Geoforum, Vol. 22, No. 4, pp. 401–419, 1991
Printed in Great Britain

0016-7185/91 $3.00+0.00

Global Environmental Change Issues in the Western Indian Ocean Region

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Abstract: Mounting evidence from both instrumental and proxy records shows global climate continues to change. Analysis of near-surface temperatures over land and oceans during the past 130 years shows marked warming during the first half of this century with relatively steady temperatures through the mid-1970s followed by a rapid warming during the 1980s. The source of this warming is unclear at present. The warmest decade in the recent record is the 1980s with some of the most pronounced warming occurring in the lower latitudes, including the Western Indian Ocean. In the context of this study, the important consequences of climate warming are: (1) the potential impacts associated with rising sea level due to thermal expansion of the oceans; (2) melting of land-based ice sheets and glaciers; (3) the increased frequency, intensity, and seasonality of tropical storms and the monsoon season; and (4) changes in local land-use practices. Rising sea level, coupled with meteorological changes, creates a potential for increased coastal erosion and loss of coastal habitats such as wetlands, mangroves, and coral reef communities. These potential impacts may affect future land-use and development practices. For example, the curtailment of tourism could alter economic growth and development. Forecasting the potential regional and local impacts of global warming is not a trivial problem. General circulation models presently do not provide the necessary fine-scale resolution required for ascertaining such smaller-scale effects. In addition, there is little agreement between the forecasts from different models of past, present, or future patterns on such fundamental climate variables as precipitation and air temperature. The absence of quality regional and local tide-gauge data of the appropriate duration necessary for calculating changes in the relative sea level exacerbates the existing theoretical uncertainty. Nevertheless, the potential impacts do represent present-day problems resulting from the alteration and acceleration of naturally occurring processes through man's activities. These types of future problems which typify the impacts forecast as a result of global warming are occurring now, partly because of human activities. Such insular impacts in the Western Indian Ocean region should be used by local governments as case studies for educating the populace, developing remedial activities, analyzing socioeconomic patterns, and formulating long-term management and policy strategies that will minimize unwanted future changes. Finally, a regional strategy is needed to address the following issues: (1) the acquisition and interpretation of tide-gauge and other geodetic data to provide estimates of the local and regional relative sea-level rise; (2) a plan to identify and suggest possible mitigation for regional and local activities (land use, economic development practices, industrial development etc.) that may directly contribute to enhanced global warming through the release of carbon dioxide and other radiatively active gases; (3) the development of regional and local policies (e.g. land use, coastal zoning, building setbacks, etc.) to minimize the impacts resulting from extant and possible future relative sea-level rise and meteorological changes; and (4) the linkages between potential changes in global (regional) climate and present anthropogenic stress upon the environment—that is, cumulative impact assessment. The challenge is to recognize the need for regional and local action in the absence of site-specific data, or scientific certainty.

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Introduction

Global climate change caused by increased atmospheric trace gas loading is expected to cause a variety of direct and indirect impacts (SCHNEIDER, 1989). These impacts include rising sea levels, changes in storm climates, changes in precipitation patterns, and alterations of ocean circulation patterns. Whereas the exact magnitude, timing, and geographical distribution of these climate responses cannot be forecast accurately with our present level of understanding, general circulation computer models can be used to project approximations of these changes (PARKER and FOLLAND, 1988). Although uncertainties persist [see LINDZEN (1990)], the prevailing view among climatologists is that there has been and will continue to be global warming of some magnitude, an intensified hydrologic cycle (RAMANATHAN, 1988), and the likelihood of changes in tropical circulation patterns (FLOHN and KAPALA, 1989).

The Western Indian Ocean region is defined here as being between ~25°S and 12°N latitude and between ~30° and 60°E longitude (Figure 1). It includes the area from the Mozambique Channel to the Gulf of Aden and the archipelago of the Seychelles on the east, to the Union of South Africa to the south, comprising the marine and coastal environments of Somalia, Kenya, Tanzania, Mozambique, Madagascar, Mauritius, Seychelles, Comoros, and Réunion. These countries are politically, geographically, and demographically diverse (Table 1). They range in type and size from small atolls, such as the Seychelles, measuring 404 km^2, to continental nations such as Tanzania, which measures 940,000 km^2. The drainage from river systems transports enormous quantities of sediment, resulting in the formation of extensive deltas that have become major centers of population and commerce (e.g. Mombassa and Dar es Salaam). Traditionally, many of these low-lying coastal areas are vulnerable to a variety of regional climatological events such as seasonal monsoons and typhoons, where typically the damage is due to storm surge (ELSBERRY, 1987).

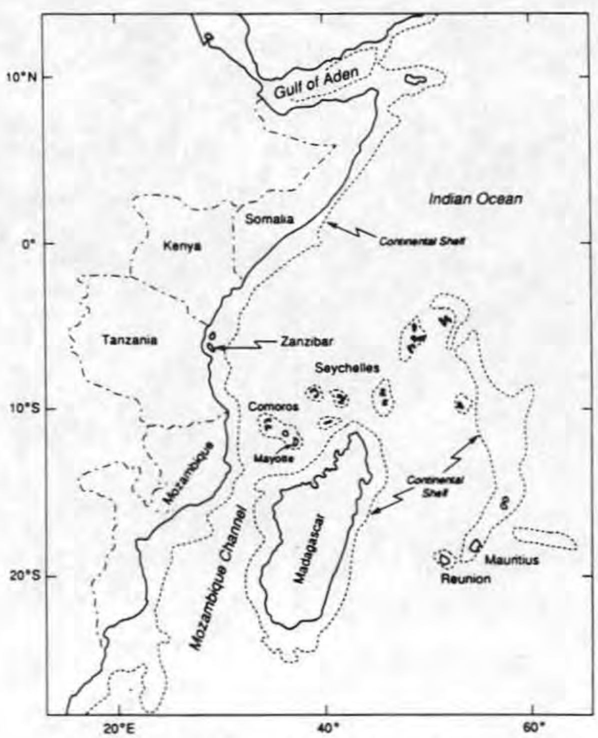

Figure 1. Western Indian Ocean region.

The Western Indian Ocean region includes many islands (Seychelles, the Comoros, Mauritius, and Réunion). Because of their high ratio of coastal zone to land area, atmospheric and relative sea-level changes have become a concern to many governments (MINTZER, 1988), and particularly to small states' governments (JAHNKE, 1990). This concern was emphasized by President Gayoom of the Republic of the Maldives (South Asian Seas region), while addressing the United Nations General Assembly and during the small states conference on sea-level rise held in Malé, Maldives, in November 1989.

Some aspects of global climate change that appear critical to the Western Indian Ocean region include: (1) alterations in meteorology, specifically the increase in land and sea temperatures; (2) the frequency, path, and intensity of storms; (3) patterns of precipitation and the monsoon storm climate; and (4) the potential rise in the relative sea level.

The purpose of this paper is to place into a regional context for the Western Indian Ocean region the problems arising from changes in global climate. Specifically, this paper will focus on the potential for impacts in the coastal zone, where the indirect pressures of climate change and anthropogenic forcings (e.g. pollution, dredging, coral mining) and policy (land use, coastal zone) collide.

