SEA LEVEL RISE - A CORAL ATOLL PERSPECTIVE

ON

A: TERRESTRIAL ENVIRONMENT

B: MARINE RESOURCES

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A: SEA LEVEL RISE - A CORAL ATOLL PERSPECTIVE ON TERRESTRIAL ENVIRONMENT

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Introduction

Sea level rise - one of the consequences of global warming is part of a long processes of change on the environment, induced largely by Man's actions. Sea level rise has fluctuated in geological history, and from the records available a 10 - 15 cm rise in the mean global sea level in the past 100 years was observed. The predicted present day sea level rise is largely attributed to the input of certain gases into the earth's atmosphere, particularly in the past 2 centuries. These gases trap the insolation and irradiation upsetting the global heat balance. The dissipation of the atmospheric heat into the sea and to the polar areas of the world is predicted to cause many changes.

Although water has a higher specific heat than land, under the predicted scenario, a 1 - 2 C increase in global temperatures by the year 2030, would no doubt, under the influx of heat transfer, lead to a thermal expansion of the sea waters. The expected higher temperatures are likely to cause melting of some alpine glaciers and polar ice caps. Both these factors tend to lead to an elevation in mean global sea level.

The impacts of an elevated sea level can have disastrous or near tragic consequences on coastal areas, in particular on deltas and oceanic islands. Because of their very low elevation, a mere rise in the sea level, combined with other oceanographic and meteorological changes induced by the global warming, the impacts on countries like the Maldives is most significant.

The recent focus on this global warming issue has won the thinking of many politicians and the many alike, in particular on a global scale, to the cause of environment. This global warming phenomena, can be regarded as a blessing in disguise for environmentalists, as their voices were little heard by the politicians and planners, before the real threats of global warming were vividly put to at high level political fora such as in Vancouver and the United Nations General Assembly in 1987. It was only with this political impetus, studies were commissioned and the general concern and the awareness about the problem began to spread.

This paper intends to discuss the scenario of a sea level rise from a coral atoll perspective, highlighting some of the areas prone to be effected and the likely impacts and extent on them.

To facilitate a comprehensive overview on the problem, this paper will consider the impacts on the terrestrial and marine resources separately, confined largely to the sea level rise scenario.
The Maldives forms a chain of coral atolls on the Laccadive-Chagos submarine ridge, which rises deeply from the deep Indian Ocean. The sequential growth of coral under the prevailing conditions has built up the chain, to what it is today. Each of the 1200 odd islands is relatively small in area, none exceeding over 5 km squared, with an average elevation of 1.6 m above MSL. The total area of the Maldives is about 90,000 square km of which only only 2% is land. The protection offered to the islands are solely restricted to their surrounding reefs. No point on any island in the Maldives is 2 km away from the sea. The circum effect of the sea on the islands in the Maldives cannot therefore be over - exaggerated.

The table below summarizes some topographical data available for 13 of the islands in the Maldives.

<table>
<thead>
<tr>
<th>Transect Name of Islands</th>
<th>Date</th>
<th>Time of water level reading</th>
<th>Length of transect (m)</th>
<th>Maximum Height above MSL (cm)</th>
<th>Height of oceanward beach crest above MSL (cm)</th>
<th>Height of lagoonward beach crest above MSL (cm)</th>
<th>Average height of village above MSL (cm)</th>
<th>Lowest point in island (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Thulhaadho</td>
<td>Feb 4</td>
<td>0630</td>
<td>394</td>
<td>125</td>
<td>115 (seaweed)</td>
<td>105</td>
<td>105-120</td>
<td>100</td>
</tr>
<tr>
<td>B Godhoo</td>
<td>*</td>
<td>1330</td>
<td>1408</td>
<td>160</td>
<td>160</td>
<td>130</td>
<td>90-125</td>
<td>85</td>
</tr>
<tr>
<td>C Rasdhoo</td>
<td>Feb 5</td>
<td>1400</td>
<td>461</td>
<td>160</td>
<td>160</td>
<td>135</td>
<td>105-130</td>
<td>90</td>
</tr>
<tr>
<td>D Hiladhoo</td>
<td>Feb 7</td>
<td>0815</td>
<td>536</td>
<td>320</td>
<td>320</td>
<td>80</td>
<td>80-110</td>
<td>80</td>
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<tr>
<td>E Maradhoo</td>
<td>*</td>
<td>1045</td>
<td>411</td>
<td>150</td>
<td>150</td>
<td>120</td>
<td>110-130</td>
<td>100</td>
</tr>
<tr>
<td>F Feydhoo</td>
<td>*</td>
<td>1145</td>
<td>493</td>
<td>150</td>
<td>150</td>
<td>110</td>
<td>100-120</td>
<td>90</td>
</tr>
<tr>
<td>G Faamunush</td>
<td>Feb 8</td>
<td>0600</td>
<td>1049</td>
<td>300</td>
<td>300(W)</td>
<td>210(E)</td>
<td>60-100</td>
<td>55</td>
</tr>
<tr>
<td>H Fares</td>
<td>*</td>
<td>1330</td>
<td>287</td>
<td>105</td>
<td>90</td>
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<td>90-100</td>
<td>90</td>
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<tr>
<td>I Thinadhoo</td>
<td>*</td>
<td>1815</td>
<td>571</td>
<td>160</td>
<td>140</td>
<td>80</td>
<td>80-150</td>
<td>80</td>
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<tr>
<td>J Veymandoo</td>
<td>Feb 8</td>
<td>1000</td>
<td>591(+457)</td>
<td>220</td>
<td>220</td>
<td>110</td>
<td>100-160</td>
<td>95</td>
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<tr>
<td>K Gurakahoo</td>
<td>*</td>
<td>1600</td>
<td>309</td>
<td>155</td>
<td>155</td>
<td>105</td>
<td>105-125</td>
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<tr>
<td>L Furanx</td>
<td>Feb 11</td>
<td>0730</td>
<td>251</td>
<td>160</td>
<td>160</td>
<td>110</td>
<td>110-120</td>
<td>85</td>
</tr>
<tr>
<td>M Huraa</td>
<td>Feb 13</td>
<td>1200</td>
<td>950</td>
<td>150</td>
<td>150</td>
<td>65</td>
<td></td>
<td>40</td>
</tr>
</tbody>
</table>

