structures thus, preserve environmental signatures to reconstruct past sea level changes. This review summarizes the present state of knowledge on inferred Holocene sea level changes and reef structures in the Indian seas, and presents predictions of the possible deleterious effects the global warming can have on coral reefs in general, and the Indian reef in particular.

## Effects of Global Warming

Eustatic sea level changes are a consequence of changes in shape and size of the ocean basins, amount of water in the oceans and the average density of sea water. The first causative factor relates to changes in mid-ocean ridge systems, the second to glaciation and ice melt, and the last to global temperature changes. Sedimentary records and fossil studies

show that the changes in the mid-ocean ridge system were responsible for eustatic sea level changes in the Jurassic and Cretaceous times when the ice caps were thought to be absent. However, these account for sea level changes of less than a mm per century. On the other hand, the main cause for eustatic sea level changes in the fairly recent past has been the periodic formation and melting of the great continental ice caps. These changes are rapid by geological time scales; since the melting of Quaternary ice sheets about 18000 yrs. B.P., the sea level rose at a rate of 7mm per year to reach the present day sea level. Not all this rise is linked to deglaciation, though thermal expansion can account for a major fraction of it, since the satellite measurements show that the sea level rise (SLR) of 2mm per year at present may well be due more to thermal expansion of the ocean than changes in the volume of ice sheets, since average temperature of the sea surface has risen by as much as 0.1°C per year since 1982.

The increased global warming-up, and the accelerated SLR phenomenon witnessed in this century are a consequence of an increase in 'green house' gases, principally carbon dioxide and to some extent chloroflourocarbons (CFC), nitrous oxide and methane in the atmosphere. The carbon dioxide and the global temperature are rising at a rate unprecedented during the last 800,000 years, and with the concentration of green house gases increasing ever faster in the atmosphere, the average temperature of the earth's surface could rise by between 2 and 5°C over the next 100 years (Frolich, 1989). The response of sea level will be to rise even more rapidly, to levels ranging from a conservative 57 cm to as much as 368 cm (Table 1), above that of the present, by the end of the next century.

Possible deleterious effects of accelerated SLR are several. Physical effects will include coastal erosion

and shoreline retreat, increased damage due to storm surges and swells, submergence of coastal wetlands, coral islands and atolls, loss of habitable land and threat to shore installations and structures, shifting of river mouths and deltas, salt water intrusion into rivers, bays and aquifers, etc. Ecological effects will range from a loss of coastal vegetation if the shoreline behind them is too steep to allow their landward migration, loss of commercial fisheries, and intrusion of nuisance organisms and predators, more towards nearshore waters than now. Global warming up due to 'green house' gases does not act on marine communities through a rise in sea level alone, but equally through a rise in sea surface temperature (SST) and increased UV-B radiation. Possible effects of a rise in SST are reduction in the survival of stenothermic organisms, shifts in the quantity and pattern of precipitation, frequency, tracks and seasonal and geographical extension of hurricanes, ocean currents, etc. Increased UV-B radiation could very well impair photosynthetic abilities of autotrophs and survival of heterotrophs, thus affecting the biological productivity of the communities as a whole.

Marine communities that will be most seriously affected by these changes are those that are near the shoreline and at or close to the sea surface. Coral reefs qualify in both these categories. Their stenotypic nature, requiring a set of uniform environmental conditions, ranging within narrow limits, would render them more susceptible to the damaging effects of the changes associated with global warming up than in other ecosystems like mangroves or estuaries which exhibit tolerance to a wide range of environmental conditions. Because of these considerations, and because of the commercial value, in terms of organic and inorganic resources as well as tourism, coral reefs are probably the best suited ecosystem on which it would be worthwhile to speculate the effects of accelerated SLR. Besides, reefs preserve environmental signatures related

to past sea level changes, both in quantitative (variations in growth rate) and qualitative (the biolithofacies produced) forms, and as such are excellent gross sea level indicators of the past.

