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REGIONAL VOICES

Coastal Zones and Climate Change

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Editors

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PRAGMATIC STEPS FOR GLOBAL SECURITY

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The **Regional Centre for Strategic Studies (RCSS)** is based in Colombo, Sri Lanka, and is an independent, nonprofit NGO that fosters collaborative research, networking, and interaction on strategic and international issues pertaining to South Asia. RCSS coordinates research on strategic and security-related issues; promotes interaction among scholars and other professionals in and outside the region who are engaged in South Asian strategic and international studies; and fosters relationships and collaboration among institutions studying issues related to conflict, conflict resolution, cooperation, stability, and security in South Asia.

The Stimson Center, located in Washington, DC, is a nonprofit, nonpartisan institution devoted to offering practical solutions to problems of national and international security. Since its establishment in 1989, Stimson has been committed to meaningful impact, a thorough integration of analysis and outreach, and a creative and innovative approach to global security challenges. Stimson has three basic program areas: reducing the threat of weapons of mass destruction, building regional security, and strengthening institutions of international peace and security. These program areas encompass work on a wide range of issues, from nonproliferation to transnational challenges in Asia, from UN peacekeeping operations to analyzing the resources needed for 21st century statecraft.

Preface

Stimson's *Regional Voices: Transnational Challenges* project is devoted to enhancing the information and analysis available to US policymakers about emerging transnational security challenges. The project draws on the knowledge and perspectives of technical and subject experts, and of political and strategic analysts, to develop an ongoing dialogue among researchers and practitioners from various disciplines and occupational backgrounds. The geographical range of the project's work covers East Africa, the Middle East, South Asia, and Southeast Asia.

Our work includes organizing workshops in the regions, entering into research partnerships with regional institutions and individuals, carrying out interviews in the field, and conducting research into the state of current knowledge and thought. We have sought the input of experts and practitioners who constitute new voices in the conversation with the US government. We have not shied away from perspectives that dissent from conventional wisdom, as long as they represent significant bodies of opinions in the countries of the regions.

During 2007, we sought to arrive at an understanding of perspectives specific to each region. This was reflected in our 2008 publication *Transnational Trends: Middle Eastern and Asian Views.* The following year, we engaged in extensive and substantial dialogue and collaboration across all the regions on themes as varied as the political economy of natural resources, climate change and river systems, maritime resources and security in the Indian Ocean, and the relationship between Islam and politics. Each of these resulted in a collection of essays by experts from the regions and from Stimson.

The current volume reflects some of our work in 2009. In addition to the work on climate change and coastal zones reflected herein, we have undertaken work in the areas of migration and urbanization, maritime security, international climate change policy, water and conflict, and political stability and internal conflict in South Asia.

We have sought to integrate these varied inquiries by asking the following questions in each area of research:

- How is evolving contemporary public discourse addressing the technical, governance, and cultural challenges of these specialized subject areas?
- How do political structures and cultural traditions constrain or facilitate effective responses? What examples or opportunities for transnational cooperation do they offer?
- What scientific, technological, and other intellectual resources are available or necessary, and how effectively are these deployed?
- What are the key relationships among social, economic, environmental, technological, and political trends? How do these trends relate to traditional security concerns? What new sources of instability, crisis, or conflict are found in these, and with what consequences?
- What are the social, political, and security consequences of rapid change?

We have sought throughout to maintain a transnational perspective, to look at trends or threats that transcend national borders, or at those that are national in scope but recur in many societies in a region. In all our conversations, conferences, meetings, roundtables, and focus groups, we have attempted to elicit the most candid discussion possible, and have done so by explicitly placing all conversations off the record and not for attribution.

Each volume in the present series consists of essays on some of these questions by experts and thinkers from the regions covered, accompanied by one or more essays by Stimson scholars designed to synthesize and analyze our findings and describe the key trends that we have noted.

Amit A. Pandya
Director, *Regional Voices: Transnational Challenges*

Acknowledgments

This volume was made possible by the generous contributions of time, energy, and intellectual analysis of numerous individuals in the United States and abroad. In addition, many people worked in many different capacities behind the scenes to shepherd the book to publication.

Our partner, the Regional Centre for Strategic Studies (RCSS), based in Colombo, Sri Lanka, merits special thanks for helping us design and carry out a workshop of international experts in Colombo in March 2009. I am particularly grateful to Amal Jayawardane, Executive Director of RCSS, Geetha da Silva, Associate Director, and Gayathri Nanayakkara, the Centre's indefatigable Program Officer, for both their hospitality and intellectual vigor.

I also wish to express deep appreciation to Stimson President Ellen Laipson, who brought her insights to bear in cochairing the Colombo conference, and to the meeting participants and interviewees who provided valuable cross-regional and multidisciplinary perspectives on the complex issues surrounding coastal zones and climate change. Experts consulted in preparation for the Colombo workshop and in the research for this volume are listed in appendix 2.