Table I Topographical data for some 13 islands (WOODROFFE, 1989)
Although subsurface information is generally lacking for the Maldives, the Deep Sea Drilling Project of 1972, between the Laccadives and Maldives (9 degrees north and 72 degrees east) cleared many doubts about the geological origin. Drilling at 1764 m depth penetrated 411 m of sediment to hit volcanic rock. The oldest sediment dated back to 58 million years. (Early Tertiary).

The Maldives is therefore geologically a very young formation and is likely to be susceptible to the prevailing environmental pressures. On the islands, the upper 10 - 20 m of reef limestones is suggested to have grown up in response to Post Glacial sea-level rise (Woodroffe, 1989). However, what distinguishes the Maldives from similar atolls in the absence of consolidated rock deposits (Edwards, 1989).

The bore hole drilling in Male', on the present day Islamic Centre site, showed 2 m thick coral sand, overlying hard coral formations down to 25 m; and beyond 30 m the material turned very soft. Assuming that such conditions are true for most of the islands in the Maldives, it may be imprecise to maintain that the bearing capacity of the islands are unlimited.

The subsurface structures for Male' are shown in fig.1.

Topographical data available for Male', the capital island, which is considered a relatively large island of the Maldives is, shown in fig.2.

The topography, size and setting of the islands, make the Maldives the most unprotected and most exposed country to the fierce forces of nature, especially to the currents, tides, and swells of the Indian Ocean. Added to these is the more severely threatening climatic and global warming phenomena. The climatic changes certainly influence the weather patterns and the ocean dynamics. The adverse effects produced by them endanger the land-based resources as well as the coastal structures. The people, thus, rest at the mercy of these potentially destructive impacts.

One can see a rather stable and uniform pattern of climatic conditions in the Maldives. Lying in the Doldrums, the temperatures are fairly constant around 30 degrees Celsius, with a little diurnal temperature range, and calm winds, except for occasional gusts under monsoonal influence. The seas are usually moderate with waves not exceeding 2 m, perhaps under extreme conditions up to 3 m. The average annual rainfall is around 1900 mm, with the maximum precipitation between May to November.

Even before considering the impacts of global warming and consequent sea level rise on a coral-atoll system, it is worthy to note the fragile ecological balance on which the Maldives and other geologically similar countries depend. Anthropogenic or natural changes have shown negative effects on the geomorphology, resources or socio-economic bases of the

In considering the reef systems of the Maldives, it is quite clear that the coral reefs are growing at its maximum tolerance. Even a subtle change is likely to have a detrimental effect on them, as observed by the bleaching and mortality of corals in the Maldives in May, June and July of 1987, which was related to an elevated surface temperature in the Indian Ocean. (Pernetta and Sestini, 1989).

Taking into account some of the oceanographical aspects of the Indian Ocean, there is cause for alarm for the Maldives, even neglecting the global warming phenomena. According to Budyko as cited by Sen Gupta and Singbal (1988), the Indian Ocean is an area of negative water balance, which means that more water is lost to evaporation than it receives which could lead to an increase in salinity. Enhance salinity could thus have a disastrous effect on the growth of corals.

Another interesting observation, by Sen Gupta and Singbal (1988) was the low concentration of dissolved oxygen in the upper water masses of northern Indian Ocean. This implies denitrification taking place and the oxygen - poor layer may react quickly to any further climatic or environmental disturbances. Sen Gupta and Singbal (1988) cites Nagvi (1987) that a slight increase in organic carbon flux due to pollution or atmospheric carbondioxide concentration, may render the layer completely anoxic. In addition development induced localised and large scale changes to the marine environment will erode the productivity of the marine ecosystem.

Sen Gupta and Kureishy (1981) termed the Indian Ocean a place of oil slicks. This is largely due to the release of oil from the ballast and tank washings along the tanker and shipping routes of the Indian Ocean. Although, the Maldives, have been fortunate enough to bypass these oil slicks, there is no guarantee that under the predicted weather changes induced by the global warming, that Maldives could be spared.

As global warming increases, most models predict a change in the wind patterns, speed and other weather modifications. (Edwards, 1989). The likelihood of increases in the frequency and intensity of tropical storms (Edwards 1989) can affect the Maldives, by the influence of the position of the Inter Tropical Convergence Zone, and it is very likely that the northern most atolls of the Maldives may be affected by these storms (Edwards, 1989).