Climate Change

Atmospheric perturbations

The cause of present and future global warming is believed to be due in part to an anthropogenic (man-

Table 1. General profile of countries in the Western Indian Ocean region*

Country	Land area (km^2)	Length of coastline (km)	Estimated shelf area—depth range 0–200 m (km^2)	Sovereignty established	Estimated population, 1988 (000)	GNP per capita ($)	GNP country growth rate, 1980–1987
Comoros	2170	340	900	1975	424	380	3.6
Kenya	582,750	536	6500	1963	22,097	340	2.0
Madagascar	595,700	4828	135,000	1960	10,894	200	−0.9
Mauritius	1856	177	1600	1968	1042	1470	5.5
Mozambique	786,762	2470	120,000	1975	14,591	150	−7.0
Réunion	2512	201	—	—	565	3000	N/A
Seychelles	404	491	48,000	1976	66	3180	0.7
Somalia	637,140	3025	32,500	1960	5712	290	3.7
Tanzania	939,652	1424	30,000	1961	23,174	220	1.6

*Source(s): *Ocean Yearbook* 3, 1982, *The World Bank Atlas*, 1988, UNEP (1982), and WORLD RESOURCES INSTITUTE (1988).

induced) atmospheric buildup of carbon dioxide and infrared-absorbing trace gases, such as methane, nitrous oxide, tropospheric ozone, chlorofluorocarbons (CFCs) and water vapour (JAEGER, 1988). Increases in radiatively active atmospheric gases have varied sources: chlorofluorocarbons used for refrigeration and air conditioning (ROWLAND, 1990); carbon dioxide from the combustion of fossil fuels (HALL, 1989), from deforestation (HOUGHTON, 1990), and biomass burning; and methane from agricultural practices (e.g. rice paddies) and ruminants (BLAKE and ROWLAND, 1988) (Figure 2). Increases in carbon dioxide may influence world ecosystems in undetermined ways through direct effects on species development and growth (BAZZAZ, 1990). The carbon dioxide content of the atmosphere has increased by nearly 25% since the industrial revolution of ~1860 (SCHNEIDER, 1987), and by more than 9% during the past 30 years (ROWLAND, 1988).

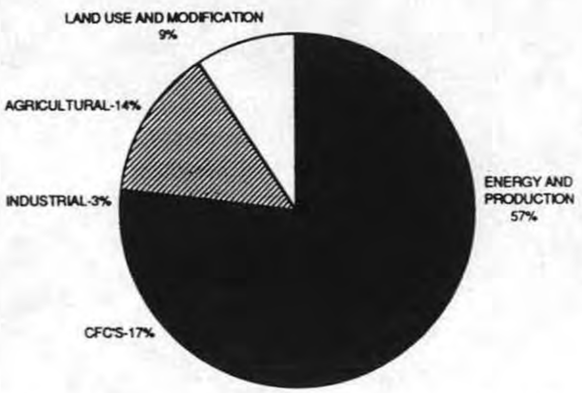

Figure 2. Activities contributing to climate change from anthropogenic forcing. Source: US EPA.

Recently, increases in methane of about 1% per year have been detected (BLAKE and ROWLAND, 1988). At mid to high latitudes, the concentration of tropospheric ozone due to human activities has more than doubled during the past century, and may do so again in just 30 years (HOUGH and DERWENT, 1990). Increases in other trace gases can also be seen (Figure 3).

Changes in climate are the norm when one studies the history of the earth. These changes include or emanate from the glacial epochs, volcanic activity, variations in solar energy, and the contemporary climatic variation of the El Niño/Southern Oscillation (JONES and KELLY, 1988). Examination of paleoclimatic records illustrates considerable natural and spatial variability which makes long-term (20–100 years) forecasting of climate change highly uncertain.

Within the limits of available measurements, researchers calculate that the mean annual temperature has steadily increased by about 0.55°C during the past century (KUO *et al.*, 1990). ANGELL (1990) suggests, however, that when the warming effects of 'El Niño' events are removed from the data, the increase in global air temperature recorded during the past 30 years is reduced by about a third. Nevertheless, warming during 1987, for example, was attributed to a more than 0.4°C temperature rise at low latitudes (23.6°N–23.6°S), which encompasses all of the Western Indian Ocean region (HANSEN and LEBEDEFF, 1988). These recent increases can be compared to the average global mean temperature increase of 5–6°C since the last ice age. Because of the

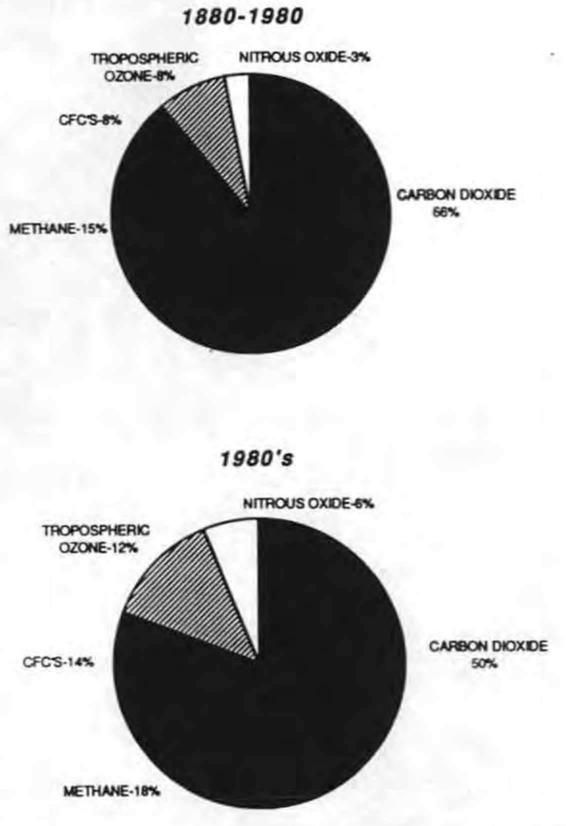

Figure 3. Atmospheric gases contributing to greenhouse forcing 1880–1980 and 1980s (note the increasing importance of the radiatively active gases other than carbon dioxide—not depicted is yet another greenhouse gas, water vapour). Source: US EPA and PHILLIPS *et al.* (1990).

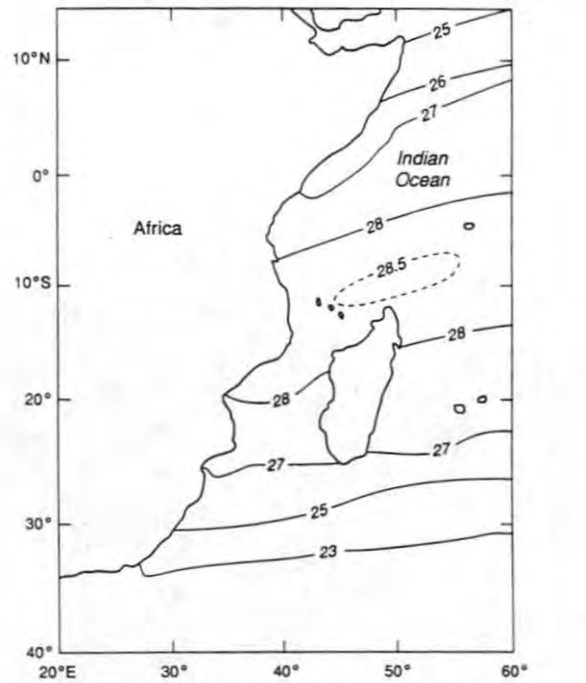

Figure 4. Western Indian ocean sea surface temperatures (SST). WU *et al.* (1990) point out that what may appear to be recent trends, generally warming, in SST may only be fluctuations on a longer temporal scale. Source: adapted and modified after NICHOLSON and NYENZI (1990).

atmospheric contributions from trace gases that have already occurred, projections have been made of a global mean temperature increase of 0.8–2.6°C over the next century (JONES and WIGLEY, 1990). Climate models indicate that during the next 30 years regional warming should be detectable and concentrated, for example, in areas of the Indian Ocean, generally near the equator (HANSEN *et al.*, 1988).

Forecasts of regional precipitation patterns are among the most difficult of the major climatic variables. Within the precision of the climate models, however, there is a suggestion of an enhancement of intense rainfall in the already rainy lower latitudes (JAEGER, 1988). Heavy rainfall results in a depletion of elements from surface soils due to more pronounced leaching and an increase in erosion. Increased erosion, combined with silt and suspended sediments resuspended by storms and monsoon winds, may in turn increase water column turbidity and adversely affect coral reefs (DE SILVA, 1988). This general trend or modelling projection (for increased rainfall), however, has not been observed for the lower latitudes over the last several decades in the Western Indian Ocean region.

