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Pressures, Trends, and Impacts in Coastal Zones: Interactions Between Socioeconomic and Natural Systems

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ABSTRACT / This paper assesses the status of coastal zones in the context of expected climate change and its related impacts, as well as current and future socioeconomic pressures and impacts. It is argued that external stresses and shocks relating to sea-level rise and other changes will tend to exacerbate existing environmental pressures and damage in coastal zones. Coastal zones are under increasing stress because of an interrelated set of planning failures including information, economic market, and policy intervention failures. Moves towards integrated coastal zone management are urgently required to guide the coevolution of natural and human systems. Overtly technocentric claims that assessments of vulnerability undertaken to date are overestimates of likely future damages from global warming are premature. While it is the case that forecasts of sea-level rise have been scaled down, much uncertainty remains over, for example, combined storm, sea surge, and other events. In any case, within the socioeconomic analyses of the problem, resource valuations have been at best only partial and have failed to incorporate sensitivity analysis in terms of the discount rates utilized. This would indicate an underestimation of potential damage costs. Overall, a precautionary approach is justified based on the need to act ahead of adequate information acquisition, economically efficient resource pricing and proactive coastal planning.

People have often favored coastal locations for settlement because, among other benefits, these areas tend to contain the greatest biological productivity. Over half of the world's population lives within 60 km of the shoreline, and coastal populations in many countries are growing at double the national rate. Historic human intervention within the coastal zone and upstream in catchment areas has often led to nonsustainable levels of resource exploitation. Sewage and siltation linked to human development, for example, are among the most significant causes of coral reef and other ecosystem degradation in much of tropical Asia, Polynesia, and the Caribbean (Lundin and Linden 1993).

The sea-level rise that has been observed over the last century poses a significant threat to such coastal zones (Wigley and Raper 1992). Human activities can also influence sea-level directly and may have led to a net change in sea-levels over the past century, although even the direction of this change is disputed. It has recently been estimated that a combination of groundwater withdrawal, surface water diversion, and land-use change (wetland loss and deforestation) may have contributed at least 0.54 mm each year since 1960 to the observed sea-level rise (Sahagian and others 1994). Other estimates suggest that irrigation and water impoundment in reservoirs and dams may have led to a net reduction in sea-level rise of -1.63 mm each year (Gornitz and Rosenzweig 1994). The latter supports the view that climate-related effects may be larger than has previously been supposed. In short, many of the world's coastal ecosystems are already under intense and growing pressure, regardless of any climate-related changes. When climate-induced change is also present, complex interrelationships and feedbacks are generated between human and environmental driving forces and impacts and climate changes and effects.

Changes expected to accompany global warming, such as accelerated sea-level rise and more frequent and severe storm events represent potential additional stresses on coastal areas. Destructive climate-related events accompanying sea-level rise include increased beach erosion, storm surges, saltwater intrusion, and

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Table 1. Climate change events and impact categories

	Climate-related events[a]					
	Sea-level rise					
Impact categories	Beach erosion	Storm surges	Salt-H_2O infusion	Siltation	Eutrophication	Cyclones
Tourism	$				$	$
Freshwater supplies			$	$	$	
Fishing	'$'	'$'		$	$	
Coastal residences	$	$				$
Commercial buildings	$					$
Wetlands	$, nm	$, nm	$, nm	$, nm	$, nm	
Agricultural and drylands		$	$	$		$
Life expectancy		$, nm			$, nm	$, nm
Culture and heritage sites	nm	nm			nm	

[a]nm = non-market impacts; $ = market priced major impacts; '$' = minor impacts.

siltation. In addition, warming of the atmosphere and oceans can lead to coral bleaching, increased eutrophication in wetlands and freshwater supplies, and damage to coastal structures and agricultural lands due to more frequent and powerful cyclones. These climate-related impacts will reduce human access to fresh water and land area for agriculture, commerce, and residences in the zone and increase the risk and scale of destruction from tropical storms. These problems in turn place in jeopardy tourism revenues, fisheries, commercial and agricultural enterprises, and human life. Both the market and nonmarket impact linkages with the different climate change effects are summarized in Table 1.

Feedbacks between human and environmental driving forces and climate-induced changes will continue to influence environmental impacts in the coastal zone, and many of these feedbacks are positive, leading to increased vulnerability. Human actions, for example, have led to the degradation of natural buffers from storms and waves, such as salt marshes, mangroves, coral reefs and dunes, the world over. To date much less human effort has been expended trying to reduce vulnerability through strategies such as beach and dune nourishment, and the adoption of insurance policies that discourage construction in low-lying areas.

Increasingly, planned and unplanned development in the coastal zone will respond both to growing human-induced pressures and to the anticipation of heightened climate change-related stress. Given access to information on potential and actual climate change, individuals and communities can launch a complex feedback process of adaptation. For this reason, assessments of potential impacts in the coastal zone will not be able to distinguish precisely between changes wrought by humans and those caused by long-term climate change. Nor can we neatly model consequences "with" and "without" climate change. Conventional analyses that have tried to make this distinction have provided a misleading view of environmental damages in coastal areas and of the costs and benefits of prevention.

In the following sections, the potential impacts of climate-related events in the coastal zone are evaluated, drawing upon recent case studies. Pressures in the coastal zone are discussed in terms of three interrelated planning failures—information deficiencies, economic market pricing, and policy intervention failures—and the corrections necessary for a more integrated approach to coastal planning. Because of the high degree of uncertainty that surrounds climate-related impacts, research efforts that increase information should be a high priority. Studies estimating the scale of assets at risk in coastal zones, a form of economic benefit analysis, have failed to encompass a range of impacts, such as wetland loss, reduced life expectancy, disruption of traditional communities, and ecosystem deterioration, because of assessment and pricing difficulties. The overall primary value of healthy evolving ecosystems, and not just individual component use values, also needs to be recognized (Turner and others 1995b). Furthermore, institutional arrangements should be aimed at increasing diversity and the potential for flexible response to changes in the coastal zone. In some cases these arrangements should help to preserve traditional communities that have developed distinct and effective strategies for responding for extreme events. Unless these issues are properly addressed, nonsustainable resource usage in coastal zones will not be reversed and damage will only increase.