The objective of this communication is two-fold. The first is to probe whether the reef structures of Indian seas provide clues to Holocene sea level changes. The second is to synthesize the possible effects of global warming up on the coral reefs of India. The latter is more pertinent, since Indian reefs not only hold a potential for commercial resources (potential fish yield alone from Indian reefs is equivalent to 10% of total annual marine fish production in India - Wafar, 1986) and are increasingly becoming a great revenue generator by way of foreign and domestic tourism.

Distribution of modern reefs in Indian waters is shown in Fig.1. Major reef formations are the fringing reefs of the Gulf of Mannar, Gulf of Kuchchh, Palk Bay, Andaman and Nicobar islands, and the atolls of Lakshadweep. Scattered patches of corals are also found in the intertidal areas, and occasionally at subtidal depths down to a few meters along the west coast of India, notably at Ratnagiri, Malwan, Redi Port and Vizhingam. Relic reefs with living hermatypic corals at depths ranging from 25 to 45m are the Gaveshani Bank off Mangalore, and the submerged banks (Bassas de Pedro, Sesostris Bank and Cora Divh) to the north of the Lakshadweep. Submerged fossil reef systems have also been located off between Vijayadurg and Vengurla (Vora and Almeida, 1990). Raised reefs, probably as a result of local upheaval of tectonic nature, are found in Ramanathapuram district (Stoddart and Pillai, 1972) and minicoy (Gardiner, 1903). There are 199 coral species under 71 genera in the Indian seas, of which 155 species belonging to 50 genera are hermatypes, and 44 species belonging to 21 genera are ahermatypes (Pillai, 1983).

## Coral Reefs as Indicators of Past Sea Levels

The usefulness of coral reefs in providing environmental signatures of Holocene eustatic sea level changes, based on a number of studies in the Atlantic and Pacific, has been recently discussed (Davies and Montagnioni, 1985). For the west coast of India, Kale and Rajaguru (1985), synthesizing information from various sources, have reconstructed late Quaternary transgression and regression history (Fig.2). An excellent summation of the studies of past sea level changes along the coasts of India is given by Merh (1987). Almost all inferences of past sea level history are, however, from strandline-generated erosional and depositional features, and occasional radiometric dating of beach rocks. Nevertheless, there seems to be at least two instances where coral reefs can be of use to infer and/or to confirm Holocene sea level changes along the west coast of India. Characteristic features on the western continental shelf of India are the submerged terraces at -92 (the Fifty fathom flat) -85, -75, -55m, among which the Fifty fathom flat is the most prominent (Nair, 1974). Radiocarbon dating of the oolite limestones and ooid grains of the Fifty fathom flat gave an age of 9000 - 11000 years B.P. (Nair, 1974; Nair and Hashimi, 1980). Occurrence of shallow water foraminifera together with oolites in samples on the Fifty fathom flat shows that this flat stood at sea level probably during the Pleistocene (Nair, 1971), and the similarities in depth and nature of the sediments of the submerged terraces at -92, -85, -75, and -55m suggest that these represent standstill sea levels during Holocene transgression (Nair, 1975). Supporting evidence for this comes from the recent findings of Vora and Almeida (1990) of the presence of submerged reef systems oriented parallel to the shoreline at water depths of 60-110m on the continental shelf between Vijayadurg and Vengurla. Dredged materials from these submerged reefs have clear evidence of the presence of colonial shallow water reef-building

corals of at least 3-4 genera. What is interesting is that the distribution of reefs broadly follows the 110, 90, 70, 60 and 40m isobaths, and giving an allowance of 20m for the downward extension of the distribution of living hermatypic corals, these depths represent sea levels of 90, 70, 50, 40 and 20m. These figures roughly correspond to the Holocene standstill depths (Nair, 1974), and most likely in each instance the reef began as a start-up reef in a standstill, kept up for sometime with SLR but failed to catch up eventually. More aptly, they are give-up reefs. In all probabilities, these submerged reefs, as well as the patchy reefs at subtidal levels close to the shore (Qasim and Wafar, 1979) contain enough environmental signatures to reconstruct with a fine precision the Holocene sea level changes on the west coast of India; they only need to be extracted.