When winds increase, it will generate steeper waves which enhance the wave energy. Additionally given the fetch of the open waters around the Maldives, the transfer of energy from a warmer atmosphere to the waters contribute to the destructive power of the waves. It has been suggested that wave heights in
the Indian Ocean are increasing, independent of storms, as similar increases in the Atlantic have being documented (Merril, J. et al, 1988). If this holds true, the danger of flooding and erosion will be severe and heavy in the Maldives. Evidence is documented that cyclones induce the greatest changes particularly on sand cays. This was clearly shown by the impact of cyclone Isaac on Tonga (1982), where on Manima, a small island, a shoreline retreat of 12 m was recorded (Woodroffe, 1983). When waves increase in intensity or frequency, the mobile, sandy beaches experience rapid changes and the result is considerable weakening of the stability of and protection of the beach. It has been substantiated that 1 cm rise in sea level has resulted in 0.5 m of shoreline retreat (Bryant, 1987).

In the Maldives, the seasonal movement of sand around the islands are very marked. Hence changes to the wave dimensions, strength or frequency will modify the long-shore currents, the swash and backwash resulting in modification of beach profiles. The effects and extent of such changes need to be individually appraised to calculate the true physical and socio-economic impacts. Undermining the stability of the islands in the Maldives, can jeopardise much of the coastal and near-shore infrastructures and installations that are economically utmost important.

If the predicted sea level rise occurs faster than the coral reef growth, or if the reefs fail to keep up with the rising sea level, the islands would be totally exposed to the mercy of the sea and waves.

Global-warming-induced changes to rainfall, is also crucial to understand, as this rainfall is needed to recharge the ground aquifer, which is vital for human population and the vegetation. The prediction under the global warming scenario indicates, an uncertainty, but Edwards (1989) predicts that the rainfall may increase, however with a pronounced dry period. With a warmer atmosphere it is not wrong to assume that evaporation would increase, this would again affect the weather, cloudiness, soil-water loss and evapo-transpiration from vegetation.

From the weather and climatological perspective, the impact of climate change on coral islands, such as the Maldives are considerable, in that it really affects the intricate ecological network of linkages even at a primary level. Although the full impact of the changes in the ocean-atmosphere dynamics remain relatively misunderstood, the point is quite clear that, even a subtle change in the environmental network process, can lead to a domino effect of ecological changes.

Although the resource base of these coral atolls are narrow and rudimentary, efforts to safeguard the little resources available must be taken cautiously. Adequate measures could only be taken if the processes and effects are well understood. The availability of fresh water could certainly be considered the
foremost land-based resource. Given the scarcity of land and the nature of subsurface geology, whatever fresh water available is from the rain which accumulates on a semi or impermeable strata in the ground. The resulting fresh water lens sustains the vegetation and the human population on these islands. In the Maldives, for instance, it has taken about 15,000 years to accumulate an adequate reservoir of fresh water. Interference with the infiltration and utilisation by man, has provoked a negative effect on this water supply. This interference is best illustrated in the case of Male', where documentation about it is well accounted.

In 1982-1983, when the study was done, it was revealed that only about 13 m thick fresh water lens was available in Male' aquifer (Binnie and partners, 1983). [Refer figures 3 and 4] However due to the high consumption rate (175 litres/capita/day - Binnie and Partners, 1983), a decline of 560,000 cubic m per year was reported (Binnie and Partners, 1986). This increases the potential for saline water intrusion or salinization of the ground water. When viewed in the light of the sea level rise scenario, the potential for salt water intrusion into the ground aquifer is much greater and this is even accelerated when exploitation of the water resources goes unchecked. To illustrate the vulnerability and the acute shortage of water resources in a coral atoll perspective, consider this example; given that the average rainfall for Maldives is 1900 mm per year, with the limited land area available, the total rainfall catch for the whole Maldives is about 566,200 m cubed or 566.2 million litres/year. Assuming a per capital use of 170 litres per day, this water is not even sufficient for use in Male', that is, 3,412,750 m cubed for 55,000 people.

This example clearly shows that there is an acute shortage of fresh water, even at the moment, without even considering saline intrusion from the predicted sea level rise. One foremost impact of salinized groundwater, either because of overdraw or sea level rise, is that given the shallow water table, the vegetation will be affected quickly. The deep-rooted trees such as breadfruit and mango first then others. It is not wrong to assume that the withering and consequent death of mango trees in Male' is largely attributed to this effect.

Some vegetation types might render unproductive because of increased salinity while others may be affected by the climatic change, in that photosynthesis or evapo-transpiration in most species of vegetation may be affected. In addition to the vegetation, cultivation can be affected easily too. Given the porosity and the permeability of the calcareous sand found in the Maldives and the top few inches of soil contain any organic matter that is able to support any cultivation, an increase in evaporation, resulting from changed climate affects the soil-moisture balance, thus affecting the growth of crops.

Increased incidence of flooding either as a consequence of sea level rise or otherwise, pose a great threat to the agricultural
practices taking place even today in the Maldives. Taro pits have been reported to have been flooded, and in the swell incident of 1987, an extensive area of cultivation was reported to have been inundated by sea water, thus causing widespread economic losses.

As the Maldives depend heavily on tourism, some possible effects and consequences of global warming and sea level rise are important to analyse. The seclusive nature of the resort islands require infrastructure to totally sustain the resort, hence large investments can be threatened by any of these adverse effects. Tourism has directly and indirectly taken a large share of the national economy, as a result any adverse effect on tourism could be viewed as a national crisis.