Populations at Risk

During the twentieth century urbanized coastal populations have increased because of the many economic opportunities and environmental amenities that coastal zones can provide, as well as because of the general urbanization process. Thus, in the US, for example, the Mississippi river delta was roughly in a state of dynamic balance before the twentieth century, but since then human intervention in the form of large-scale engineering works, levees, dams, canals, and water diversions has effectively starved the wetlands of needed freshwater and sediments. Relative sea level is rising at a rate of 1 m/100 y in this region and up to 100 km^2 of wetlands are lost each year (Warrick and Rahman 1992, Titus 1991).

Other human interventions have contributed to degradation of coastal natural resources. In Bangladesh, run-off, sediment flow, and deposition rates have been attributed to changes in the flood defense systems as well as deforestation in the headwaters of the Ganges–Bramaputra–Meghna river system (see Warwick and Rahman 1992, Ives and Messerli 1989). These changes have then contributed to detrimental effects on coastlines and fisheries and have played a part in the increased frequency and severity of inland flooding. Small island states (many of which are low-lying) face particularly severe threats. Pollution and mining of coral in the Maldives, for example, will further serve to inhibit that country's capability to respond to sea-level rise.

The trend of increasing coastal urban population is expected to continue globally, with the most dramatic increases forecasted to be in Asia, Africa, and South America (World Resources Institute 1994). Perhaps as much as 66% of the present human population lives within 60 km of the shore and this figure could be 70% by the year 2000 (Pernetta and Elder 1992). Coastal populations will continue to increase at a higher relative rate (double in some developing countries) than the population in general. Two-thirds of the population of developing countries (3.7 billion) is expected to be living along the coast by the year 2000 (IPCC 1994). Sixty-five percent of cities with populations above 2.5 million inhabitants are located along the world coasts, and several of these are already at or below present sea level.

To take some examples of this population pressure, in the United States over the period 1960–1990, the population in the coastal counties grew by 41 million (43%). A similar picture emerges from Australia. Between 1983 and 1991, 90% of all building activity in Australia took place within the coastal zone (Resource Assessment Commission 1993). The developing countries of the Eastern African Region (Somalia, Kenya, Tanzania, and Mozambique plus the islands of Comoros, Seychelles, Madagascar, Reunion, and Mauritius) provide another stark example. Some 55 million people live in the region with most of the major towns and cities located in the coastal strip. In Mozambique, for example, 75% of the total population is concentrated in the coastal strip 40 km wide (Ngoile and Horrill 1993). Small island states typically have experienced population growth rates of around 3% per annum, although the rate of emigration is also high in some cases. Many islands are also densely populated, with the capital island of the Maldives, Malé, providing an extreme example. It is home to 56,000 people despite being only 1700 m long and 700 m wide (Pernetta 1992).

On a global basis, the IPCC (1994) has estimated that between 100 million and 250 million people live below the maximum storm surge level and some 60 million may be subject to significantly increased flooding risks from relatively small increases in mean sea level (and excluding the potential effects of increased storm frequency and severity). Because of regional differences in storm surge events, the increased risk of flooding due to sea-level rise is greater than average for Asia (especially the Indian Ocean coast), the south Mediterranean coast, the African coast, and the coasts of the Caribbean and other small island states.

Human interactions with extreme events can determine whether these phenomena merely pose hazards or lead to major economic losses. Thus, a natural hazard is an extreme event that threatens human well-being, while a natural disaster is an event that overwhelms societal coping capabilities and therefore imposes a heavy cost burden on society (Mitchell and Ericksen 1992). On average about 45 fully developed tropical cyclones occur each year somewhere on Earth. Approximately 15 of these storms approach or cross the coastal zone and represent potential hazards, but only two or three of these inflict substantial losses and are recorded as natural disasters. Annual damages have been estimated at around US$1.5 billion, with a death toll of 15,000–23,000 (Smith 1992, Bryant 1991).

Resources at Risk

The coastal zone (8% of the global surface area) may account for as much as 25% of global primary production. Ninety percent of the current world fisheries harvest (5%–10% of world food production) comes from within national exclusive economic zones (i.e., from within 200 miles of the coast), and most of what is caught comes from within 9 km of the shore. In Australia, for example, the gross value of production in the fishing industry was $1.4 billion in 1992–1993; and recreational fishing was worth $2.2 billion in the 1980s. Fish and seafood are important sources of protein. In some countries around the tropical oceans, people rely on seafood for 40%–95% of their protein intake. In the Southeast Asian region, seafood averages 60% and in the Pacific and Caribbean region the average is 90% of the diet (Lunden and Linden 1993). Fisheries are also important economic assets in the East African region, with Mozambique and Tanzania, for example, relying on annual harvests of more than 50 kT/yr (Ngoile and Horrill 1993).

The fishing industry will be affected both by sea-level rise, storms, and other climate-related changes. Fishing activities will be affected by potential beach erosion, and facilities will be threatened by sea-level rise and more intense storms. The loss of coastal wetlands may be of particular importance to the fishing industry. Such wetlands are important breeding grounds for coastal fish species but are currently being lost at rates of more than 1% per annum in some areas (IPCC 1994). Bigford (1991) estimated that a 50% reduction in wetland productivity would lead to a 15%–20% loss in estuarine dependent fish harvests.

Demographic and other socioeconomic trends have combined to produce a growing urban and industrial concentration in the coastal zones worldwide. The use of the coast and small island states for tourism has also expanded at a very rapid rate. International tourist demand has risen from 285 million arrivals in 1980 to 443 million in 1990, and coastal zones have attracted a significant proportion of this tourist pressure (WTO 1991). While precise patterns of settlement and mixes of economic activities vary from place to place, the general urbanization and industrialization trend is common to most coastal zones.

Since the late 1970s tourism has become the second most important item in world trade, surpassed only by oil. By the late 1980s global tourism was generating expenditures and receipts of US$ billion, or around 5% of global GNP. Gross tourism financial benefits will continue to be very important for small island economies. The loss of beach tourism and recreation areas because of sea-level rise, and more storms leading to increased beach and reef erosion, would represent a significant economic effect for many developing countries and especially for small island states.

Coastal wetlands are likely to be particularly severely affected by rises in sea level and have already experienced significant cumulative losses (Turner and Jones 1991). Potential wetlands loss will also be affected by the form of response option chosen by policy makers. Thus, a complete protection policy in the United States may mean a 50% loss of wetlands (Titus 1991).

In developing countries, mangroves, which extend to around 174,000 km^2 world wide (World Resources Institute 1994), are important wetland ecosystems both in terms of direct use values (fishing and forestry) and local/international recreation value. On this basis, the estimated annual revenue from one mangrove swamp in Trinidad has been put at US$681/ha (1993) (Brown and Adger 1994 based on Rambial 1980). Ignoring the storm buffering capacity of mangroves, their loss would represent globally some US$118 billion (undiscounted) over the next century.