The inability of the submerged reefs to sustain a continued landward migration is probably as a result of some drastic changes in the climate. Sedimentary evidence (Nair and Hashimi, 1980) does indeed suggest a sudden change in climate from dry to moist, and from sporadic short-lived flash floods to prolonged spells (about 3 months' monsoon prevailing at the present) during Holocene. Our present day observations clearly indicate that terrestrial runoff in monsoon reduces drastically the salinity and light penetration in the coastal waters for distances up to several miles, and increases the suspended load, all of which are detrimental to coral growth and survival. Had these occurred when the climate changed suddenly, as in all probability it did, they alone would have been enough to kill the reefs. Nevertheless, stragglers from these submerged reefs still exist, mostly as patches of massive large-polyped forms, capable of tolerating wide changes in environmental conditions better than would the ramose, small-polyped forms, which incidentally, are totally absent from these patches near the shore (Qasim and Wafar, 1979). The other representative

of the extensive reefs of the outer shelf that survived Pleistocene drowning is the Gaveshani Bank, farther south ( $13^{\circ} 24' N$ ;  $73^{\circ} 45' E$ ), about 100km off Mangalore, at a depth of 32-38m. The drowning of this bank is evidence of a rapid rise of Holocene transgression along the western continental margin of India, probably at a rate of 10mm per year (Nair and Hashimi, 1988).

Another region where coral reefs preserve evidence of eustatic sea level changes is the Lakshadweep. In two of the atolls here (Kadmat and Bangaram), presence of a series of submerged terraces in the seaward reefs at 10-15m, 21-36m and 43-47m is evidently as a result of glacio-eustatic and climatic changes (Siddiquie, 1975). Apart from the above, terraces at the depth of 45m, 69m and 82m have also been observed, amongst which the terrace at 82m is very prominent (Chauhan and Chaubey, MS). The terrace at 82m corresponds to similar features at different locations along the west coast of India having an age of  $8900 \pm 132$  years B.P.; other terraces are also manifestations of sea level standstills, and confirm at least three such events i.e. at 60m, 48-36m and 30-25m in this region since then (Chauhan and Chaubey, MS). These, and other such atolls are obviously keep-up reefs that have tracked sea level rise. On the other hand, Byramgore and Cheriapani reefs to the north of the Lakshadweep atolls are catch-up reefs, which unlike the southern reefs, are still just below the present sea level and yet to form the islands. The submerged banks further north (Bassus de Pedro, Sesostris Bank and Cora Divh) are the reefs that got drowned during the late Quaternary transgressions. Recently, we dredged over these banks and carried out hydrographic observations (R.V.Gaveshani, cruise 206). Dredging yielded abundant live corals, especially of the hermatypic species, and an assortment of fauna and flora characteristic of coral reefs. Interestingly, oxygen levels near the top of the banks were higher than in the water column above, and this is a clear indication

that these banks are metabolically active and growing.

### **Future Effects of Accelerated SLR on Indian Coral Reefs**

Biological studies of Indian corals and reefs are, with a few notable exceptions, quite recent in origin and deal mainly with systematics and distribution of corals, and reef-associated fauna and flora, interspersed with occasional studies on productivity and ecosystem processes (Wafar, 1986). Prediction of how the coral reefs will respond ecologically and biologically to SLR and global warming related changes would pre-require, to cite a few, a knowledge of coral calcification and growth rates, effects of increased temperature on physiological processes such as growth, reproduction and survival, vertical zonation of corals, effects of increased UV radiation on zooxanthellar photosynthesis and survival of coral planulae, etc. Unfortunately, no such studies have been carried out on Indian corals so far, and a visualization of what will happen to Indian reefs if sea level rises rapidly will have to be constructed based on such data from elsewhere.