As global ocean and atmospheric temperatures increase, atmospheric stability will decrease and result in an amplification of storm activity in some locales. Experimental evidence suggests that for the Western Indian Ocean, as elsewhere, cyclonic activity relies on the breadth of the pool of seawater warmer than 26°C (EMANUEL, 1988) (Figure 4). EMANUEL (1987) emphasizes that, as climate changes, the size of this warm pool will be altered, potentially changing the frequency of occurrence, intensity, magnitude, and paths of cyclonic storms and seasonal monsoons. This is particularly significant for the Western Indian Ocean given the historical pattern of cyclonic activity in the greater Madagascar area (Figure 5). Most of these storms—about 11% of the annual global total of tropical cyclones occur in the Southern Indian Ocean—follow the South Equatorial and Madagascar Currents (Figure 6). Taken together, the increased frequency and intensity of severe storms will likely increase erosion and shoreline recession,

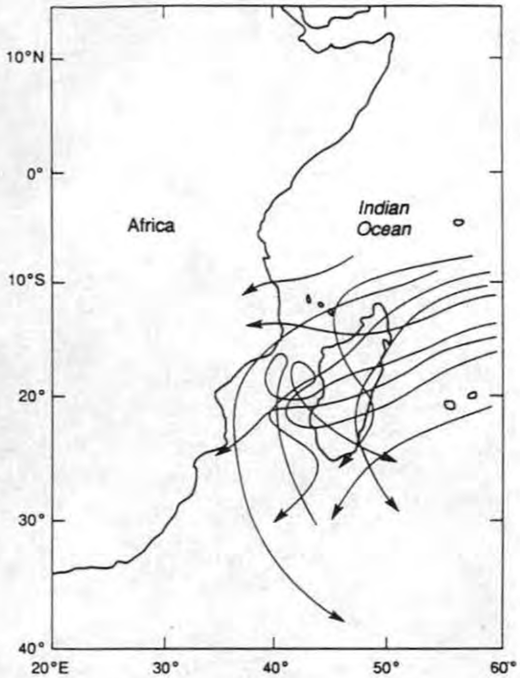

Figure 5. Typical paths of cyclones affecting the vicinity of the Mozambique Channel (compare with trade winds and ocean currents in Figure 6). Source: adapted and modified after UNEP.

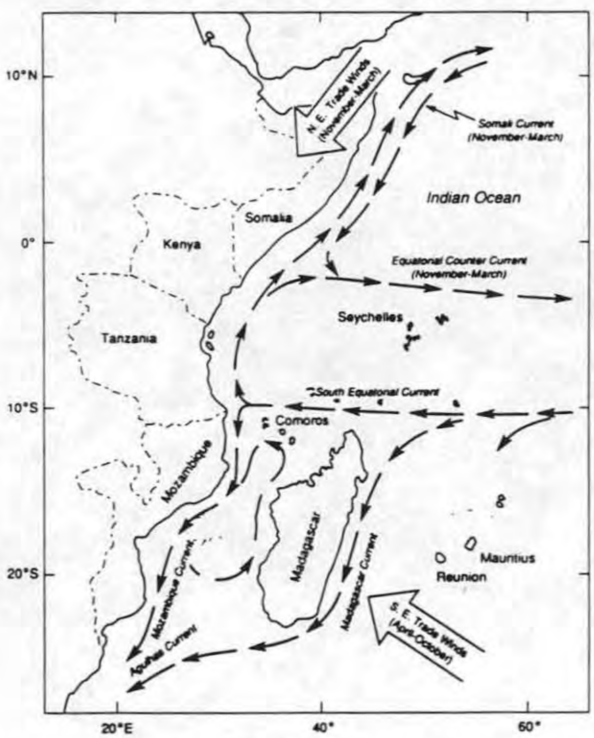

Figure 6. Western Indian Ocean trade winds and ocean currents. Source: adapted and modified after UNEP.

with potential impacts on the social and economic (including tourism) development of countries in the Western Indian Ocean region. Developing countries at high degree of risk from storms would include Mozambique (CARTER, 1987). If an intensification of the monsoon circulation occurs, some parts of the Indian Ocean region will experience a trend toward wetter summers and drier winters (ZHAO and KELLOGG, 1988).

Although the magnitude, timing, and geographical distribution of these climatic changes cannot be forecast with a degree of certainty, generalized large-scale projections of these changes can be extrapolated with the aid of general circulation models (GCMs) (PARKER and FOLLAND, 1988). At present, none of the GCMs has the capacity to forecast meaningful regional 'fingerprints' for contemporary warming (DICKINSON, 1986) or precipitation (GROTCH, 1988), or to offer detail on regional surface hydrology, notably soil moisture and runoff (GLEICK, 1987).

Global change is a large-scale environmental problem that would intensify issues concerning international security, behavior, and relations among nations (GLEICK, 1989). The lack of regional scale model resolution of global changes, however, limits the ability of governments to interpret and understand the implications of climate change, and to anticipate effectively by defining a management strategy.

Sea-level rise

Large economic and social effects from moderate changes in sea level (<50 cm) can be expected in heavily populated coastal regions that are already at or near the mean sea level (MIKOLAJEWICZ *et al.*, 1990). The historical trend in the global sea-level rise has been calculated to be on the order of 12–15 cm during the past century (GORNITZ and LEBEDEFF, 1987), to in excess of 20 cm (PELTIER and TUSHINGHAM, 1989) (Table 2), though, at present, the sea level seems to be rising at a rate of 1–2 mm/year (BRYANT, 1988). All these estimates are fraught with uncertainties, however, because of land movement at tide-gauge locations [e.g. EMERY and AUBREY (1991)]. Land motions vary greatly, contaminating tide-gauge records. AUBREY (1985) and EMERY and AUBREY (1991) claim that the sea-level rise during the past century ranged from 0–30 cm; land motion is so great that refinement of

Table 2. Estimates of past increase in mean global sea level*

Author(s)	Rate (cm per century)	Method
FAIRBRIDGE and KREBS (1962)	12	1900–1950 (selected stations)
EMERY (1980)	30	1935–1975 (selected stations)
GORNITZ *et al.* (1982)	12	1880–1980 (many stations)
KLIGE (1982)	15	1900–1975 (many stations)
BARNETT (1983)	15.1 ± 1.5	1881–1980 (selected stations)
BARNETT (1984)	22.7 ± 2.3	1930–1980 (many stations)
GORNITZ and LEBEDEFF (1987)	9–12 ± 1–3	1880–1982 (selected stations)
RAPER *et al.* (1988)	12 ± 12	1880–1980 (many stations)
OERLEMANS (1989)	9.5 ± 5.5	1850–1985 (many stations)
PELTIER and TUSHINGHAM (1989)	24 ± 9	1920–1970 (selected stations)
PIRAZZOLI (1989)	4–6	1880–1980 (many stations)
WYRTKI (1990)	10–15 ± 10	Undetermined

* Adapted and modified after RAPER *et al.* (1988).

this estimate is not possible with existing data. More significant is the relative sea-level rise, the combination of land and water movement. Earlier estimates anticipated an average global rise of between 72 and 216 cm for the next century (HOFFMAN *et al.*, 1983) with 11- and 21-cm rises in the global sea level envisioned during the next 35 years (HOFFMAN *et al.*, 1986). A rise in the sea level of 100 cm by 2050, however, is unlikely from global change alone (MEIER, 1990) (Table 3). All estimates of the future sea-level rise are subject to significant error because of uncertainties in climate change models and climate–ice feedback.