An OECD study has quantified the more significant economic resources at risk from sea-level rise in OECD countries (OECD 1991). Total dryland loss in OECD countries following a 1-m rise in sea level might be around 76,000 km^2. The value of this land depends on its current and future use. Land values differ widely across different use categories. Marginal agricultural land may have a value of no more than US$1 million/km^2, whereas prime residential sites can fetch up to US$500 million/km^2. A 5-km stretch of beach close to Sydney is estimated to have a real estate value of US$35 million/km (O'Neill 1990), while the 500-km shoreline in the San Francisco Bay area has a real estate value of US$50 billion (US$500 million/km) (Gleick and Maurer 1990).

If extreme weather events become more frequent and intense, or their distribution changes, then urban areas and related capital assets will be at risk in countries such as Japan, Australia, the United States, and in some countries bordering the North Sea in Europe. In the Netherlands, for example, the financial impacts of a 10% change in the intensity of storms may be worse than those of a 60-cm rise in sea level (Nijkamp 1991).

Rising sea levels can lead to saltwater infusion into freshwater sources and aquifers. Urban areas in low-lying coastal areas are especially vulnerable, but areas substantially inland along tidal rivers may also be affected. For example, a study of the potential effects of sea-level rise on drinking water supplies in Philadelphia, which is situated some 30 miles from the Atlantic ocean along the Delaware River, concluded that a 0.73-m rise in sea-level would increase chloride concentrations in the city above drinking water standards (Hall and others 1986, Thatcher 1986).

The magnitude of the economic assets at risk in coastal zones depends not only on the expected severity of the external stress (i.e., sea-level rise and extreme storm events) but also on a number of other factors including the level of protection already in place in the zone. An OECD study (OECD 1991) indicates that most of the urbanized and industrialized sections of coastline in the high-income economies are already heavily protected and so capital asset losses in these areas are unlikely to be significant unless the climate-induced threats turn out to be very severe or protection costs become prohibitively expensive (because of upgrading and maintenance and operational costs) relative to protected assets values.

All coastal zones of the world are vulnerable to the range of possible impacts from sea-level rise and storm

Table 2. Indicators of vulnerability to climate-change-induced 1-m rise in mean sea level for selected low-lying states (adapted from Nicholls 1995)

Country	People affected		Capital value at loss		Land at loss					
					km²				Adaptation	Costs
	# People (×1000)	% Total	Million US$	% GNP	1 m	0.5 m	% Total	Wetland at loss (km²)	costs (million US$)	cost/yr (% GNP)
Antigua	38	50	—	—	2		0.4	3	76	0.32
Argentina	—	—	5,600[a]	6[a]	3,400[b]	1,600	0.1	1,100	>1,800	>0.02
Bangladesh	71,000	60	—	5[c]	25,000		17.5	5,800	>1,700[d]	>0.06
Belize	70	35	—	—	1,939		8.4	—	—	—
Benin	1,350	25	126	12	230		0.2	85	>430	>0.41
China	72,000	7	—	—	35,000		—	—	—	—
Egypt[e]	4,700	9	59,272	204	5,800		1.0	—	13,133	0.45
Guyana	600	80	4,000	1,115	2,400		1.1	500	200	0.26
Japan	15,400	15	807,000	72	2,000		0.5	—	>159,000	>0.12
Kiribati	9	100	2	8	4		12.5	—	3	0.10
Malaysia	—	—	—	—	7,000		2.1	6,000	—	—
Marshall I.	40[f]	100	175	324	9		80	—	>380	>7.04
Mauritius	6	1	—	—	10		0.5	—	—	—
Netherlands	10,000	67	186,000	69	2,165		5.9	642	12,286	0.05
Nigeria	3,200[g]	4	18,000[a]	52	18,600[b]	(9,000)	2.0	16,000	>1,400	>0.04
Poland	235	1	24,000	24	1,700		0.5	36	1,500	0.02
Senegal	>110[g]	>1	700	14	6,100[b]	(1,700)	3.1	6,000	>1,000	>0.21
St. Kitts-Nevis	—	—	—	—	1		1.4	1	53	2.65
Tonga	30	47	—	—	7		2.9	—	—	—
Uruguay	13[g]	<1	1,800[a]	26	96[b]	(44)	0.1	23	>1,000	>0.12
USA	—	—	—	—	31,600[h]		0.3	17,000	>143,000	>0.03
Venezuela	56[g]	<1	350[a]	1[a]	5,700[b]	(2855)	0.6	5,600	>1,700	>0.03
Subtotal	177,892		1,107,025		148,765			58,790	>337,961	
Total (local studies)	935		18,000		16,894			3,250	951	
Total	178,827		1,119,525		165,659			63,040	>338,912	

[a]Minimum estimates—capital value at loss does not include ports.

[b]Land loss from 0.5 m mean sea-level rise (Nicholls and Leatherman 1995).

[c]Source: Broadus (1993).

[d]Adaptation for Bangladesh only provides protection against a 1 in 20 year event.

[e]Adaptation costs for Egypt include development scenarios.

[f]National estimate.

[g]Minimum estimates—number reflects estimated people displaced.

[h]Best estimate is that 20,000 km² of dry land is lost, but about 5400 km² is converted to coastal wetlands.

surges, although to different degrees. As a rule, small island developing states are judged to be the most vulnerable, followed by low-lying delta areas in developing countries. For island states the major economic threats to small economies are dominated by tourism. Table 2 shows estimates of land, wetland, and capital loss as indicators of vulnerability for selected low-lying countries, as estimated by Nicholls (1995) for the IPCC. The results show that for small island states, 100% of the population is at risk from future climate change impacts.

Many small island countries would lose a significant part of their land area with a sea-level rise of 0.5–1.0 m. The Maldives, for example, have average elevations of 1.0–1.5 m above existing sea level (Pernetta 1992). Submergence and erosion can convert many small islands to sandbars and significantly reduce the usable dry land on the larger, more populated islands. Saltwater intrusion and loss of the freshwater lens may be an equally binding constraint on human habitation in some islands, particularly smaller atolls (Leatherman 1994).

About a dozen small island states in the Pacific Ocean region alone have been classified as profoundly or severely vulnerable to accelerated sea-level rise of 1 m by 2100 (Pernetta 1992). Impacts would be on the scale of major social and economic disruption, with a subset of these countries possibly ceasing to exist.