I am indebted to chapter authors Alain De Comarmond, Mohamed El Raey, Nazria Islam, Nirmalie Pallewatta, Rolph Payet, Golam Rabbani, A. Atiq Rahman, and Poh Poh Wong for their commitment to this project, their valuable analytical contributions, and their patience with the process of publication.

This book owes its existence to the talent and dedication of the *Regional Voices* team and others who worked many minor miracles. Corey Sobel, Research Associate on the *Regional Voices* project, performed essential roles in the coordination, research, and editorial work for the volume. Research Associates Kendra Patterson and Jumaina Siddiqui shouldered much of the effort in organizing the Colombo conference. Director Amit Pandya, who coedited this volume, provided vision and intellectual leadership. Stimson's Director for External Relations, Nancy Langer, played a major part in bringing this volume to completion; as did Alison Yost, who is largely responsible for the production values, and Shawn

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Finally, I owe my sincere apologies and thanks to anyone I have inadvertently failed to acknowledge.

David Michel
Senior Associate, *Regional Voices: Transnational Challenges*
March 2010

Introduction

Coastal areas figure among the most vulnerable of all environments to global climate change. Projected impacts from global warming include rising sea levels, stronger tropical cyclones, larger storm surges, increasing sea surface temperatures, and—as the oceans absorb more of the carbon dioxide that human activities emit to the atmosphere—growing acidification of surface waters. For coastal ecosystems and communities, the repercussions could be considerable, threatening the livelihoods, health, and welfare of millions of people. More frequent and severe storms can inundate low-lying coastal zones, destroying infrastructure and displacing populations. Higher water levels and larger wave surges can contribute to accelerated shoreline erosion and retreat. Mounting sea levels can also exacerbate saltwater intrusion into the rivers and aquifers that furnish freshwater to coastal settlements. Warmer water temperatures and acidifying oceans can degrade the ecology of coral reefs and threaten the artisanal and commercial fisheries that nourish many seaboard communities.

Climate threats to coastal regions reverberate well beyond the shoreline. Both farmland affected by saltwater incursion and fisheries menaced by higher ocean acidity feed populations distant from the water's edge. Ports, roads, rail lines, and other facilities that could be damaged by cyclones and storm surges serve producers and consumers located far inland. Refugees fleeing coastal flooding may be driven into neighboring countries or even further afield. Countering such risks will present both opportunities for international cooperation and possibilities for international conflict. Many of the coastal countries most vulnerable to global warming have contributed little to world emissions of greenhouse gases, and many possess limited capacity and few resources to counter or cope with prospective climate damages. These nations will require international assistance—technical, financial, and institutional—to enable them to adapt to and rebound from the looming greenhouse impacts that they cannot avoid.

The countries of the Indian Ocean rim, from East Africa and the Arabian Peninsula to South and Southeast Asia, are particularly susceptible to climate change's coastal impacts. One 2007 study assessing the climate threat to low-lying coastal settlements found that 6 of the 10 most vulnerable states worldwide—ranked by total population living in exposed areas—lie on the Indian Ocean.[1] Another analysis, in a 2009 World Bank paper, examined

the dangers to developing nations from potential storm-surge disasters. It concluded that 5 of the 10 countries with the greatest percentage of coastal population at risk, 5 of the 10 countries with the highest percentage of coastal GDP at risk, and 6 of the 10 countries with the highest proportion of coastal urban areas at risk are located around the Indian Ocean basin.[2] Climate pressures especially endanger small or low-lying islands like Mauritius, the Maldives, and Seychelles. Major infrastructure in these countries—roads, airports, seaports, towns—is situated almost exclusively along the coasts. Moreover, most small islands possess only limited freshwater resources, making them all the more vulnerable to saltwater invasion of their aquifers or diminished rainfall. Human exposure to such hazards will almost certainly increase with ongoing coastal development. Under Intergovernmental Panel on Climate Change (IPCC) scenarios, the world's coastal population could grow from 1.2 billion in 1990 to anywhere from 1.8 to 5.2 billion people by the 2080s.[3]

Coastal Zones and Climate Change examines the environmental stresses on coastal areas of the Indian Ocean and the resulting dilemmas confronting coastal managers and policymakers in a warming world. It presents analyses by experts in the region and at Stimson. The work for the volume had its inception in a workshop cohosted by Stimson and the Regional Centre for Strategic Studies (RCSS) in Colombo, Sri Lanka, March 19–20, 2009. The workshop gathered experts from academia, think tanks, government, and NGOs to consider emerging climate risks and potential policy responses.