The relative sea-level rise is defined as the net change in the local sea level resulting from eustatic sea level changes and the vertical movement of the land from tectonic activity (glacio- and hydro-isostasy) and subsidence resulting from compaction and drainage of fine grained sediments, and the removal of minerals, petroleum, and water (MILLIMAN *et al.*, 1989; VELLINGA and LEATHERMAN, 1989). Global warming generates higher relative sea levels by two major processes: (1) thermal expansion of the upper ocean layers (Table 4), and (2) an increase in meltwater from continental and alpine ice sheets (AUBREY, 1985) (Table 5). Historical relative sea-level data, however, which depict changes in sea level relative to the adjacent land, include many sources of uncertainty. Superimposed on this global signature are regional tectonic trends that may have considerable spatial and temporal variability (EMERY and AUBREY, 1991; BRYANT, 1988). Variability in sea-surface measurements include glacio-isostatic tectonic changes in land masses (AUBREY *et al.*, 1988), meteorological (e.g. atmospheric pressure, humidity, wind speed and direction), and oceanographic (e.g. currents and wave height) changes (AUBREY and EMERY, 1986).

Although the absolute global rise of the ocean (eustatic change) is much debated, the concern for the Western Indian Ocean region is the relative sea-level rise. For the Western Indian Ocean region, however, there is only one tide-gauge station (Mauritius) that is long enough to be useful for estimating changes in the relative sea level (EMERY and AUBREY, 1989). The calculated rate of relative sea-level rise for this station is approximately 3 mm/year. Potential impacts from rising relative sea levels include loss of wetlands, altered patterns of coastal erosion, increased landward penetration of saline waters into

Table 3. Estimates of future global sea-level rise (cm)*

Author(s)	Best estimate (range)
GORNITZ *et al.* (1982)[3,9,11]	40
REVELLE (1983)[4,9–11]	71
HOFFMAN *et al.* (1983)[5,9,11]	56–345
PRB (1985)[5,10–12]	10–160
HOFFMAN *et al.* (1986)[5,9–12]	58–367
ROBIN (1986)[7,8]	25–165
JAEGER (VILLACH, 1987)[3,8]	−4–140
RAPER *et al.* (1988)[1,9,10–12]	8–28
OERLEMANS (1989)[1,3,5,9–12]	20.5,[1] 33.0,[3] 65.6[5]
MEIER (1990)[3]	30
MIKOLAJEWICZ *et al.* (1990)[2,9,13]	19
WARRICK and FARMER (1990)[1,9–12]	17–26
WYRTKI (1990)[2,13]	10

*Source: adapted and modified after RAPER *et al.* (1988).
[1]To year 2030.
[2]To year 2040.
[3]To year 2050.
[4]To year 2080.
[5]To year 2100.
[6]Excluded.
[7]For $T = 1.5$–$5.5°C$.
[8]Components of sea-level change not separately reported.
[9]Thermal expansion.
[10]Alpine glaciation.
[11]Greenland ice sheet(s).
[12]Antarctic ice sheet(s).
[13]World oceans, locally larger or smaller rates.

Table 4. Contribution of thermal expansion to future global sea-level rise*

Author(s)	Estimate (cm)
GORNITZ *et al.* (1982)[3]	20
REVELLE (1983)[4]	30
HOFFMAN *et al.* (1983)[5]	28–115
HOFFMAN *et al.* (1986)[5]	28–83
RAPER *et al.* (1988)[2]	4–12
OERLEMANS (1989)[1]	6.5
MEIER (1990)[3]	10–30
MIKOLAJEWICZ *et al.* (1990)[6]	19
WARRICK and FARMER (1990)[2]	8.4–14

*Source: adapted and modified after RAPER *et al.* (1988).
[1]To year 2025.
[2]To year 2030.
[3]To year 2050.
[4]To year 2080.
[5]To year 2100.
[6]Over a 50-year period (carbon dioxide × 2).

estuaries and aquifers, disequilibrium of river deltas, and increased flooding during storms on coastal plains (HEKSTRA, 1989).

Environmental Issues

Stress from anthropogenic sources

The landscape problems for the rapidly developing countries of the Western Indian Ocean region stem primarily from demographics and economic activities that recently have increased in intensity (Table 1). Changes in global climate will likely accentuate, and generally exacerbate (directly or indirectly), other impacts of humans on the environment. Problems of sewage and industrial effluents, agricultural wastes, and oil spills are largely exaggerated in coastal areas and range in severity from chronic to relatively benign. Increasing urbanization and industrialization throughout the region has increased significantly the volume of sewage and industrial wastes discharged directly or indirectly into coastal waters. Throughout the region, inadequate waste management controls—including the siting of dumps—along with equipment shortages have created a growing problem (GESAMP, 1990; UNEP, 1982). Much of this waste is discharged untreated or at best partially treated. Only 17% of east Africa's 27 million coastal population and less than 40% of the population in the countries bordering the northern Indian Ocean has access to sewers (ORMOND, 1988).

The increased manufacture and use of pesticides in wastes from an expanding agriculture in the region presents a growing threat to terrestrial and aquatic ecosystems. While organochlorine and organomercurial pesticides have been banned in industrial countries, they are still being manufactured and used in developing countries (UNESCO–UNEP, 1982). DDT and other agrochemical compounds are used on sugar cane and cotton fields (BLISS-GUEST, 1983). It is estimated that 25% of the land-applied pesticides reach the coastal waters where they are accumulated into, and contaminate, important commercial and artisanal fisheries. This poses a twofold threat to both the ecology of the coastal waters and human health through the consumption of contaminated fish and shellfish. The problems experienced in industrial countries during the decades of the 1960s and 1970s have now become those of developing countries during the 1980s, and will likely last into the next century.

Table 5. Contribution of ice sheets to future global sea-level rise*

Author(s)	Estimate (cm)		
	Alpine	Greenland	Antarctica
GORNITZ *et al.* (1982)[3]		20 (melting)	
REVELLE (1983)[4]	12	12	
HOFFMAN *et al.* (1983)[5]		28–230 (melting)	
PRB (1985)[5]	10–30	10–30	−10–100
HOFFMAN *et al.* (1986)[5]	12–37	6–27	12–220
RAPER *et al.* (1988)[2]	4–10	1–4	−1–2
OERLEMANS (1989)[1]†		5	12
MEIER (1990)[3]	16 ± 14	8 ± 12	−30 ± 20
WARRICK and FARMER (1990)[2]	8.3–12.6	1.8–3.1	−1.9 to −3.3

*Source: adapted and modified after RAPER *et al.* (1988).
†0.5 mm/K warming—time dependent upon increase in temperature.
[1]To year 2025.
[2]To year 2030.
[3]To year 2050.
[4]To year 2080.
[5]To year 2100.

Other forms of anthropogenic stress include oil spills and other petroleum discharges (BLISS-GUEST, 1983). It is estimated that, of the 1206 million tonnes (MT) of global marine oil transportation in 1983, 579 MT, or 42.5%, were shipped from the Persian Gulf countries, some heading through the Western Indian Ocean region to their ultimate destination. Comparatively, 40% of the total oil spilled into the world's oceans discharges into the Indian Ocean basin, with tankers being the largest source of spills (SAIFY and CHAGHTAI, 1988). In addition, an increasing emphasis on offshore oil exploration in the Western Indian Ocean region leads to the potential for a major tanker accident, making this region increasingly vulnerable to oil pollution. The major sources of oil pollution identified are: (1) spillage of drilling fluids (muds) from offshore drilling in the exclusive economic zone (EEZ); (2) discharges (e.g. ballasts) by tankers and cargo ships within the EEZ; and (3) oil discharges in port areas from terminal operations, bunkering, and refining. Already, coral reef and sandy beach ecosystems have been adversely affected by oil pollution in the Seychelles, Kenya, Madagascar, and Tanzania (SEN GUPTA and QASIM, 1988). Estimates of the total oil spilled from tanker traffic, harbor operations, coastal industries, etc., come to about 33,000 tonnes/year in East Africa (SEN GUPTA and QASIM, 1988).