Even the less vulnerable small islands would suffer significant economic effects from the loss of beach tourism and recreation areas because of sea-level rise and more storms leading to increased beach and reef erosion. Among the Caribbean islands, for example, in 1988 income from tourism as a percentage of GDP was highest for Antigua and Barbuda (69%) and for the Bahamas (53%), but a dozen Caribbean islands reported that tourism revenues made up more than 10% of the GDP (ECLAC 1991, quoted in Hameed 1993). The Indian Ocean islands of the Seychelles and the Maldives have also seen a steady growth in tourism. Total receipts from tourism generated foreign-exchange earnings of US$94 million in the Maldives (US$15 million in 1981). This represented some 60% of the country's total foreign-exchange earnings. Since 1985 tourism has been the single biggest contributor to the GDP of the Maldives. Tourism to developing countries has increased significantly in recent years, and small island developing states have experienced a particularly rapid increase. Tourist numbers to Mauritius, for example, have increased from 1800 visitors in 1968 to 180,000 in 1988 (UNEP 1991).

Significant land loss to the sea through inundation of deltas is one of the main results from a study of selected middle- and lower-income countries that utilized a new rapid and low-cost reconnaissance technique—aerial videotape-assisted vulnerability analysis (Nicholls and Leatherman 1995). Five countries were included in the analysis—Senegal, Argentina, Uruguay, Nigeria, and Venezuela—and a sensitivity analysis was also undertaken encompassing current sea-level rise (0.18 m per century), 0.5 m and 2.0 m by 2100. Even with current rates of sea-level rise (0.2-m rise), there is significant land loss. Senegal, Venezuela, and most particularly Nigeria have the largest amount of land loss amounting to 350 km^2, 1140 km^2, and 2,800 km^2, respectively. More than 95% of their total loss involves inundation of land in deltas or around estuaries.

Some of the world's most productive agricultural land is found in low-lying coastal areas and in the flood plains of major rivers. Thus about 85% of the world's rice is produced in the South, Southeast and East Asia, and around 10% of this output is derived from areas that may be vulnerable to accelerated sea-level rise. Less favorable hydraulic conditions caused by a 1-m rise in sea level would affect the food supply of more than 200 million people, if no adaptive measures are taken. The large deltas of Vietnam, Bangladesh, and Myanmar (Burma) seem to be especially vulnerable (IPCC 1994).

In Bangladesh some 110 million people densely populate an area of 144,000 km^2, 80% of which is made up for the complex Bengal delta system created by the Ganges, Brahmaputra, and Meghna rivers. It has been calculated that a 1-m sea-level rise (13 cm global sea level plus local subsidence of 70 cm by 2050) would threaten about 7% of the country's habitable land (5% of the total population) and a 3-m rise (2 m global sea level plus 1 m local subsidence) would threaten 26% of the land and over 27% of the total population (Broadus 1993).

In Bangladesh, 16% of the rice production area would be inundated and 13 million people would be displaced. It would also be difficult to replace croplands lost to the sea because the countryside is already extensively cultivated. Of the 24.5 million acres in the nation thought to be cultivable, more than 90% is already in cultivation. The Sunderbans, the second largest mangrove swamp in the world, could also be lost, In the Nile delta, sea-level rise combined with subsidence would destroy 12%–15% of the agricultural land and displace over six million people (Nicholls and Leatherman 1995).

When developing economies are hit by weather-related disasters such as cyclones (with coastal zones bearing the brunt of such storms), they face a disproportionate impact on human populations. An estimated 85% of the people killed, injured, or made homeless as a result of storms, cyclones, and floods between 1960 and 1990 were from developing countries (Berz 1991). In the four coastal plains of China, millions of people, including inhabitants of cities such as Shanghai, and extensive areas of agricultural land would be at risk. National economic losses as a percentage of total GNP (but not as absolute costs) follow a similar pattern. In 1989, for example, US$7.6 billion of losses from natural disasters were recorded in the United States, with more than 50% due to one event, Hurricane Hugo, but these losses represent less than 0.1% of the gross national production (GNP) of the United States. Three countries in Latin America—Bolivia, Ecuador, and Peru—had to face costs of US$4 billion due to the El Niño weather of 1982–1983. This cost burden, however, represented 10% of their combined GNP (Mitchell and Ericksen 1992). In other respects, developing countries face lower costs because many communities have infrastructure that is more adaptable and mobile than those of developed nations, e.g., dirt tracks are more easily rerouted than eight-lane highways.

Information, Economic Market, and Policy Failures

Vulnerability is a multidimensional concept encompassing biophysical, socioeconomic, political, and ethical factors. It includes some notion of the susceptibility of a coastal area or small island state to the risk of external shock and damage posed by climate-induced

Table 3. World coast conference vulnerability classes[a]

Impact categories	Vulnerability classes			
	Low	Medium	High	Critical
Population living in risk zone (no/total) × 100%	<1%	1–10%	11–50%	>50%
Population at risk from 1 metre rise in sea-level (no. × probability)/1000	<10	10–100	100–500	>500
Capital assets value at risk (total loss/GNP) × 100%	<1%	1–3%	3–10%	>10%
Land loss (area/total area) × 100%	<3%	3–10%	10–30%	>30%
Protection/adaptation costs (total cost/GNP) × 100%	<0.05%	0.05–0.25%	0.25–1%	>1%
Wetland loss (area/total area) × 100%	<3%	3–10%	10–30%	>30%

[a]Source: IPCC (1994)

sea-level rise and increased storm frequency and severity. The susceptibility status of an area is conditioned by past, current, and future population and settlement patterns and rates of change, together with its aggregate and per capita level of economic wealth (i.e., the scale and distribution of economic entitlements possessed by the local population). In general, the higher the level of economic development and per capita entitlements provided, and the greater the economic and resource diversity within the system, the less susceptible any given coastal zone should be. Paradoxically, however, areas with higher levels of economic development, but a low coping potential, may be more vulnerable, because they have more to lose.

Table 3 relates proposed vulnerability classes of low to critical vulnerability, as set out in the World Coast Conference 1993 Report, to economic and physical indicators discussed above. This table therefore defines high vulnerability as 10%–30% loss of existing wetlands, over 10% of the population living in the hazard zone and other economic indicators. The classes are necessarily arbitrary and do not indicate interaction between the components. For example, a high proportion of the population being forced to migrate owing to stress in the coastal zone would have implications for the other economic and social spending categories: central government expenditure on coastal protection or on wetland conservation may have to be augmented by redirected funds in the face of severe adjustments. The physical and social systems therefore coevolve in the face of external shocks, and classification of vulnerability in separate parts of the system is inappropriate.