The tourism industry in the Maldives can be said to be exclusively marine-based. Hence it is important to forewarn the dangers posed by sea level rise or global warming to the marine or coastal environments.

An important aspect of tourism is the International Airport, which functions as the stepping-stone for the tourism industry. The Airport is an extension of two islands joined to form the 2.8 km runway. Considerable amount of money is invested here and the dangers of flooding is very real, as the 1987 incident showed. This is largely due to the low-lying nature of the air-strip, which measures only 1.5 m above mean sea level.

From the discussions above, it is evident that coral atolls are very vulnerable to the predicted climate change or sea level rise. The development that has taken on these coral atolls makes these islands more prone to any influences in the perspective of sea level rise or climate changes.

The limited resource base, the low-lying nature of the islands, and the exponential growth of population are difficult to compromise tends to pull the limited resources in many directions.

Realistically, there are natural limitations, and the development options are very much restricted. Development, in these atoll systems, would take place at some cost, at least, to the natural environment and what ever changes that have occurred in the development process would be very difficult to reverse. Therefore, it is important to view the development approach in a holistic manner considering all aspects of options available. Certain protective measures taken, can also have a detrimental effect. Trial and error can prove to be useful, as individual problems may require individual options. But in such an ecosystem, there is little room for error. A small environmental mistake may cost for generation.

Being victims of the consequences of global warming and subsequent sea level rise process, to which they did not contribute at all, time is running out for these small states to
wait for any assistance or guidance on the course of action to take. Therefore, timely action must be initiated on whatever possible grounds.

Given the uncertainties, and the lack of data on dimensions that would be affected, it may not be possible to predict the exact impacts these changes are likely to have on complex coral atoll system such as the Maldives. Therefore, it is time to embark on data collection, formulate strategies and plan ahead and appeal to the international community to work, think and act together to save this very planet, of ours, from jeopardy.

In the wake of the sweeping economic and social developments already taking place and the apprehension of expected climatic changes, the fate of these small low - lying countries lie in a cautious and a well - planned environmentally sound management strategy. Although this may pinch the economy, the road to survival may depend on this cautious approach.


B: SEA LEVEL RISE - A CORAL ATOLL PERSPECTIVE ON MARINE ENVIRONMENT

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Introduction:

Over the past three years, no environmental issue has dominated the minds of politicians as well as the decision makers, than the "greenhouse effect" and "sea level rise". This has stimulated a large part of the intellectual mass to concentrate on issues of managing the limited resources that make up our Planet earth.

During the past two years, a large number of future scenarios have been formulated based on data which are available, but deficient to provide a reliable estimate to a high degree of confidence, what the impact of global warming and sea level rise would have. Scientific studies have begun to draw conclusions about future trends.

This paper which should be treated as substantive material for the overall paper, on coral atoll perspective, will deal with critical issues that may accelerate the rate of deterioration of the coral atolls, which may begin to emerge in the short term; due to human and natural impact.

To illustrate the extent of the impact, the established scenario of a sea level rise between about 17 and 26 cm by 2030, corresponding to the 1 to 2°C warming over the same period (Edwards 1989) can be assumed or given the full range of uncertainties, the rise could be as little as about 5 cm or as large as about 45 cm, but the extremes are unlikely (Holdgate. 1989).

Based on the existing assumptions on sea level rise, in the coming 40 years, the most extreme situation will be faced by low lying oceanic islands and atolls such as the Maldives. Because high islands do not exist, thus displacing whole populations.

Clark (1989), Woodroffe (1989), Edwards (1989) suggest Coral Communities may thrive in the short term, within the given scenario of the established range of sea-level rise. Buddemeier and Smiths' (1988) review of coral reef growth in relation to rapidly rising sea level suggests, vertical accretion may increase to its maximum rate but may not be able to sustain in the long run if the present conditions remain the same.

In recent report of Maldives by Woodroffe (1989), he suggests there appear to be important differences between groups of atolls and also within atoll groups. These differences within the atoll related to climatic differences and human impact on the present day reef systems justifies a host of environmental problems that need to be addressed when predicting reef responses to rising sea levels.

In this context, the paper will present an overview of the environment impacts identified and present a perspective for future research.
Background:

Since man first started life on coral reefs and reef associate coastal areas, he has devised means of utilizing the productivity and diversity of its resources. Reefs have been used for their food, materials for building and more recently for complex organic chemicals; at a level that do not interfere with the natural productivity of reefs. Their sustenance depends on the long term health of the reefs.

Man's use of reefs due to expanding market economics and growing population; puts pressure on tropical marine resources, which remain the sole natural resource to the majority of the island nations.

As managing a reef involves regulating the behavior of the people whose activities affect that resource, it is of prime importance to create community awareness of the need to manage the resource in a sustainable manner.

Till the end of the second world war, the population of Maldives obtained almost all their protein from the sea. In this subsistence economy, the main resource exploited was fish, even though small quantities of mollusks have been utilized as food.

Being an old civilization (Heye Dahl 1986) and situated on the Arab China trade route, these islands have experienced heavy exploitation of certain marine organisms mainly mollusks. Until the end of the 16th - 17th Century heavy exploitation of money cowries took place to be exported to Africa and to Asia to be used as currency. So prolific was the trade in cowrie shells that early accounts (Browder, 1969) relate that as many as forty shiploads each year were observed leaving the Maldivian islands fully loaded with nothing but these money cowrie shells. Ornamental shell trade has always existed to some extent.