Expanding agriculture in the region has created land-use complications. In the Seychelles, poor agricultural practices, including the absence of adequate terracing, have led to siltation in estuaries and in Mahé Harbor (UNEP, 1984). Cultivation in Kenya has moved into marginal areas of poor rainfall, creating deficient soil conditions as well as soil loss from the practice of shifting cultivation (FINN, 1983b). Cultivation practices combined with deforestation and livestock overgrazing have had pronounced effects on the flow and sediment loads of the rivers of this region. The estuaries and continental shelf have received large quantities of sediment from these land-use practices (FINN, 1983a). Large-scale sedimentation from rivers has even affected the aesthetic qualities and recreational potential (beaches and coral) of tourism, particularly in Nossi-Bé, Madagascar, and Malindi in Kenya (FINN, 1983a). Moreover, the port at Malindi has now become unusable because of the sedimentation problem. In Somalia, inappropriate development and poor management of resources have led to the destabilization of 465,000 ha of coastal sand dunes, posing a threat to settlements and agricultural land (UNEP–IUCN, 1987).

Rates of terrigenous sediment reaching the Western Indian Ocean coast via rivers from soil eroded in the uplands, is estimated to be $\sim 4.8 \times 10^8$ m^3 annually (FINN, 1983b; MILLIMAN and MEADE, 1983). Some of this sediment may be trapped, however, behind hydropower dam projects either existing or proposed for this region. Some dam projects can create environmental stress in coastal areas. For example, decreased riverflow and reduced sedimentation can lead to coastal recession, increases in tidal penetration, and expanded salt water intrusion into rivers and aquifers. One example is in the Zambezi

River delta in Mozambique, where saline intrusion reaches at least 80 km inland via the river channel, increasing salinity into agricultural areas and affecting shrimp nurseries (FINN, 1983b). Another example is the proposed dam project on the Rufiji River delta in Tanzania. Although consulting engineers noted that saline intrusion oscillates landward 5–50 km at present, FINN (1983b) states that, if the dam is built to specification, the delta would recede by as much as 1 m or more annually from reduced sedimentation, irrespective of any further recession due to relative sea-level changes. MILLIMAN (1988) reports that deltas naturally subside at rates from 1 mm to several centimeters per year. A delta with a subsidence rate of 1 mm/year during the next century would subside 10 cm. These factors need to be addressed when plans are drawn for damming or diverting rivers and similar development schemes.

Stress from global warming

Forecasts of continued global warming, although uncertain, suggest the potential for increases in the relative sea-level rise and in storm intensity and frequency in the Western Indian Ocean region. One problem with these forecasts is that they lack a sense of realism and immediacy for the involved countries and populace. Consequently, it will be difficult to garner the political and public support necessary for capital investitures and alterations of profitable socioeconomic patterns to minimize potential impacts. One approach to resolving this impasse is to identify existing local alterations in physical structures (e.g. beaches), physical processes (e.g. erosion), ecosystems (e.g. wetlands, corals, etc.) and socioeconomic patterns (e.g. building setbacks/zoning) that are analogous to what future problems might arise from global warming. The following examples illustrate how existing human activities combined with natural processes are causing impacts in the Western Indian Ocean region, and they offer an opportunity to study the conditions anticipated from a rising relative sea level and increased storm intensity and frequency. An accelerated relative sea-level rise from climatic warming can cause potential impacts on a variety of ecosystem components, such as coral reefs, wetlands, mangroves, and fisheries, resources that have been identified as major areas of concern to the countries in the Western Indian Ocean region and elsewhere.

The economic impacts of a relative sea-level rise emanate from the physical effects that a rising sea level will have on the production and consumption of goods, services, and amenities (GIBBS *et al.*, 1983). One of the most important economic impacts from a relative sea-level rise for the Western Indian Ocean region is shoreline retreat, resulting in a decrease in the available land for recreational, residential, or commercial purposes. This is of particular concern because one of the most important developing economic sectors in the Western Indian Ocean region is coastal tourism.

The occurrence of ciguatera and red tides, both caused by toxic algae, has become a global problem for marine biological resources, especially shellfish and finfish. These toxic organisms are known to cause illness and even death in humans. ANDERSON (1989) hypothesizes that apparent increases in red tides and toxic algal blooms may be linked to global change. Increases in ciguatera or red tide events as possible secondary effects of climate change in coastal areas could have an economic impact, particularly through shellfish aquaculture and fishes that are important sources of food (SHUMWAY, 1990).

Critical Marine Habitats

Coral reefs

Coral reefs and their associated communities are among the most economically important coastal marine habitats and likely threatened by global climate change (BUDDEMEIER and SMITH, 1988). In many areas of the Western Indian Ocean region coral reefs support important commercial fish species including, for example, snapper (ORMOND, 1988). The significance of the reefs for fisheries relates to their high primary productivity, which appears to range from 2000–5000 g C/m^2/year (LEWIS, 1977). As a consequence of this high productivity, the standing crop of fish on the reefs may reach 5–15 times that of the productive North Atlantic fisheries, producing sustained maximum harvests of 10–20 MT km^{-2} (SALM, 1983). Once coral reefs become degraded, however, as they have in southwest Madagascar, the species diversity of the fishes can decrease by more than 50% (VASSEUR *et al.*, 1988). In Kenya, the richness of the reef fisheries is being affected adversely by river siltation, dynamite fishing and other anthropogenic perturbations, threatening the economic livelihood of 12,000 artisanal fisherman (SAMOILYS, 1988). Because of the patchiness of reefs and their unique nutrient recycling patterns, the total catches of fisheries may not be as high as those of productive temperate upwelling areas. They are, however, important source areas for sustainable artisanal fisheries.

Coral reefs are among the most diverse ecosystems, comparable to tropical rainforests in biological diversity with about 3000 different species (SALM, 1983; ORMOND, 1988). Two major functions of coral reefs are their roles in coastal protection and in island building. SALM (1983) emphasizes that more than 75% of all Indian Ocean island archipelagoes and isolated islands were formed by reef deposition, including 47% of the total land of the Seychelles. In addition to providing a haven for marine mammals, sea turtles, shellfish, crabs and fisheries, coral reef communities also are important tourist attractions and a source of many pharmacologically active compounds used in medicine (RUGGIERI, 1976).

Despite the acknowledged economic and ecological value of reef communities, degradation and destruction is occurring at an alarming rate in tropical regions. The deterioration of coral reefs, seagrass beds, and mangroves from sedimentation is partially to blame in the decline of tropical fisheries (ROGERS, 1990). Upstream land and soil erosion, deforestation, dredging, and mining lead to elevated riverine sediment loads. The siltation that follows is probably the single most destructive influence on coral reefs. This problem has been particularly acute in the Comoros, Kenya, Madagascar, Mozambique, and the Seychelles (GREEN and SUSSMAN, 1990; SALM, 1983). In Kenya, for example, only an estimated 2.5% of the landscape is forested (FINN, 1983b). Mining for construction, lime production, road building, and dredging for harbor development have caused extensive damage to reefs in the Western Indian Ocean (FINN, 1983b), especially in the Comoros (LIONNET, 1983) and on Mahé Island in the Seychelles (SEN GUPTA and QASIM, 1988). An increase in human population density on Mayotte led indirectly to an increase in terrigenous material in sediments in coastal ponds and lagoons (HATCHER *et al.*, 1989).