The question of most serious concern is whether the coral reefs as a whole can escape drowning if the sea level rises rapidly. Fig.3 is a hypothetical situation relating projected SLR in the next century and the coral reef growth rates. SLR curves are from the figures in Table 1, and the reef growth projections are based on a range of 1-3 mm growth per year for atolls and 10-12mm growth per year for fringing and barrier reefs (Wells, 1989). I have intentionally adopted such low figures, even though linear growth of many corals can be double or more than these figures (see for e.g. Gomez, *et al.*, 1985), since actual reef growth (reef accretion) is a much slower process than linear extensions of coral colonies. As would be obvious from this figure, the atolls will be the most affected.



At low growth, they would begin to drown within the next 10-20 years even if the SLR follows the "low" projection scenario; at high growth they may keep up for about 50-60 years but will eventually drown, perhaps not out of the euphotic zone but to deeper levels. This itself will further accelerate the sinking process, since calcification and coral growth are light-dependant (Dustan, 1975), the low light probably operating by reducing the photosynthetic removal of carbon dioxide by zooxanthellae from the symbiotic system, thus slowing down the aragonite precipitation (Borowitzka and Larkum, 1976). On the other hand, fringing and barrier reefs may fare better, keeping up well with the sea level rise up to the "mid-range" projection throughout the next century.

The next predictable consequence of SLR is the loss of land, habitable or otherwise, and this assumes an importance of its own in areas presently associated with coral reefs. The typical example is the Lakshadweep islands. These are low-lying islands with the highest point not higher than a few meters above the sea level. Even a 1m rise in sea level is adequate to reduce drastically the land area of the islands which measure, even otherwise, not more than a few square km at present, and a 2m rise will virtually make human habitation impossible (Fig.4). The island accretion, if the radiocarbon date of the storms beaches is any indication, can be from 10 to 200mm per year (Siddique, 1980) but it is doubtful whether this will be of any great use in counteracting the secondary effects of SLR, since the reef accretion may not match island accretion and may lose its protective value as a barrier against storm surges and erosion. Regardless of the manner in which land loss may occur i.e. submergence and/or erosion, it will have wide repercussions: economic, geo-political, cultural, etc. Coral reefs of the Lakshadweep are the only one of their kind to exist in pristine state in the Indian seas, and have just begun to generate revenue from tourism, both domestic and

foreign, which is expected to expand rapidly in the near future. This will be lost along with the land. Secondly, these islands extend the EEZ of India by several thousand square km. With the loss of land the base for monitoring their resources and defence interests of this area will be lost, and the cost of policing these waters from the continental shoreline which is 200-250 km away will increase several-fold. Lastly, the local residents of the islands maintain a distinct ethnic identity. Most island communities are closely knit and social interactions between the residents of different islands, and between the islands and the mainland are limited. Loss of habitable land will mean their resettlement in the mainland with the attendant socio-cultural problems. These effects will not be severe with other coral islands such as those of the Gulf of Mannar as they lie close to the mainland and are uninhabited anyway, or those of the Andaman and Nicobar islands, which are high islands with a steep shoreline that would reduce land loss to the barest minimum.

SLR can also affect the vertical zonation of corals on a reef. There are really very few corals that live within a narrow depth range (e.g. 0-5m for *Acropora palmata* in Atlantic - Lighty et al., 1982), but a rapid rise in sea level will favour a vertical extension of the fast growing species, with the slow growing species sinking down in the zonation structure. The farther they sink, the more slower will be their calcification rates, and eventually they will sink out of the euphotic zone. The coral diversity will diminish, entraining associated bio-ecological changes, especially on the food chain organization, since most of the reef organisms, especially the fishes, are notoriously specific in their association with particular coral species.

### Elevated SST

SLR is not the only way through which the effects

of global warming will manifest on coral reefs. Increase in sea surface temperature (SST) and UV-B radiation resulting from a reduction in ozone cover can also affect the coral reefs. We only can speculate on these possible effects from what little we know about coral physiology.