Traditional conservation and management aspects have existed but these measures were mainly to avoid social and cultural conflicts. These traditional measures, has helped in avoiding complete depletion of those species commonly exploited.

Some of the traditional as conservation methods adopted by local inhabitants were: Exploitation of marine turtles which have been considered a religious taboo until 1950 when this ban was lifted. In 1978, ban on turtle fishery based on size class limitation have been introduced into the law. With these however, ban on collection of turtle eggs have still not been introduced. Even today few islands still use the traditional systems they have adopted in managing the turtle population for their use.

The situation prevalent today however, is quite different. It could be related to the result of an evolution which began after the second world war, when development in the western context
took place. Cash economy took over the barter system prevalent. Age old customs and social values changed to imported values. Fishing was no longer part of a subsistence economy but became the much needed foreign exchange earner. These changes, however, had little effect on the traditional lifestyle of the island folks living in the outer atolls, away from the capital Malé. The main reason being lack of interisland contacts.

The greatest impact having far reaching consequences took place during the first half of the 70's; when three major developmental steps were taken ie:

i) Introduction of foreign freezer vessels for the collection of fresh tuna.

ii) Introduction of tourism into Maldives.

iii) Mechanization of fishing vessels, increasing the mobility of the island populations. Introduction of freezer vessels made cash readily available on the outer islands followed by increased mobility created by mechanization followed by increased demand for a number of natural products by the expanding tourism market.

This major technological change expanded the market-economy within and outside the country. Within the early 80's the marine environment as well as the dynamic coastal areas of the coral islands started showing stress. The only natural resources that are available to the population being in the marine environment, which is in equilibrium for thousands of years started showing stress.

During the period, research has been initiated within the Fisheries sector and in 1987, coral reef research has been incorporated.

The foregoing description will provide an overview of the problems identified and research options applied or planned.

PRESENT STATE OF KNOWLEDGE ON MARINE ENVIRONMENT:-

The biota of reef flats have been studied since the beginning of the Century. Stoddart (1966) provides an extensive bibliography of work carried out in the Maldives. During and after the International Indian Ocean Expedition brief descriptions of reefs of the Maldives have been carried out by Klausewitz, Hass, Eibl-Eibesfeldt, Scheer, Rosen and Muller. However, biological and ecological information on reef systems monitored over long periods of deeper reefs and marine life is generally poor.

Long term, monitoring programs have recently being introduced, to a large extent on the resources exploited by the local population. With the developments that had taken place in the mid and late seventies, series of monitoring programs have been established. The following table provides a summary of the activities that have been identified.
TABLE 1. NATURAL CAUSES IDENTIFIED CAUSING STRESS TO REEFS.

1. CORAL BLEACHING
2. CROWN-OF-THORNS STARFISH INFESTATION
3. CRACK ON REEF
4. "FREAK TIDES"
5. SPECIES SPECIFIC POPULATION EXPLOSIONS
6. MASS MORTALITY
7. SEA LEVEL RISE?

TABLE 2. ACTIVITIES CAUSING STRESS TO REEFS IN MALDIVES

1. FISHING : Baitfishing for Pole and Line fishery. 
Reef-fish fishing. 
Collection of invertebrates. 
Anchor damage.

2. TOURISM : EFFLUENT discharge 
Collection of invertebrates 
Diving 
Construction of groynes & solid jetties.

3. MINING : Coral mining 
Sand mining 
Aggregate mining.

4. DREDGING

5. RECLAMATION

6. POLLUTION : Biodegradable - Sewage 
               - Garbage 
               Non biodegradable - Oils 
               Chemicals 
               Garbage

Summary of stresses outlined above has been dealt with by various consultants who have worked in the marine sector. Study carried out on "Geological, geotechnical and ecological studies of selected atolls of the Republic of Maldives" by the Tropical Coastal management consultant limited (Wood 1987) provides a series of natural causes that cause stress and provides recommendations. Kenchington (1983), provides an overall environmental management program, Brown and Dunne (1986) gives recommendations based on a study carried out on the Environmental Impact of Coral mining in the Maldives. Munch Petersen (1985) describes the historical use of marine resources by the local population. In 1989, series of reports have been prepared on the implications of sea level rise in the Maldives. Pernetta, J and G. Sestini (1989), Woodroffe (1989), Hulsbergen and Schroder (1989), and Edwards (1989).
RESOURCE MANAGEMENT

Coral reefs in an atoll system has limited resources for human existence. Without reference to the marine resources, however, atoll life represents a situation where subsistence production is often an extremely difficult and the tasks of generating any real surplus is even more difficult.