In Mayotte, direct excavation of sand and coral for building materials has resulted in detrimental effects on coral reefs and their associated marine resources. Coral mining is accompanied by altered water circulation and sediment resuspension (HATCHER *et al.*, 1989). In addition, widespread deforestation and land clearing has led to siltation damage to the fringing reeds (WELLS, 1988). These activities also change turbidity, salinity, mixing, and nutrient loading in abutting marine systems (HATCHER *et al.*, 1989). Collection of shells on the reefs, for both traditional purposes and, increasingly, the tourist industry, is creating its own set of impacts through damage to the reefs by souvenir collection for the ornamental trade. Of significant importance too, are the predation of corals by the 'Crown-of-Thorns' starfish, other tourist activities such as anchor damage, and the overexploitation (e.g. reef dynamiting) of food species.

Eutrophication from sewage discharge can result in serious damage to corals in tropical areas through nutrient enhanced algal growth and resulting turbidity (ORMOND, 1988). Sewage pollution of coral reefs has been a problem for some time in Kenya, Mauritius, Tanzania, and the Seychelles (SALM, 1983).

Coral reef animals are sensitive to temperature increases because many of these species can tolerate only narrow ranges in temperature and are already living at temperatures close to their upper limit of tolerance. Episodes of severe coral bleaching and the subsequent mortality have been seen in the Western Indian Ocean, particularly in Mayotte, Réunion, and on the coast of Tanzania (WELLS, 1988; BUNKLEY-WILLIAMS and WILLIAMS, 1990).

PORTER *et al.* (1989) suggest that the tropical species (e.g. corals) that may already be at their physiological temperature limits may be susceptible to marginally elevated sea surface temperatures such as those thought to be a consequence of global warming trends [see also FOLLAND *et al.* (1984)]. During the bleaching event(s) on Mayotte, sea surface lagoon temperatures reached an unusually high 29°C; this may have combined with low oxygen levels and high turbidities to accentuate the bleaching event(s) (WELLS, 1988). Gradual climate change or sudden disturbances may increase coral reef biodiversity (that is the total number of species), though adaptation to these disruptions develops over a long evolutionary span (CONNELL, 1978).

BUDDEMEIER and SMITH (1988) have suggested that the growth of coral reef communities may not be able to keep pace with projections of relative sea-level rise as high as >3–5 mm/year. This, coupled with the present degradation of coral reefs in the region from sedimentation and anthropogenic pressures (e.g. quarrying) puts this ecosystem under additional stress and at risk of permanent and irreparable damage (DE SILVA, 1988).

Mangrove forests

Mangrove communities, like coral reefs, constitute an important natural resource to countries bordering the Indian Ocean. They too have a high productivity (350–500 g C/m^2/year and serve as an important habitat for a myriad of species (ORMOND, 1988). Despite their enormous value as a renewable resource, mangrove forests within the Indian Ocean region are relatively small in area (~472,500 ha), and they are being destroyed at an accelerating rate (KUNDAELI, 1983). Available data on mangroves suggest that they cover more than 28% of the coastline of Somalia and Madagascar, and more that 48% in Mozambique; however, their coverage is decreasing throughout the region (BLISS-GUEST, 1983).

Coastal populations use timber from mangroves for fuel, construction material for homes, and for boat building. Extensive harvesting of mangrove forests for local housing and charcoal in Kenya has dwindled mangroves to 587 km^2 (BLISS-GUEST, 1983) or about 46,000 ha, around 9.5% of all mangrove area in the region (KUNDAELI, 1983).

Mangroves are also cut for commercial use as timber (poles for export) and for agricultural development. Legal and illegal harvesting of mangroves for use as firewood and tannin continues to be a problem. In addition, mangroves have been cleared for the development of tourist resorts (BLISS-GUEST, 1983). In general, the destruction and utilization of mangroves is being conducted with little regard to the 16–30-year silvicultural cycle. For other locations within the Indian Ocean Basin, for example on the west coast of Sri Lanka, traditional fisheries and other associated uses of mangroves (as forest areas) provide between 20 and 60% of the income for village households (AMARASINGHE, 1988).

Mangrove ecosystems are important to the ecology and economy of coastal areas for several reasons (KUNSTADTER, 1986). They constitute a nursery and feeding ground, and export decomposible organic matter into adjacent coastal waters. Their decomposing leaves provide food for meiofauna, molluscs, and commercially important species of crustaceans and fin fish. In addition, mangroves provide important habitat for over 300 species of plants, thousands of species of marine invertebrates and vertebrates, and 177 bird and 36 mammal species (ORMOND, 1988). Organic matter from mangroves serves as an important source of nutrients, and is a primary energy source for vertebrates, crustaceans and other organisms. In the Western Indian Ocean, commercially harvestable supplies of shrimp, for example, rely critically upon the mangrove ecosystem. REAY and STEWARD (1988) state that the average net primary production of mangroves is about 19 times higher than in the open ocean, and 3½ times higher than agricultural land. Mangrove forests also provide an important buffer to coastal erosion and flooding which is particularly important during periods of monsoon.

In addition to direct destruction, mangrove forests are particularly susceptible to impacts that affect their subaerial roots which allow oxygen access to the often anaerobic underground system, and their leaves which provide both carbon synthesis through photosynthesis and salt excretion allowing the plants to live in salt water. Siltation and erosion from dredging and land filling operations can coat mangrove aerial roots. Oil pollution is another hazard which has been shown to kill mangrove plants within 48–72 hr (ORMOND, 1988). Mangroves are particularly sensitive to herbicide damage to the foliage, which is responsible for salt secretion and photosynthesis. These chemicals also prevent reestablishment of new mangrove communities for at least 6 years. This is particularly alarming in view of the increasing use of pesticides and herbicides in this region.

Discussion

The data available on pollution for the countries of the Western Indian Ocean region are at best fragmentary and at worst nonexistent. Consequently, it is difficult to determine the magnitude and extent of pollution. This situation may give the impression that the region is not yet seriously polluted and hence not ready for regional collaborative action. Such a conclusion is unsound (GESAMP, 1990). Being able to assess the significance of any problem is directly related to the quality and quantity of available information. Interpretations based upon fragmentary data are themselves of limited value. Nevertheless, the potential and actual occurrences of pollution incidents documented above, other nonpollution activities that are effecting the ecosystem, and the potential cumulative effects of global climate changes, suggest that it is time to develop and/or amend the necessary legal framework, at both a national and a regional level, to assure the protection and preservation of the marine and coastal environment.

Cumulative impacts

The variable effects of global climate change, coupled with present environmental stress from human activities upon landscapes (ecosystems), bespeak the need for cumulative impact assessment. An attempt to evaluate the exposure, response, risk, and vulnerability of cultural, economic, social, biological, and physiographical implications of global change and its local basin-wide, regional, and interregional manifestations can be described as a cumulative effects impact assessment (BEDFORD and PRESTON, 1988; KOTLYAKOV *et al.*, 1988). Cumulative impacts can be defined further as the impact on the local, regional, or global environment which is a consequence of the incremental impact of the action (e.g. climate change). The cumulative effects of environmental variability (including climate change) on many scales determines the mean state of an ecosystem (McGOWAN, 1990). Minor but collectively significant actions taking place over a period can result in cumulative impacts (PRESTON and BEDFORD, 1988).[1] A flow diagram to illustrate the interplay of natural and anthropogenic forcings upon the cumulative impacts is illustrated in Figure 7. In addition, while greenhouse gases normally occur in unification, synergistic effects of interacting combinations, superimposed upon direct effects, is also important (PARSONS, 1990).