Coral reefs thrive at water temperatures ranging from 17-18°C to 33-34°C (Guilcher, 1988), with the most optimum growth occurring at between 25-29°C. Notwithstanding the wide tolerance of the reefs to temperatures, the coral species constituent of a given reef are really stenothermal, and are adapted to only the ambient water temperatures in which they grow. For example, *Pocillopora damicornis* from Hawaii had a growth optimum at 27°C whereas the same species at Enewatak atoll where ambient water temperatures are higher, had a growth optimum at 31°C (Clausen and Roth, 1975). Similarly, upper lethal limit of temperature for sub-tropical corals is 2°C lower than their tropical counterparts (Coles, et. al., 1976). Poor adaptability of Scleractinian corals to slowly elevating water temperatures was observed as early as the beginning of this century by Mayer (1914), who reported physiological stress in a number of corals at temperatures between 31.8 and 36.4°C, and death at temperatures exceeding 35.8°C. Summarizing the effects of temperature on coral growth and survival from laboratory studies as well as field observations where thermal effluents from power plants and OTEC power cycles were discharged directly on the reefs, Neudecker (1987) showed that corals suffer sublethal effects such as expulsion of zooxanthellae (bleaching) and reduced growth rates at temperatures 3-4°C, and near-total mortality at temperatures 4-6°C, above ambient. From their studies on the effects of elevated temperature on three coral species in Hawaii, Jokiel and Coles (1977) concluded that corals apparently have little or no ability to acclimate and that if at all they do, then the process of adaptation may require

many generations. Temperature also seriously affects coral reproduction: Jokiel and Gunter (1978) showed that the ability of *Pocillopora damicornis* to reproduce was curtailed under sub-optimal conditions far more severely than was the growth rate, and that successful reproduction diminished by up to an order of magnitude with a 1°C temperature change from the optimum.

The predicted 2-5°C rise in global temperature, if it translates into an equivalent rise in SST, can have deleterious effects on coral survival, especially when the corals already live at temperatures near their upper thermal tolerance limits (Coles, et. al., 1976) as in most world reefs. Given the record of poor adaptability of corals to elevated temperatures, a very slow rise in SST can alone help the corals to acclimate in the long run, if at all they do. How the SST will increase in the next century can however be only anybody's guess.

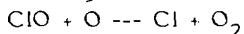
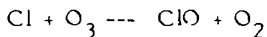
Hurricane formation requires water temperatures of 27°C or greater than that (Wendland, 1977) and presumably therefore, global warming will result in an extension of the hurricane season and also extend their latitudinal range. Hurricane events are relatively random at present, nevertheless the damages they inflict on the coral reefs are considerable. Summing up the effects of hurricanes on coral reefs, Stoddart (1985) observed that the immediate effect of hurricanes will be a mortality of ramose corals, at times up to 100%, and the continuing effects will be delayed mortality of damaged organisms, disruption of linkages between reef components and the continuing movement and adjustment of storm-generated sediment bodies. Recovery of a reef is usually slow, often taking a decade or so to return to pre-hurricane state. Not only the possible increase in the frequency of hurricanes as a result of global warming can ravage more reefs over a wider geographical area, and repeatedly, but also can have a serious economic fall-out in the form

of loss of commercial reef-related resources. For example, after Hurricane Iwa struck Hawaiian islands in 1982, aquarium fish industry almost collapsed (Preffer and Tribble, 1985), and is probably yet to recover to its pre-storm level.

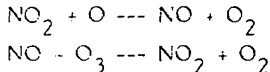
Another possible effect of the increase in SST will be a shift in ocean current patterns. Its likelihood is uncertain, but in the event it happens, the consequence, with respect to adult corals, will be an enhanced mortality if cooler or more warmer waters are advected onto a reef. Changing current patterns would also affect coral planulae dispersion and settlement. Sexual reproduction in corals is accompanied by the liberation of planulae which pass through a planktonic phase before settling on a hard substratum. Usually the planktonic phase is short and early settlement apparently is a characteristic of planulating species (Stimson, 1978). However, some brooded planulae are longer-lived (Richmond, 1981), and the coral species that produce such planulae are likely to face inability to recolonise the same area or extend their distribution to wider geographical areas if the current regime gets altered unfavourably.