Vulnerability also includes the institutional capability or capacity of a region or a country to cope with or manage (prevention and alleviation measures) the impacts as well as the relevant physical and socioeconomic dimensions. This capacity itself is determined by a range of factors including national wealth and indebtedness and cultural and other factors.

Interrelated failures—information deficiencies, policy intervention failures and economic market failures—have led to resource damage and losses and have constrained the effectiveness of management policies aimed at mitigating this damage. Unless these failures are properly addressed, the current nonsustainable trends in coastal zones will not be reversed and losses will increase. At the core of the failures dilemma is a problem of information, either the complete absence of data or inadequate data. Fundamentally, the interface between natural science research and models and social science research and models needs to be better defined and elaborated (Turner 1991). The great variability in the quantity and quality of environmental and other data available to assess the possible impacts of accelerated sea-level rise and more frequent extreme events at a regional level underscores the urgent need for greater data compatibility. The compatibility should apply to different scientific disciplines and to different national agencies charged with data collection and interpretation.

Scientific uncertainties continue to shroud the scale and significance of potential combined sea-level rise and storm-event risks at the regional level. Existing knowledge about severe weather climatology and about the nexus between weather and its impacts are inadequate. Emanuel (1987), for example, has suggested increased hurricane intensities as a result of higher sea-surface temperatures, but in some regions interannual variations in tropical cyclone activity are dominated by Southern Oscillation (SO) effects (Holland and others 1988). Uncertainty over SO predictions under climate-change scenarios, however, means that cyclone behavior prediction in the region remains an uncertain art. Nevertheless, the combined accelerated sea-level rise and storm-surge event is a potentially very significant threat.

The legislation that regulates construction and development in coastal zones is often contradictory and insufficiently comprehensive to respond adequately to the complex relationships that exist (OECD 1993a,b). The lack of coordinated policies and ineffective coastal management policies has merely served to compound value and land-use conflicts among the various interested parties. The result has been increasing levels of resource degradation and loss, which an OECD study has cataloged in case studies covering southeast Tasmania, Australia, Izmir Bay, Turkey, and the Aveiro estuary in Portugal (OECD 1993b).

Policy conflict is a common outcome of multisector, multiagency, and multilevel government involvement in coastal zone management (OECD 1993a). In the United States, for example, agricultural policy has contributed to the coastal eutrophication process; subsidized flood insurance has encouraged inefficient and potentially hazardous coastal development and redevelopment; and federal tax and resource development policies conflict with wetlands and other environmental resource conservation requirements. Coastal urban communities have displaced wetlands and added to the pollution loading of coastal waters (see Turner and Jones 1991, for a survey of the relevant literature).

On the other hand, legislation in the United States is succeeding in discouraging uncontrolled development in some coastal areas. In 1980, 50% of the 280 coastal barrier islands along the US Atlantic and Gulf coasts were at least partially or heavily developed. A law passed in 1982 effectively removed all federal subsidies for construction on many undeveloped barrier areas. Consequently, a study of 157 units in the Atlantic and Gulf coasts found that over the period 1982–1989 major development had occurred on only 10 of the units (Weber 1990).

A lack of coordination of the different resource uses and constraining policy regimes, together with inadequate knowledge of the dynamics of the coastal processes and systems, has resulted in inadequate overall management of highly pressured zones. The pressures have been added to and the negative resource impacts compounded by a further set of market failures.

Whenever resource allocation decisions are made without the guidance of information on the externalities involved (i.e., due to the complete absence of prices or heavily distorted prices), they are prone to result in economic and environmental loss or damage. Many of the resources located in coastal zones provide important functions and services that are not fully accounted for in coastal planning. The rapid loss of coastal wetlands is a classic example of this failure situation. The result of the underpricing of the waste assimilative functions of rivers, estuaries, and coastal waters, and therefore the inappropriate disposal of a variety of household and industrial wastes into the water medium, causes the assimilative capacity to be breached. Groundwater loss, in turn, is more the result of compensatory behavior exhibited by individuals suffering from an underprovision of water services. The proliferation of private wells in northern Jakarta, for example, has lowered the water table to such an extent that saline intrusion now affects a 10-km-wide zone along the coastal plain. Overpumping of groundwater has also led to land subsidence and asset damage in Jakarta, Bangkok, and Los Angeles County.

Existing regulatory instruments in coastal zone management systems therefore need to be augmented by economic incentive instruments (with their pricing effects). Some OECD countries are moving in this policy direction with a tax *de séjour* in some tourist areas, transferable quotas for fish, fines for noncompliance with legislation, and the establishment of resource rentals for the occupation of water space.

In summary, vulnerability to present and future threats is manifest in increasing frequency of events with negative impacts on human welfare. Susceptibility to these events is caused by failure phenomena: failure to implement appropriate planning and management, enhanced by the market's failure to provide environmental protection for essentially public goods, but measures can be taken to support and augment the resilience of coastal systems (natural and human) to better cope with external stresses and shocks. Economic approaches to finding appropriate strategies and values for coastal resources are now discussed.

Economic Valuation

In economic terms natural assets in the coastal zone can yield direct use values and indirect use values, as well as nonuse values (Turner 1988, 1991, Barbier 1994), many of which are generally ignored in coastal planning. A range of methods is available to evaluate such environmental benefits. At a generic level, a spectrum of evaluation methods and techniques can be distinguished (Figure 1) and used depending on the objective of study. The more comprehensive the technique, the more information that will be made available to assist in the appraisal of policy options from a societal perspective.