Another example of cumulative effects summarized by PRESTON and BEDFORD (1988) includes the indirect effect of ocean thermal lag. This is seen where disturbances such as atmospheric buildup of radiatively active trace gases produce effects delayed spatially or temporally {through ocean lag [see CESS and GOLDENBERG (1981)]} from the original disturbance. In another example, the water quality function and trace gas contribution of wetlands (e.g. methane), particularly as they pertain to the measurement of atmospheric fluxes, ultimately must be understood so that a credible basis for assessing cumulative impacts is established on wetlands at a biospheric level (HEMOND and BENOIT, 1988). In fact, the scale at which human impacts accumulate on the landscape is greater than the scale at which regulators and policy decisions are presently made. In addition, proactive hazard management in developing countries is inhibited by low levels of income and literacy, poor communications, high population densities, and meager land-use planning (e.g. tourism development) (CARTER, 1987).

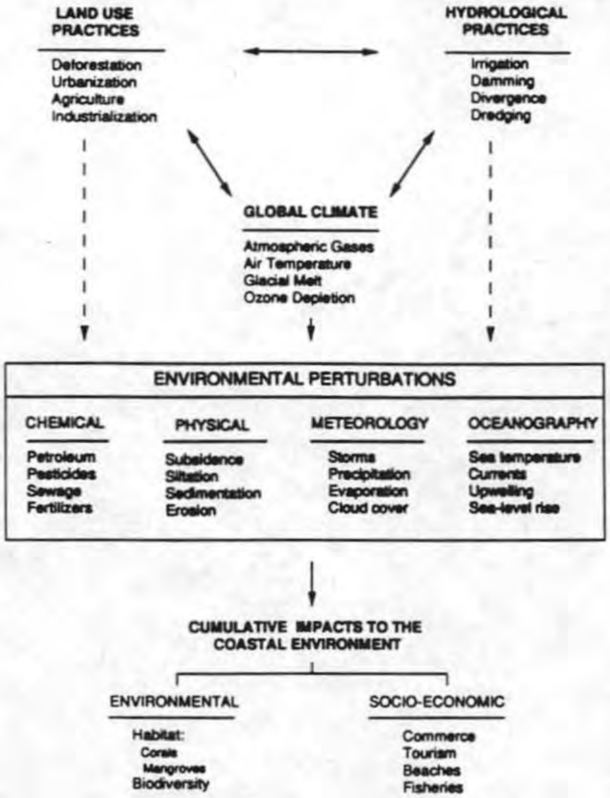

Figure 7. Paradigm describing interactions of anthropogenic forcings, their resulting environmental perturbations and cumulative impacts upon the coastal landscape (not meant to be exhaustive).

Tourism

Tourism is growing rapidly in these developing countries; however the capacity to control its impacts—those associated with construction, land development, and interference with sensitive biota—is generally inadequate (HATCHER *et al.*, 1989). Further, the cause of degradation of several reef areas has been tourism. Tourism is an important and growing source of revenue in parts of the Western Indian Ocean region. The energy demands of modern tourism are large, with air-conditioned hotels and refrigeration being indispensable. As a consequence, electrical generation capacity largely from fossil fuel use continues to accelerate (KRISTOFERSON *et al.*, 1985).

The leading economic activity for the Seychelles is tourism, with the main tourist attraction being the beaches (UNEP, 1984). Earnings from tourism in

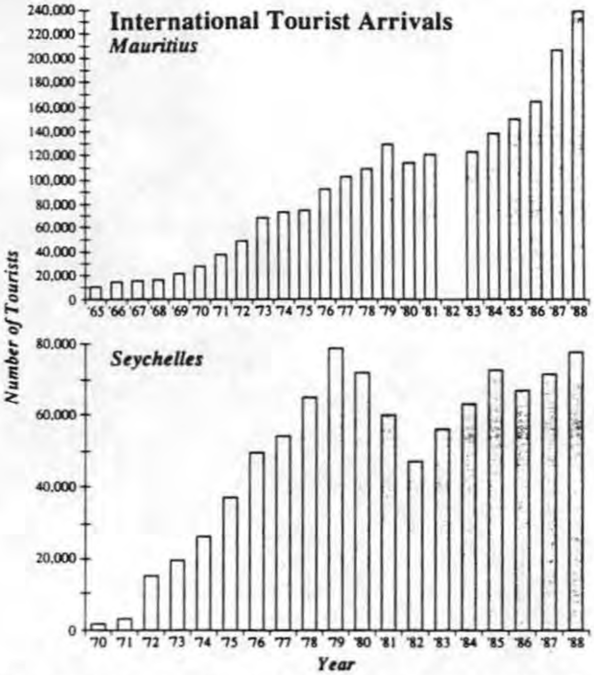

Figure 8. Tourism in Mauritius and the Seychelles. Primarily based upon the coast, tourism is a vital source of revenue for these archipelagoes.

Mauritius are exceeded only by those from sugar exports (IUCN–UNEP, 1982). Since 1984, a record number of tourists has visited Mauritius each year, making tourism the third largest foreign exchange earner (see Figure 8). Beginning in the 1960s, the expansion of tourism in Tanzania shifted from a regional to an international market. Beach tourism on the coast near Dar es Salaam emerged as one of the three major types of tourism (CURRY, 1990). Because most of the countries in the Western Indian Ocean region rely on their beaches as a basis for their tourist industry, the conclusion that 70% of the world's sandy shorelines are presently retreating suggests dire consequences for the tourist industry (WARRICK and FARMER, 1990). The acceleration of the relative sea-level rise will only exacerbate coastal erosion in locales where there are already existing problems. Along the Mahé, Seychelles coast the entire circumference is subject to erosion, and generally erosion is more common than progradation (WAGLE and HASHIMI, 1990).

Coastal systems

The expanding coastal indigenous and tourist populations of the Western Indian Ocean region are making burgeoning demands for the limited coastal resources and the area the natural resources occupy. These demands include encroachment of building infrastructure on the coast, mining of sediment for construction material, and placing of shore protection devices such as groins and breakwaters. Incidental demands, those indirectly resulting from human activity, are global warming and the relative sea-level rise as well as the inappropriate placement and use of coastal structures partly resulting from local land-use practices. Examples of human activities combined with varying associations of natural and anthropogenic stresses have resulted in some notable impacted locales within the Western Indian Ocean region.

Coastal areas that are already out of equilibrium from either natural or anthropogenic disturbances, or a combination of both, can be found throughout the Western Indian Ocean region. Erosion modifies these shores considerably, depending upon their age, composition (volcanic, coralline, combination of both), geologic history, exposure to erosive forces (storm swell, wave runup), and anthropogenic impacts (sand mining, reef dynamiting, dredging). In Tanzania, progradation occurs around deltas; however, erosion is predominant elsewhere, destroying coastal coconut plantations (BIRD, 1985). COOKE (1974) suggests that fluctuations in the land–sea interface, resulting in contemporary beach erosion, are primarily due to eustatic forcings, because no appreciable land motions (up or down) have been ascertained.

In Tanzania indications of subsidence locally may be seen in the numerous creeks and estuaries (MSANGI *et al.*, 1988). Many of the estuaries have eroded 40 m or more below the present mean sea level since late Pleistocene times (ALEXANDER, 1985). MSANGI *et al.*, (1988) stated that near the capital, Dar es Salaam, the shore exhibits a series of step faults creating tectonic subsidence; this subsidence, coupled with erosion, has led to the formation of the harbor. In general, the erosional processes that occur along the shore are believed to have started at least 40 years ago and maybe as long as 140 years ago (BIRD, 1985). On some of the offshore islands, the remains of medieval structures (on the west coast) that lie between the tidal extremes demonstrates the extent of historical subsidence (ALEXANDER, 1985).

A recent survey of the Mozambique coast has revealed that most coastal areas are eroding, as shown by many undercut and slumped mangroves positioned on the beaches, cliffed beaches, and some breaching of vegetated barrier islands (TINLEY, 1985). Estuaries, likely indicators of geologic subsidence or Pleistocene sea-level rise, such as the United States Atlantic coast, occur periodically along the entire shoreline. The Zambezi delta, which has prograded for much of the past century, has exhibited signs of erosion since the completion of the Kariba Dam about 30 years ago (BIRD, 1985). It is not known if the erosional processes are due to the isostatic sinking of the continental shelf, or due to the contemporary rise in the sea level. Further, the percentage of erosion resulting from anthropogenic forcing is not known (TINLEY, 1985).