Though fish and other marine resources have been marketed since the beginning of the 13th and 14th Centuries there exists traditional management practices which sustained the population from total depletion. In recent years, however, with the developments that has taken place in the seventies there has been some expansions in marine product exports, the table below provides a relative picture of the trend in marine resources utilization.

| Table 21 - Export of Marine Products - Quantity |
|-------------------------------|------|------|------|------|
| (tonnes)                     |      |      |      |      |
| Frozen skipjack              | 13796.296 | 17091.361 | 17799.049 | 13670.855 | 1971 |
| Frozen reef fish             | 0.008 | 0.355 |
| Dried skipjack               | 397.750 | 796.250 | 1318.050 | 1214.550 | 121 |
| Dried shark fin              | 10.600 | 20.785 | 18.434 | 24.383 | 1 |
| Salted dried reef fish       | 682.750 | 1894.724 | 1671.299 | 1439.755 | 58 |
| Salted dried fish            | 838.250 | 1814.750 | 1320.950 | 2836.550 | 42 |
| Cowrie shells                | 54.483 | 17.504 | 40.000 | 30.350 | 2 |
| Red coral                    | 46.100 | 84.701 | 54.000 | 6.150 |
| Ambergris                    | 0.044 | 0.023 | 0.026 | 0.002 |
| Canned fish                  | 613.440 | 722.093 | 432.390 | 1919.284 | 274 |
| Dried mackerel               | 5.300 | 14.050 | 6.500 |
| Dried reef fish              | 0.536 | 6.000 | 10.250 |
| Sea cucumber                 | 0.031 | 2.557 | 33.436 | 55 |
| Chips                        |       |       |       |       |
| Fish paste                   | 0.457 | 17 |
| Fish meal                    | 736.475 | 131 |
| Bone dust                    | 40.000 | 0.050 |
| (litres)                     |       |       |       |       |
| Shark liver oil              | 79400 | 53400 | 33400 | 40000 | 2600 |
| (numbers)                    |       |       |       |       |
| Live tropical fish           | 37255 | 650650 | 86312 | 69216 | 6810 |

Source: Ministry of Fisheries and Agriculture
Table 22 - Export of Marine Products - Value (Rufiyaa)

<table>
<thead>
<tr>
<th>Product</th>
<th>1984</th>
<th>1985</th>
<th>1986</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>74126640.60</td>
<td>110214195.34</td>
<td>113546712.71</td>
</tr>
<tr>
<td>Frozen skipjack</td>
<td>47254330.92</td>
<td>62501708.54</td>
<td>68371090.44</td>
</tr>
<tr>
<td>Frozen reef fish</td>
<td></td>
<td>169.12</td>
<td>2998.55</td>
</tr>
<tr>
<td>Dried skipjack</td>
<td>4822841.05</td>
<td>9320520.01</td>
<td>16320262.42</td>
</tr>
<tr>
<td>Dried shark fin</td>
<td>1015393.95</td>
<td>2103283.72</td>
<td>2345860.90</td>
</tr>
<tr>
<td>Salted dried reef fish</td>
<td>2706332.18</td>
<td>10015306.94</td>
<td>9988950.93</td>
</tr>
<tr>
<td>Salted dried fish</td>
<td>4733826.78</td>
<td>12356582.93</td>
<td>7014150.88</td>
</tr>
<tr>
<td>Cowrie shells</td>
<td>172575.24</td>
<td>56752.29</td>
<td>130860.15</td>
</tr>
<tr>
<td>Red coral</td>
<td>168136.87</td>
<td>216663.86</td>
<td>74478.46</td>
</tr>
<tr>
<td>Ambergris</td>
<td>483956.00</td>
<td>322900.07</td>
<td>535370.64</td>
</tr>
<tr>
<td>Canned fish</td>
<td>10060813.99</td>
<td>10792770.19</td>
<td>6429352.72</td>
</tr>
<tr>
<td>Dried mackerel</td>
<td></td>
<td>16501.13</td>
<td>54970.40</td>
</tr>
<tr>
<td>Dried reef fish</td>
<td>1890.54</td>
<td>48444.67</td>
<td>7</td>
</tr>
<tr>
<td>Sea cucumber</td>
<td>200.00</td>
<td>182613.14</td>
<td>311</td>
</tr>
<tr>
<td>Chips</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish paste</td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Fish meal</td>
<td></td>
<td>195</td>
<td></td>
</tr>
<tr>
<td>Bone dust</td>
<td></td>
<td></td>
<td>62848.78</td>
</tr>
</tbody>
</table>

| (litres)                      |            |               |               |
| Shark liver oil               | 2411610.14 | 1890751.49    | 1242230.23    |

| (numbers)                     |            |               |               |
| Live tropical fish            | 296823.48  | 555345.73     | 805078.18     |

Source: Ministry of Fisheries and Agriculture

There is growing concern that atoll states would find it extremely hard and harmful to ever achieve a high degree of self-reliance, due to the narrow resources base.

Since the last quarter of the 70's efforts have been made to monitor various marine resources that are critical to the economy of the country. A very comprehensive fishery law has been passed by the parliament in 1987, which covers management and development of all living marine resources.

In the beginning of the 80's resource assessment and longterm monitoring programs have been identified and executed. The programs outlined is directed towards the living marine resources. With the establishment of Coral Reef Research Unit within the overall living marine resources research, few studies have been initiated.
1. FISHERIES:

Historical data on utilization of fishery resources by the local community suggests that local communities have been using the pelagic, tuna like species rather than the reef fish resources. Compilation and publication of fishery statistics have been initiated in the late 50's and in 1979, these data have been published annually. Summaries of earlier data (1959-1961 and 1966-1983) are given in Anderson (1986). This document provides details of catch by species, vessel type and atoll, as well as fishing fleet and effort data.