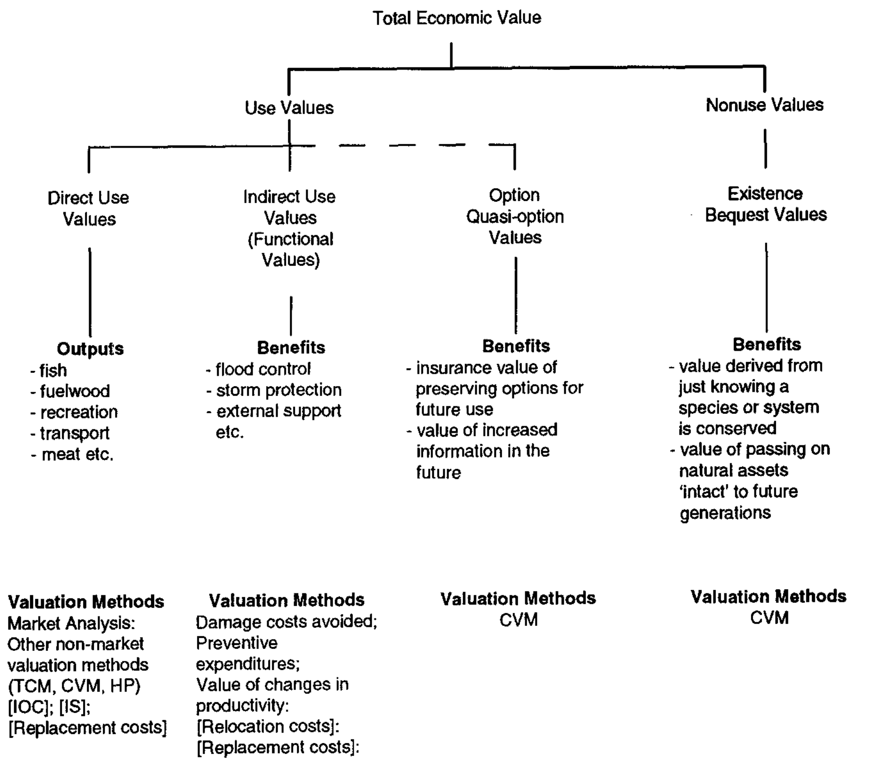
The so-called total economic value of an ecosystem can be estimated via a number of monetary valuation methods (see Figure 2 for a wetland example). A full range of valuation techniques is required to quantify the economic value of wetlands. Even if all the elements are appraised, another evaluation problem arises when the individual private values are aggregated to obtain a total social/economic value. This is the argument that

1. Financial Analysis:	2. Economic Cost-Benefit Analysis:	3. Extended Cost-Benefit Analysis	4. Environmental Impact Assessment	5. Multi-Criteria Decision Methods
financial profitability criterion; private costs and revenues; monetary valuation	economic efficiency criterion; social costs and benefits; monetary valuation	sustainable development principles; economic efficiency and equity trade-off environmental standards as constraints; partial monetary valuation	quantification of a diverse set of effects on a common scale, but no evaluation	multiple decision criteria, monetary and non-monetary evaluation

Increasing Complexity: multiple decision criteria; multiple effects; increasing scale of analysis

Adapted from Pearce and Turner (1992)

Figure 1. Evaluation methods.



Notes:
Market Analysis: based on market prices
HP = hedonic pricing, based on land/proprty value data
CVM = contingent valuation method based on social surveys designed to elicit willingness to pay values
TCM = travel cost method, based on recreationalist expenditure data
IOC = indirect opportunity cost approach, based on options foregone
IS = indirect substitute approach
[ ] =valuation methodology to be used with care
Source: Adapted from Barbier (1989)

Figure 2. Valuing wetland benefits.

ecosystems have primary value that is conditional on the existence and maintenance of the healthy ecosystem rather than on any individual human use (Turner and others 1995b). Preserving some overall ecosystem size and structure at the landscape level is probably required if resource conservation and utilization is to be sustainable. The scientific details on habitat size, diversity, and threshold limits are not currently available, and therefore a precautionary approach opting for conservation rather than development has much to recommend it.

Empirical studies have confirmed that conserved ecosystems such as mangroves and other coastal wetlands possess significant economic value, both in terms of use and nonuse outputs identified in Figure 2. Mangrove forests have been shown to sustain more than 70 direct human activities ranging from fuelwood collection to artisinal fisheries (Dixon 1989), with the value of these functions estimated to be up to $680 ha/yr (Brown and Adger 1994).

Many of the functions and services that wetlands provide are nonmarket goods and therefore do not carry appropriate market prices and value. Although wetlands are capable of yielding a range of goods and services, some uses preclude others and so some caution is necessary when utilizing total economic value estimates. Published estimates vary from US$1.5 million/km^2 to US$13 million/km^2, but the average is US$2–5 million/km^2 for OECD countries and US$1.25 million/km^2 for developing countries (Fankhauser 1995). One recent study took a median value of US$8 million/km^2 as an approximate total wetland value (OECD 1991). This resulted in an estimated potential damage due to loss of coastal wetlands in OECD countries (excluding Canada, Australia, and New Zealand) of US$400–500 billion (undiscounted) by the end of the next century. Taking recreational value and storm buffering function value only, estimated at US$216/ha/yr in 1989, the wetland loss in OECD countries would represent some US$2 million/km^2, or US$100–125 billion in total (Costanza and others 1989). Economic losses resulting from the threat of climate change and other stresses are therefore significant for natural areas as well as for urbanized or developed coastal land.

In principle, a global picture of the potential damage costs in coastal zones and small island states can be built up via the aggregation of the growing number of existing local assessments (see IPCC 1992, Turner and others 1995a, Gleick and Maurer 1990, Milliman and others 1989, Den Elzen and Rotmans 1992, Rijkswaterstaat 1991, Nicholls and Leatherman 1995, Nijkamp 1991). Table 4 summarizes the results of some studies that have assessed protection and damage costs for a range of sea-level rise scenarios in the Netherlands, United States, United Kingdom, and Uruguay. The damage cost estimates in particular are only partial and therefore are almost certainly underestimates. The general picture that emerges for the industrialized countries is that for sea-level rise up to and approaching 1 m by 2100, current defense systems with some modifications are sufficient to protect the bulk of dryland assets. Only wetland losses are significant.

Fankhauser (1995) has calculated protection costs for OECD countries facing a sea-level rise of 50 cm by 2100. The revised protection cost is US$521 million/yr. The overall conclusion is that for OECD countries it is cost-effective to protect most of their coasts (Fankhauser 1995). The situation facing developing countries is, however, substantially different. In general they face greater risks of experiencing adverse impacts due to sea-level rise because their existing sea and coastal defense systems are relatively less well established. On the other hand, the lack of engineered defense systems can be counterbalanced in some countries by the natural adaptability of traditional means and ways of life.