### Increased UV-B Radiation

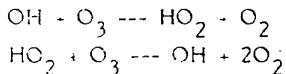
Green house gases, especially nitrous oxide, chlorocarbons (methyl chlorine, carbon tetra chloride, methyl chloroform, chlorofluorocarbons, etc.) and methane not only provoke global warming but also lead to ozone depletion in the stratosphere through catalytic cycles involving nitrogen and chlorine species (Stordal and Isaksen, 1986). In the stratosphere, the chlorocarbons are photolysed to give free chlorine species which depletes ozone in the following catalytic cycles.



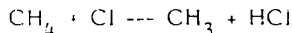
Similarly, nitrous oxide decomposes to  $\text{NO}_2$  in the upper stratosphere, and the nitrite depletes ozone in the following catalytic cycles.



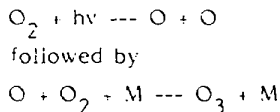
Methane in the upper stratosphere is oxidized to form water vapour which is the source of oxides of hydrogen in the following reactions.



However, in stratosphere below 40 km, methane reacts with chlorine as



thus reducing the catalytic effect of chlorine species by forming HCl. In these layers, 'self-healing' by increased UV radiation can regenerate ozone through oxygen recombination in the following reactions:



Notwithstanding the regeneration of ozone, the continued emission of green house gases will lead to a depletion of stratospheric ozone, and if the emissions continue at the rates in which they were occurring in 1980, then by 2050 the global ozone depletion will be about 2.6%, characterized by a high latitudinal gradient with  $\leq 2\%$  depletion at low latitudes, and  $> 10\%$  depletion at high latitudes (Isaksen and Stordal, 1986).

Loss of ozone cover will result in increased quantities of ultra-violet radiation, among which the UV-B (280-320 nm) is the most lethal, reaching the surface of the oceans. A decrease of 10% of ozone cover, as is most likely to occur in the next century, will result in a 28% increase in DNA damage and a 21% increase in plant damage at 45°N (Worrest, 1986). The harmful effects of UV-B radiation on marine planktonic communities are well documented, and are summarized by Worrest (1986). The most important among them are a marked reduction in the photosynthetic capacity of phytoplankton, shift in their species diversity and community composition, and increased mortality of zooplankton, especially fish eggs and larvae. The cumulative effect of these changes will be a drastic reduction in marine fish production.

UV radiation is harmful to a wide variety of coral reef forms. Jokiel (1980) demonstrated that a variety of reef organisms like sponges, bryozoans and tunicates were killed after 1-2 days of UV radiation, and that these epifauna can survive in intensive sunlight only if the UV portion is filtered out. Corals unadapted for UV radiation were killed rapidly when exposed to intense sunlight and UV (Scelfo, 1986), and coral growth, measured by  $^{45}\text{Ca}$  incorporation, was completely inhibited in long wave UV range (Roth et al., 1982). In corals exposed to UV radiation, planulation decreases markedly (Jokiel, 1985). The zooxanthellae are extremely sensitive to UV-A and UV-B radiation (Jokiel and York, 1984), and full incoming UV radiation completely inhibits growth in several strains of them (Pead, 1986). However, organisms living in shallow areas of the reefs can adapt to high UV levels. Corals as well as several other organisms from shallower depths have much higher UV absorbing pigments (Scelfo, 1986; Jokiel, 1980), and the shallow water turf algal communities, when exposed to UV wavelengths, responded only by increasing their respiration rates without

any change in photosynthetic parameters (Carpenter, 1985). An area of coral biology where studies on effects of UV-B radiation will prove beneficial is the survival of planulae. They are doubly susceptible, as plankton living near the sea surface, and as hosts deriving nutritional benefits from zooxanthellar photosynthesis, which itself is susceptible to UV-B damage.

Contrary to the misconception that UV is absorbed by the sea water, UV penetrates clear ocean waters nearly as well as visible light (Jerlov quoted in Jokiel, 1980). This is of critical importance in coral reef waters which are well known for their high transparency. In these ecosystems, therefore, UV-induced damages to producers and consumers, can become more severe even if there is a slight increase in incident UV radiation, and this will be still more aggravated by the sessile nature of most of its inhabitants; even the nektonic forms usually associate themselves with one coral species or another, and thus have a limited range of movement within a reef.