Biological and fisheries related research on tunas had been initiated in 1984. Present programs on tuna include:

a) A sampling program to determine length frequencies of skipjack and yellowfins in six different areas.

b) Gonad sampling to determine spawning periods.

c) Exploratory fishing using gillnets and longlines.

d) Baitfish biology in collaboration with Solomon Islands and ACIAR.

e) Tagging program to be initiated in January '90 to determine migratory patterns and schooling of stocks and substocks.

f) Socio-economic studies have been conducted to determine the mobility experienced when the country moved into the mid 70's when major technological and developmental steps were taken.

Tuna Fisheries in the Maldives still remains an artisanal mode of fishery even though this fishery provides 85% of the total fish production in the Maldives. More than 50% of the Catch is export- ed in various forms, making fisheries as the most important natural resource for the Country.

Foreign fishing in the Maldives EEZ is permitted by licence within an area beyond 75 miles of the coastline. The permitted area is approximately 58% of the area of the EEZ. Pole and line fishing, trolling and longlining are permitted.

With the development of tourism, marine fish resources other than tunas were in demand. Even though, there existed no regular fishery for reef fish types, the community responded to the demands.

During the reef fish resources survey carried out as a pilot program in Malé Atoll, provided some catch rates using different types of gear. For 134, set bottom longline operations resulted in average of 28.1 kg/operation, out of which 1% of commercial value. Average number of fish was in the range of 4.8 to 8.4 per 100 hooks depending on habitat.

For the handline, overall catch rate of 1.8 kg/line/hour of which 71% of commercial value. Catch rates for traps are very low when compared with other gears used in the survey. Table below shows main species caught by various gears during exploratory fishing in north Malé Atoll.
TABLE

<table>
<thead>
<tr>
<th>Fish Species</th>
<th>Traps</th>
<th>Handline</th>
<th>Longline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lutjanus gibbus</td>
<td>4.34</td>
<td>25.60</td>
<td>0.07</td>
</tr>
<tr>
<td>Lutjanus bohar</td>
<td>10.63</td>
<td>12.46</td>
<td>18.75</td>
</tr>
<tr>
<td>Aprion virescens</td>
<td>2.28</td>
<td>4.27</td>
<td>18.75</td>
</tr>
<tr>
<td>Luxodon macrorhinus</td>
<td>-</td>
<td>1.36</td>
<td>14.05</td>
</tr>
</tbody>
</table>

Good longline catches have been recorded outside atoll between 80 and 100m depth and also between 140 and 170m depth.

Based on the above study, reef resources survey program have been expanded in early 1989 to study the resources at various biotopes and apply remote sensing data to extrapolate the resources, for the whole of Maldives, to a high degree of reliability.

Initial studies confirm, the reef fish resources will remain under-utilized due to logistical problems to create a demand in the international markets. Reefs, atolls and reef fishing communities are scattered over a wide expanse of ocean. In order to market reef fish in its prunne form requires and expensive operation not worthy of investments. However, potential for ranching remains as most demersals are location specific to a large degree.

No culture programs exists in the Maldives. The main reason being lack of understanding of the reef resources traditionally by the community. This provides an important tool for managing a resource not known by the community before.

TROPICAL LIVE FISH TRADE

Tropical live fish trade have been initiated by the private sector since late 60's however, no major, organized exports took place until 1980 when few live fish exporters obtained licences. This trade have been monitored since the onset of trade. Since there are two major parties involved close cooperation exists between the exporters and managers. Based on the information obtained from customs data and the reef monitoring program. A scientifically justifiable quota system was introduced in 1988, which helped the exporters to organize their trade. To provide more information to the exporter, customs officers and the field officers, a fish guide is being prepared with assistance from ICOD.

Other basic programs conducted at present include supporting research activities to the three broad areas mentioned above. These include:

a) To catalog all marine living resources.

c) Cataloguing all fishing gear used in the Maldives.
d) Taxonomic identification of economically important reef fishes.
e) Potential for sustaining the sea cucumber fishery.

ENVIRONMENTAL PROGRAMS:

Apart from the applied research programs which was initiated in the beginning of the eighties, series of environmental programs have been carried out to complement the much needed data to relate it to optimize resource utilization.

These programmed activities are given below:

i) Effects of degradation of the environment on local reef fisheries in the Maldives. A three year collaborative research program initiated in 1987 to determine the nature of the Maldivian reef fishery and the extent and degradation of the reef environment. Preliminary results suggests that both fish numbers and fish biomass are significantly positively correlated with the increasing degree of complexity of the habitat and there exists no significant correlation of fish numbers and biomass with either percentage living coral cover or with coral species diversity. Thus indicating that a key factor in the maintenance of a thriving fish community is a topographically complex habitat that offers refuge and shelter sites. (Brown, 1989).

ii) The Environmental Impact of Coral mining on Coral Reefs in the Maldives.

With the growing population and increased earning from the new market economy, a steadily increasing demand for building materials have caused serious threats to number of reefs and islands associated with these reefs.

Coral nodules and sand being the only natural material available for the community for construction. In 1985, some 270,000 cm ft of coral was extracted for use in Malé, by mining the upper 1-2 m of shallow reef flats (Brown and Dunne 1988). With the rate extraction, if no alternative resources are found it has been estimated that all reefs in north Malé Atoll would be barren by the year 2014, with minimal or no recovery at all within the period.

Major concern is the loss of both coral and associated reef resources to the economy and the impact on marine tourism, which is the second most important economic sector of the country.