Substantial protection costs would be required in some developing countries in order to protect urban areas and related activities such as beach tourism. Some nine small island states appear in the IPCC list of countries facing the highest coastal protection costs as a percentage of their total economic wealth. The global average percentage of GNP required annually for coastal protection is 0.037% (OECD 1991), but the percentage for the Maldives is 34% and for Kiribati, Tuvalu, Tokelau, Anguilla, Guinea Bissau, Turks and Caicos, Marshall Islands, Cocos Islands, and the Seychelles it is between 5% and 35% (OECD 1991).

Several caveats are in order to put the protection and damage cost estimates presented in Table 4 in perspective. The baseline scenarios on which all the studies depend assume that existing settlement and related economic assets patterns and development trends continue largely unchanged into the future, but the mere threat of extensive loss of land and other assets may stimulate macroeconomic effects within the national economy. Some assets may be relocated, others may be adapted so as to reduce the damage implications. On the other hand, the damage cost estimates will represent underestimates because they neglect many nonmarket environmental assets values and costs such as the cost of resettling of refugees. Finally, besides the scientific uncertainties surrounding sea-level rise, the impact studies do not adequately capture the risks posed by combined sea-level rise and possibly more frequent or intense extreme weather events. It is also assumed in most models of sea-level rise impacts that the rise in sea level will be a slow and gradual process, although this may not be the case for all regions. Scientific uncertainties are compounded by the socioeconomic adaptation uncertainties referred to above and by the fact that the economic cost estimate results are very sensitive to changes in the discount rate that is applied.

Table 4. Sea-level rise damage and protection costs: Netherlands, UK, USA, and Uruguay

Response option costs: damage costs (DC) and protection costs (PC) (US$ billion, 1991)	Sea-level rise scenarios (m)									
	0.2 by 2050	0.2 by 2100	0.4 by 2100	0.5 by 2100	0.6 by 2050	0.8 by 2050	0.9 by 2100	1.0 by 2100	1.0 m (by 2100) 5.0 m (by 2300)	2.0 by 2100
Netherlands[a]										
Maintain current defenses (DC)		$19 bill						$126 bill	>$2324 bill	
Improve current defenses (PC + (DC)		$19 bill						$335 bill	$115–148 bill	
New improved defenses (PC + DC)		$71–120 bill						$71–120 bill	$76–117 bill	
Retreat (DC)		$33–67 bill						$40–79 bill	$91–148 bill	
Netherlands[b]										
Improve defenses (PC)			$17 bill				$21 bill			
United Kingdom–East Anglia region[c]										
Maintain current defenses (PC)	$247 mill		$257 mill		$283 mill	$294 mill				
Improve current defenses (PC)	$350 mill		$435 mill		$547 mill	$908 mill				
Retreat (DC)	$2489 mill		$2530 mill		$2624 mill	$2680 mill				
Maintain defenses option: net benefits	$1888 mill		$1809 mill		$1762 mill	$1671 mill				
Improve defenses option: net benefits	$2006 mill		$1969 mill		$1935 mill	$1624 mill				
USA[d]										
Retreat (DC)				$88–213 bill				$187–511 bill		$466–159 bill
Maintain current defense (PC)				$70–100 bill				$156–1543 bill		$418–668 bill
Uruguay[e]										
Improve defences (PC)				$2 bill				$3 bill		$5 bill

[a]Nijkamp (1991); estimates include both protection and damage (human health, capital assets and environmental impacts) costs depending on the given response option. No discount rate cited.

[b]Den Elzen and Rotmans (1992); dike, dune, and water management defensive expenditure; 2% rate of discount.

[c]Turner and others (1995a); agricultural land, property and selected environmental impact damage costs; mainly seawall defense system costs; 6% rate of discount.

[d]Titus (1991); costs refer to property loss or protection only (75% confidence interval).

[e]Nicholls and Leatherman (1995); protection costs for urban areas only, 80% of which is for beach nourishment.

Discounting and Equity

The discounting procedure, in the context of long-run costs and benefits, has been a controversial issue in economics and public policy. Coastal zone management raises a series of equity concerns both within contemporary social systems and across intergenerational time. Climate-change policy in particular highlights intergenerational equity because future generations are affected by current decisions made in response to climate and other environmental change effects but cannot influence such decisions. Thus, for example, if the current generation decides to adopt a wait-and-see policy in the context of climate change and other change phenomena, a potentially significant cost burden is transferred to the future. On the other hand, the adoption of a precautionary approach now (greenhouse gas emissions reduction measures and proactive protection investments in coastal zones and elsewhere) would mean certain near-terms costs and only potentially significant large long-term benefits.

It is not within the scope of this paper to summarize all the salient points of debate in the discounting and discount rate controversy. Rather we would argue that in the context of coastal zone management, cost–benefit analysis of policy options should be undertaken via a range of discount rates. Further, in this resource management context, which is characterized by equity concerns, long-run cost and benefit effects and complex environmental considerations, the weight of argument is in favor of low discount rates (i.e., relative to market rates of interest). The actual range of discount rate that should be adopted in the economic assessment of projects and policy options should be closer to the social rate of time preference (i.e., pure time preference, the myopian effect, plus a measure of diminishing marginal utility of consumption) than to productivity of capital (market) rates favored by finance ministries (e.g., 8%–10%.

The social rate of time preference discount rate depends on whether one assumes that the pure rate of time preference is zero or positive and on what one estimates to be the rate at which utility diminishes as the level of consumption rises, as well as the rate of increase in per capita incomes. According to Cline

(1992) the effective discount rate in the global warming policy responses context is 2% per annum. We would argue that a range from 0.5% to 3% seems reasonable and is compatible with a sustainable development goal (Broome 1992).

Institutional Analysis

It is the case that conventional impact evaluation techniques and indicators for assessing potential damages from climate-related events, such as GDP and population at loss, protection costs, and cost–benefit analysis, reflect a largely Western perspective based on economics. Alternative approaches from anthropology and sociology seek to assess changes in culture, community, and habitat and their interactions. For example, a study of coastal vulnerability and resilience to sea-level rise and climate change in Fiji and Western Samoa computes a sustainable capacity index (Nunn and others 1994). This is based on the sum of ratings of vulnerability and resilience for many categories of cultural, social, agricultural, and industrial impacts, at the local, regional, and national level. Areas with higher concentrations of assets are judged to be more vulnerable, while areas with diversity and flexibility in the system, whether natural or managerial, tend to be viewed as more resilient. The study evaluated potential impacts to subsistence economies according to the view that communities in which people feed and clothe themselves with little cash exchange are more vulnerable, but that subsistence economies in which staples can be replaced with other crops tend to be more resilient. In addition, cultural sites are ranked according to the level of national interest in their preservation. The study concludes that subsistence economies and cultural assets are more vulnerable in Fiji and that conventional and quick analyses of relatively high-lying islands such as Fiji would tend to underestimate the potential vulnerability of these areas, given that most people live in the low-lying coastal plain and the majority of cash and subsistence economic activities take place in the low-lying areas (Nunn and others 1994).