## Conclusion

One might wonder whether this pessimistic view of the effects of accelerated SLR is wholly warranted. The answer is yes, and the evidence for this is not far off from our country: in Maldives, erosion and land loss is the result of SLR, and it would not be long before our own islands, especially those of the Lakshadweep, suffer this fate. Secondly, the secondary effects of global warming such as those associated with increase in SST and ozone cover reduction may well have the potential to compound the effects of accelerated SLR. It is important to direct our research efforts towards a better understanding of the effects of climatic changes and SLR on coral reef ecosystems so that suitable solutions can be contemplated from now on. Perhaps the picture need not be totally pessimistic: increase in SST may extend the warmer waters



well into higher latitudes, and we may have more coral reefs, after all.

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**TABLE - 1****Estimated Sea Level Rise (in cm) Through 21st Century**

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Year	Low	Mid-range low	Mid-range high	High
2000	4.8	8.8	13.2	17.1
2025	13.0	26.2	39.3	54.9
2050	23.8	52.3	78.6	116.7
2075	38.0	91.2	136.8	212.7
2100	56.2	144.4	216.6	345.0

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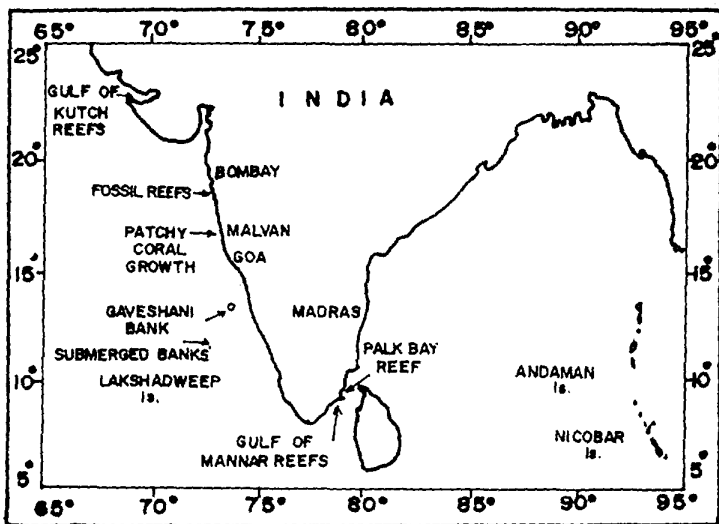