Based on the recommendations made in the reef mining study, two research programs have been formulated specifically to curb misuse of the coral cover which of extreme importance in the context of sea-level rise.
One program is to try and rehabilitate degraded reefs using artificial blocks. The other program is to assess the impact of mining selected submerged reefs to minimize destruction. Both programs have been formulated and approved pending execution.

Series of environmental problems have been identified in the late 70's and beginning 80's, that had no direct link to human impact. Most of these problems relate to the lack of information of the resource base and the environment. Research in the Maldives being a recent activity, most of the programs underway are directly related to consolidating base line information through monitoring and socio-economic studies. It has been felt, that the human condition and his link to the natural environment are extremely important areas to consider when dealing with atoll island systems. Main reason being the narrow resource base its limitations.

By mid 80's most of the problems identified in the marine environment sector have been considered and research activities have been developed to find alternative management strategies.

Due to the lack of manpower and financial resources, those programs that need to address a remedy to those problems that have a direct, economic bearing have been considered.

Crown-of-thorns starfish infestation is one such program, where investigations and the generous environmental awareness campaign have already been initiated. ICOD funding have recently been obtained to expand this awareness campaign. A workshop held in August 1989 have recommended series of short term and long term programs to manage the infestation, the main reason being, the cause of COT infestations still remain a mystery to the scientists working in this field.

Establishment of a coral reef research unit in the overall fisheries research program is an important step taken to integrate the environmental factor in management planning.

Geological, geotechnical and ecological studies of selected atolls of the Republic of Maldives carried out by Tropical Coastal Management Consultants Limited in 1987 provides guide lines to incorporate series of reef related activities that need to be monitored over a long period of time.

In addition to studying the biological condition of the reefs, recommendations are made to monitor certain environmental parameters.

**AWARENESS PROGRAMS IN MARINE ENVIRONMENT:**

Even though fisheries and marine related tourism are the mainstay of the economy, careful planning of the industries did not take
place until the end of the 1970's. Thus many of the activities, although they have been started well and willingly, there is a general lack of expertise in almost all fields concerned. The complexity of the present and coming problems require more staff with a higher educational background.

A relative shortage in education is particularly evident in basic marine fishing technology, marine engineering, environmental dynamics, marine biology, oceanography and management. At present these shortcomings are met by sending staff and those involved at the technical level, short term training courses provided in the region or elsewhere. With assistance for international organizations a maritime training institute is being in the country to provide basic training in navigation, marine engineering and boat maintenance.

Realizing the lack of knowledge about the marine related activities and the marine environment in the community; fisheries science curriculum have been developed in 1982 and recently being accepted by the London G.C.E. board. This subject is taught in all secondary level education institutions of the country.

Regular radio programs, T.V programs and annual publications about the marine environment has been initiated in the beginning of the 80's and has been well accepted by the community.

Symposium on the Application of Distance Education of Marine Resources Management organized by the Commonwealth of Learning in June 1989 is an important aspect taken at an international level to make use of the new technology to reach the disadvantaged communities of the world specially, those living in islands.

**PERSPECTIVES FOR FUTURE RESEARCH:**

The foregone deliberations did provide only those areas which needed special attention in the present context. Research activities in the marine related fields have been extensively summarized in speeches made by the President Naumoon (1987, 1988, 1989), the reports by Pernetta and Sastini (1989), Edwards (1989), Woodroffe (1989), Hulsbergens (1989), Kenchington (1983), Brown and Dunne (1988), Holgate (1989) provides an extensive package to deal with the problem and the alternative strategies to work on at an international level. The Langkawi Declaration on Environment, demonstrates an effective response to the concerns of small states. It outlines various options the International, Regional and Local communities can work on.

Within this context, atoll human cultures provide striking examples of the astounding adaptability of man to environment. Their skills are highly developed by their powers of observation and their tradition of passing on their knowledge from generation to generation.
However, with the rapid progress of modern technology and engineering the ability of man to cope with and control the forces of the environment seems to be only a matter of money and persistence. The fallacy of this belief is that the planet earth is in a flux to achieve a stable and predictable balance. Attempts to control this forces have little or no effect on the natural processes and often exacerbate their effects. "Global Warning" or "Sea-level rise" marked the beginning of a major experiment to achieve a revolutionary change in our institutional approach to the management of the global environment.

For the first time in the history of mankind governments have considered an environmental issue that would threaten the existence of mankind on this planet. For the first time in the history of mankind governments have identified human communities that are victimized by environmental threats beyond their financial and manpower capabilities.

Future research, therefore, cannot be limited by geographical limitations in the context of small island states. The new technology available today need to be used to link all island states research programs. Holistic studies need to be carried out using remote sensing and satellite data which can be communicated to areas where they are most relevant.

Future research, should aim to build up a Geographic Information System among low lying island states in the short term to be able to predict the rate of environmental deterioration.

The aim of future research should be to streamline economic demands in the context of environmental limitations.


BROWN, B.E., SHEPHERD, A.D. et. al. (1989) Effects of degradation of the environment or local reef fisheries in the Maldives. Summary report to ODA.


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Address by His Excellency Mr. Maumoon Abdul Gayoom, President of the Republic of Maldives before the United Nations General Assembly on the issues of Environment and Development. N.Y.

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A Summarize Translation of the Republic Day Address delivered by His Excellency Mr. Maumoon Abdul Gayoom, President of the Republic of Maldives.

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The Langkawi Declaration.

MOFA (1989)