The geography, demography, and the historical record provide insights into the potential environmental issues of the Western Indian Ocean region. Extensive riverine runoff drains both agricultural and urban sources of pollution that directly effect the nearshore environment. The deltaic coasts for many countries makes them particularly vulnerable to the indirect effects of global warming (e.g. sea-level rise, storms, etc.). Shipping activities support the extensive coastal commerce, making this region particularly vulnerable to marine accidents that would likely affect large areas of the coastal zone. The diverse political and economic structures of the countries constituting the Western Indian Ocean will require cooperation in order to develop the types of comprehensive scientific and technical plans, as well as the necessary international (legal) agreements, to address the regional and global environmental impacts in this area.

Table 6. Flexible policy responses to climate change

Response options	
Limitation and prevention	Limit the increase of trace gas emissions
	Increase energy conservation and efficiency
	Identify areas vulnerable to sea-level rise
	Modify land-use (e.g. agricultural, coastal zone, forestry, municipal, etc.) and hydrologic management practices (e.g. damming, groundwater extraction, etc.)
Adaptation (passive)	Reaction to events as they unfold
(active)	Adjustments taken now and modified periodically to make future accommodation easier
Mitigation and intervention	Technical engineering countermeasures (e.g. groins, jetties, seawalls etc.)
	Technological changes (e.g. chlorofluorocarbons and organochlorine pesticide alternatives)
	Recycling (e.g. organic composting)
	Alternative energy sources (e.g. solar biomass)
	Consumption tax—carbon fee
	Water conservation policy
	Building setback policy in the coastal zone

Policy Responses to Climate Change

Data collection, dissemination, monitoring, and field activities must be an integral part of the planning process to provide the technical foundation for informed policy responses. Certainly to be included within the realm of responses to global climate change are continued data acquisition, reporting, and monitoring necessary to guarantee the interpretation of trends and comparison with GCM projections (WOOD, 1990). Improved satellite altimetry observations and networks of tide-gauge stations—surveyed with accurate geodetic positioning techniques [see CARTER *et al.* (1989) and PRESCOTT *et al.* (1989)]—may eventually allow scientists to extrapolate the contemporary anthropogenic climate-induced signal from the background noise of natural variations (THOMSON and TABATA, 1989).

Nevertheless, several possible policy responses could be employed to lessen the rate and impact of climate change both globally and regionally (Table 6). TITUS (1986) suggests purchasing options on land in order to maintain coastal ecosystems so that coastlines may remain natural and not armored by seawalls; this is one anticipatory policy. A guide to a country's ability to adapt to changing climate conditions may well be its level of economic development and diversity. It is more likely that a country having a higher level of economic development will have resources which will allow for better adaptation to global climate change (WEISS, 1989). Few countries of the Western Indian Ocean region have sufficiently high levels of economic development and diversity, so most will find adaptation difficult. For example, petroleum consumption (fossil carbon dioxide) in Tanzania grew by 2.5 times over a recent 20-year period to satisfy energy expansion (MWANDOSYA and LUHANGA, 1985).

In the Western Indian Ocean region there are no accessible institutional structures to deal with marine and littoral resources, let alone impacts from global climate change. Few trained personnel, no defined national policies, and scarce financial resources have led to haphazard responses to environmental perturbations (IUCN–UNEP, 1984a). Development of Coastal Area Management Plans should be fermented as a way to integrate land use with multiple-use zoning of shores and seas under national jurisdiction (IUCN–UNEP, 1984a). Even in countries like Mauritius and the Seychelles where Town and Country Planning Programs do exist, the build-up of subsidiary Acts and administration over programs by different authorities dilutes their effectiveness (IUCN–UNEP, 1984b). HOPLEY (1990) has demonstrated the effectiveness of incorporating economic, environmental, and social variables to coastal planning, particularly on a regional scale.

In the face of the scientific uncertainties accompanying the projected impacts of climate change, emphasis ought to be focused on: (1) improved scientific data for projecting impacts; (2) energy efficiency and conservation; (3) alternate fuels (solar, photovoltaics or biomass) and industrial chemical usage (such as phaseout of CFCs); (4) reforestation; and (5) periodic reevaluation and adjustments of policy decisions (LAVE, 1988; WHITE, 1990). Research on science-policy issues—specifically how scientific information is used in the formulation of decisions about climate change for coastal and ocean resources policy—needs to be conducted (LAVE, 1988). Other key policy actions might include minimizing land-use changes that contribute to the input of trace gases into the atmosphere (deforestation), and prohibiting coastal development (groins and jetties) that promotes erosion. Incentives for the revegetation and reforestation of fallow land should be implemented. In addition, adaptation, mitigation, and prevention (if economically and technologically feasible) of acknowledged climate change activities may be employed to halt environmental climate change in advance (SCHNEIDER, 1989). SCHELLING (1984) believes that compensatory transfers of capital, income, and technical assistance are important international mechanisms of adaptation. Emissions trading of trace gases among nations is another proposed approach that could help the nations of the Western Indian Ocean adjust (SUN, 1990). In many instances, the projected impacts of future climate changes, however, will exacerbate environmental changes presently taking place and documented elsewhere [see UNEP (1984)].

Although the vulnerability to climate change may be less pronounced when viewed on a regional scale, local site-specific impacts within a region may be considerable. The developing countries, however, are projected to have the higher increases in emissions of carbon dioxide because of their need for economic growth (WHITE, 1990). There will be specific adaptations to the individual features of each (marine) environment in any particular geographic location, the Mozambique Channel, Gulf of Aden, Formosa Bay (Kenya), and so forth (STEELE, 1989). It is essential that the areas/countries of greatest vulnerability be identified [see, for example, EDWARDS (1987), MILLIMAN *et al.* (1989) and GABLE and AUBREY (1990)] and that local governments prepare policy options to mitigate unwanted impacts. The use of past climates as analogues of the future is one source of climate change impact scenarios that could be utilized (COHEN, 1990).

Cooperation among government administrators, policymakers, and scientists is essential in order to help facilitate the process of choosing proper response options. WEISS (1989) suggests that the use of scientific advisory boards or councils, such as provided in the Montreal Protocol on Substances that Deplete the Ozone Layer [see KOEHLER and HAJOST (1990)], should be given serious consideration for any convention concerning global climate change. Intergovernmental organizations can help establish an effective implementation process, although each east African country is unique in its experience and should seek its own strategy to global change problems while eliciting examples from elsewhere. The participation and perspectives of existing regional and local organizations concerned with environmental degradation, and the cumulative effects of environmental perturbations contained with global change impacts, need to be strengthened.

Acknowledgements—This research was sponsored by NOAA National Sea Grant College Program Office, Department of Commerce, under Grant No. NA 89-AA-D-SG090 to the Woods Hole Oceanographic Institution (WHOI) Sea Grant Program through Project No. R/S-23-PD. Additional support was provided by the Andrew W. Mellon Foundation to the Coastal Research Center of WHOI. Commentary on earlier versions of the manuscript was provided by J. D. Milliman (NSF), D. A. Ross (WHOI), M. G. Collins (WHOI), S. F. Edwards (NOAA) and two anonymous reviewers. WHOI Contribution No. 7370.

Note

1. Much of this work stems from the National Environmental Policy Act (U.S.A.) of 1969, particularly sections 38

CFR 1500.6 and 40 CFR 1508.7. Thus, it seems that environmental impact observations when discerning effects of global climate change(s) need to take these factors into account. At present many studies on climate change do not. If they did, the likely conclusions would be to implement some flexible land-use and coastal area management program.

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