Fig. 1 Distribution of coral reefs and coralline banks in the Indian seas



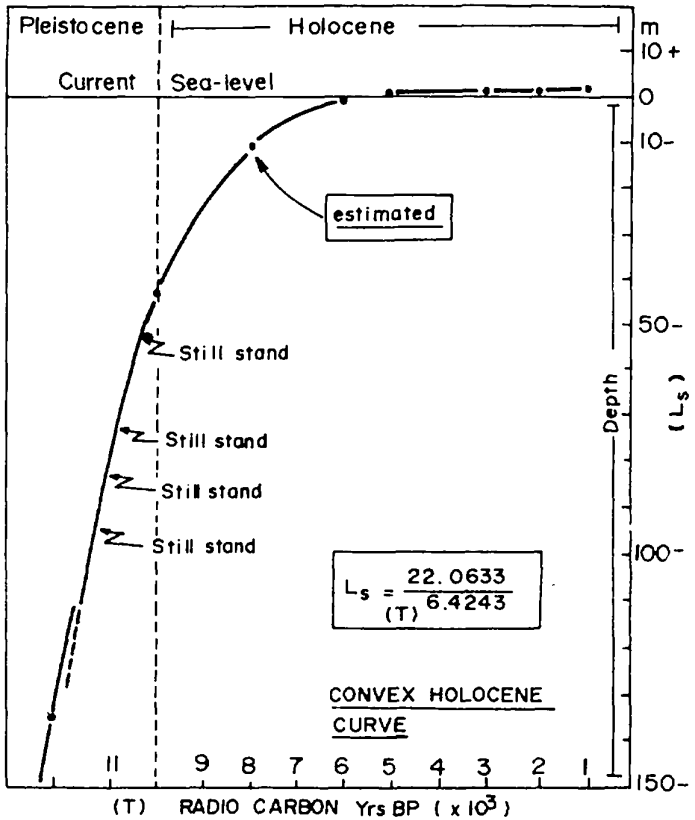


Fig. 2 Late Quaternary sea levels along the west coast of India (Source: Kale and Rajaguru, 1985).

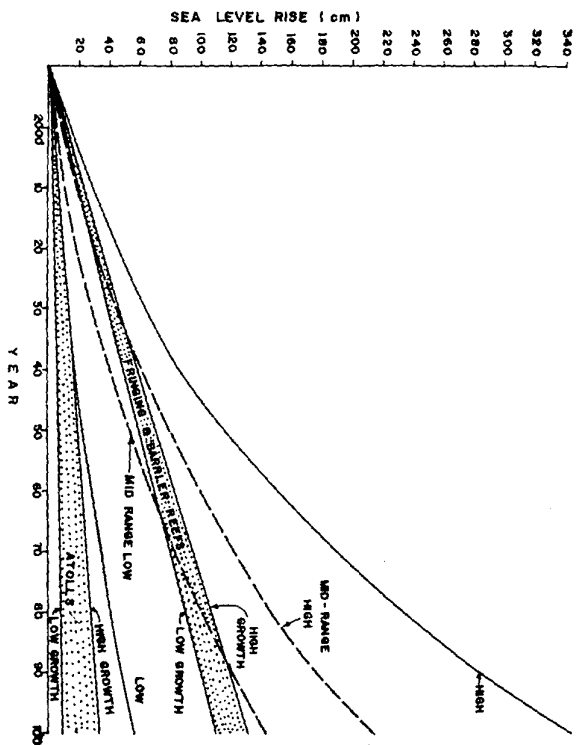


Fig. 3 Comparisons of the projected sea level rise rates and reef growth rates

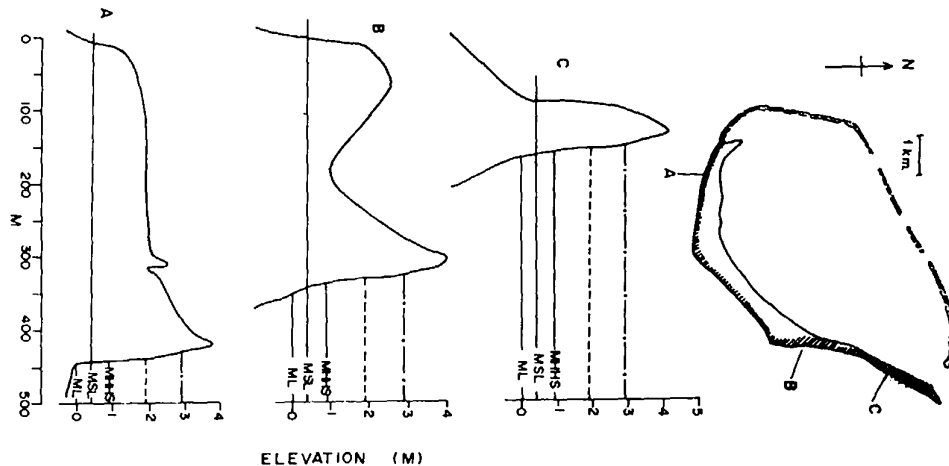


Fig. 4 (a) Minicoy island. Dotted zone - reef; shaded zone - rocky region in the island. (b) Topography along lines A, B and C shown in (a) Present levels are shown by ML (mean low), MSL (mean sea level), and MHHS (mean high high spring) --- shows future MHHS if the MSL rises by 1 m. - - - shows future MHHS if the MSL rises by 2 m. (Source: Shetye *et al.*, 1990).