The vulnerability of traditional societies will vary, however, according to their past experience with extreme events and flooding and the degree of social cohesion that is preserved in these communities. Some traditional societies have developed networks for support and reciprocity that are more effective than the natural disaster programs of even the wealthiest countries. For example, in 1971 the rivers of the Red River delta in Vietnam burst their banks, leaving a half million people homeless. The coastal population had centuries of experience in responding to droughts and floods, however, and had evolved time-tested communal management arrangements. As a result, few deaths resulted from an event that would have been catastrophic in some other regions (Wisner 1978). Paradoxically, changes to facilitate the spread of a market economy, such as decollectivization of agricultural holdings, may lessen Vietnam's ability to recover from some disaster events in the future (Pingali and Xuan 1992).

Conclusions

Climate change in the coastal zone can lead to impacts such as sea-level rise, beach erosion, saltwater intrusion, and storm surges. In addition, the coastal zone can be affected by eutrophication, enhanced by rising temperatures, and changing frequencies, intensities, and distributions of severe weather, such as cyclones. The physical impacts of sea-level rise enhance vulnerability of human populations and of physical environments to nonsustainable stresses. Further, the physical changes can exacerbate the existing social and economic stresses on many coastal populations. In general, the processes of climate change and associated sea-level rise will tend to have greatest impact on small island developing states, followed by low-lying deltas in low-income developing countries and coastal lowlands throughout the developing world. The socioeconomic circumstances that lead to these threats being ignored or underestimated are policy, information, and market failures. If these failures are reduced through coordinated coastal planning and the redefinition of property rights to avoid open-access utilization of coastal assets, then the effects of the physical environmental changes will be ameliorated, as natural systems and socioeconomic systems coevolve in the vulnerable coastal zones.

Such actions as the strengthening of transboundary forecasting and warning systems, hazard insurance schemes, resource pricing of groundwater, reduction of subsidies for agricultural drainage, and other policy failure corrections would reduce future vulnerability (Pearce and Warford 1993).

Because a disproportionate share of the global economic wealth is now located in the coastal zone, policy makers have been under pressure to both protect and enhance the wealth-creation potential of the zone. The result has been additional coastal construction and modification of physical shoreline processes, often with negative biophysical impacts. A set of interrelated failure phenomena (information, policy, and market failures) have both contributed to resource damage and loss, as well as constraining the effectiveness of management policies aimed at mitigating the problems.

Estimates suggest that most of the urbanized and industrialized sections of coastline in the higher income countries are already heavily protected, and so capital asset losses in these areas are unlikely to be significant if best guess sea-level rise estimates prove accurate. However, these regions are still vulnerable to events such as hurricanes, storm surges, and droughts. The overall combined event risk would also pose a threat to some coastal areas in the developed world in Japan, Australia, the United States, and parts of Europe. About 50 million people experience flooding annually, based on estimates of existing protection levels. Increases in the frequency and severity of storms would further increase the population subject to annual flooding.

Extreme weather events inflict a disproportionate cost impact on developing countries, whose economies are already highly stressed and fragile and therefore less able to afford effective response mechanisms. Disasters related to climate change have a greater probability of more deaths in poorer than in richer countries. Additionally, proportionate economic losses follow a similar pattern.

The optimal response strategy will depend on the costs of the various options, the nature of the risks, the assets potentially at risk, and the consequent damage costs. It will therefore vary from region to region. Protection and potential damage cost studies suggest that for the OECD countries sea-level rise up to 1 m by 2100 is unlikely to necessitate radical upgrading of existing defenses protecting developed coastal areas (OECD 1993b). Wetland losses in this region may, however, be significant, with secondary implications for fisheries production. For those regions where industrialization has occurred in the coastal zone, it is cost-effective to protect most of their coasts.

Nonindustrialized regions face greater difficulties because their coastal zone defense systems are less well established, the costs of protection are relatively high (between 5% and 35% of gross national products in the poorest countries such as small islands in the Indian and Pacific oceans), and coastal assets such as agriculture and fishing represent a larger proportion of overall wealth. In terms of the number of people protected from flooding, and protection costs as a proportion of GNP, the coastal regions of continental South and Southeast Asia, the Pacific coast of South America and the southern Mediterranean will have greater opportunities for adaptation than the coastal regions of small island states.

While it is possible to claim that most vulnerability impact assessments undertaken to date are overestimates of the likely effects of climate change, such a claim is premature. This claim is based on the argument that previous studies take a 1-m rise in sea level as the basis for analysis rather than the recently revised best guess estimate of 48 cm with a range of 15–90 cm in the year 2100 (Wigley and Raper 1992). In fact some studies model a range of scenarios, including 25-cm and 50-cm sea level rises, and are not restricted to a 1-m assessment. Threshold effects are also not usually accounted for, i.e., the relationship between impacts and sea-level rise is taken to be linear, and the low-probability/high-impact and cost effects are effectively ignored.

All of these studies, however, fail to make a full (total economic value) assessment of possible impacts. The valuation analysis usually fails to encompass a range of nonmarket impacts because of the inherent pricing difficulties. The discount rates applied to the analysis will also greatly affect the magnitude of the damage estimate outcomes. Less than full valuation of inputs and high discount rates will both serve to underestimate true damage costs. The important point to note here is that changes in the socioeconomic parameters used in the assessment procedure are as significant as changes in the physical parameters such as rates of sea-level rise.

Any assessment therefore should be treated with caution because the scientific uncertainties relating to the climate-related threats are compounded by socioeconomic uncertainties. The major physical uncertainties relate to the overall impact of climate change on precipitation (and hence on the sedimentation budget of coastal deltas and estuaries), on ocean currents and the associated coastal impacts, on temperature impacts on coastal ecosystems such as coral, as well as the uncertainties over the direct impacts of sea-level rise and storm-surge frequency. The socioeconomic uncertainties center on the rate and extent of human adaptation. The time dimension and the rate of the physical changes and impacts are key factors. Precautionary action taken now therefore postpones impacts and allows greater opportunities for adaptation.

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