In the collection's opening paper, Nirmalie Pallewatta surveys the diverse ecology of the Indian Ocean's coasts and details the observed and prospective climate change impacts on the region's ecosystems. Coastal ecosystems count among the most ecologically dynamic and productive on Earth. They provide vital ecosystem goods and services, supplying food, fuel, and materials, and regulating hydrological cycles and nutrient flows. Yet society largely undervalues these roles, leading to the unsustainable exploitation of coastal resources and the degradation of essential ecosystem functions. Global warming threatens to exert additional stresses on coastal areas. Climate impacts such as stronger storms, sea level rise, and increases in the temperature and acidity of ocean waters will interact with and exacerbate the effects of other environmental and human pressures. Beyond certain thresholds, Pallewatta warns, these pressures could trigger dramatic and potentially irreversible damage to coastal fisheries, coral reefs, mangrove forests, and other vulnerable ecosystems.

Climate change exposes coastal populations to several dangers. As cyclones grow more frequent and intense, they will place more coastal communities at risk from inundation and erosion. Mounting sea levels will produce higher storm surges, carrying flooding farther inland. As sea levels rise, saltwater will invade rivers and aquifers, contaminating the freshwater sources on which many settlements depend for drinking and farming. These

threats to the Indian Ocean seaboard are explored in the volume's second paper by Nazria Islam, Golam Rabbani, and A. Atiq Rahman. The authors then take a closer look at coastal management strategies and policy challenges in Bangladesh and Sri Lanka. Bangladesh has formulated a national Climate Change Strategy and Action Plan that includes coastal adaptation. Sri Lanka has created a dedicated Coast Conservation Department. Nevertheless, the authors find that coastal management suffers from institutional weaknesses in both countries, while decision making often remains fragmented among different agencies and across different sectors. Policymakers must improve coordination at all levels, they counsel, and find effective ways to increase the involvement of local stakeholders in policy design and implementation.

Egypt presents in microcosm nearly the full array of coastal risks arising from climate change. Coastal flooding could inundate large swaths of the densely populated Nile Delta, while saline intrusion from sea level rise could taint thousands of square kilometers of prime cropland, imperiling the agricultural sector that employs one-third of Egypt's labor force. At the same time, increasing acidity and warming surface water temperatures harm the coral reefs and marine life that attract tourists to the Red Sea, potentially jeopardizing the economy of a region that provides 90 percent of the country's tourism revenue. In his paper, Mohamed El Raey assesses these and other prospective climate risks and evaluates their implications for the Egyptian economy and society. He concludes that policymakers must elaborate a national integrated coastal management plan to guide climate adaptation strategies, and he calls upon the international community to help Egypt confront these challenges with technical, financial, and capacity-building assistance.

The small island developing states (SIDS) make minimal contributions to the greenhouse gas emissions that cause climate change, yet they are perhaps the most vulnerable of all countries to global warming's impacts. They have also been among the most active of all countries in pressing the international community to combat the greenhouse threat. Alain De Comarmond and Rolph Payet maintain that SIDS can lead the development of green technology as well as green diplomacy. Drawing on case studies of soft-engineering coastal protection measures in Seychelles, safe island relocation centers in the Maldives, and biofuels production in Vanuatu, they argue that SIDS have made significant strides in innovating and adapting sustainable technologies suited to their individual circumstances. Even so, to effectively realize their considerable potential as incubators of green technology, SIDS must supply the enabling policy and institutional frameworks, removing regulatory hurdles, building up their R&D capacities, and providing the necessary infrastructure and market opportunities.

All the countries of the Indian Ocean region will have to take action to adapt to the effects of global warming. Poh Poh Wong describes the various approaches available for reducing the exposure and sensitivity of coastal areas to climate impacts and explains the adaptation

challenges coastal managers must surmount. He finds that although the individual countries of the Indian Ocean region struggle with many of the same issues, they lack a common regional policy framework for addressing their shared problems. Such a framework could fulfill several useful roles. It could facilitate wider data collection, distribution, and evaluation and help establish early warning systems at the regional scale corresponding to environmental risks that transcend national boundaries. It could also foster technology transfer and disseminate best practices. Ultimately, Wong contends that successful adaptation will require both institutional initiatives and conceptual innovations to meet the climate threat to coastal zones.

The papers by the experts from the region furnish close studies of crucial issues and actors. They examine climate impacts on coastal ecosystems, explore adaptation strategies, and illuminate the policy pitfalls and possibilities facing particular countries around the Indian Ocean rim. In the book's concluding paper, David Michel ranges across these analyses and draws out a number of key themes. Coastal managers throughout the region, he notes, confront many of the same environmental threats (e.g., sea level rise, storm surges, saltwater intrusion) and many of the same societal risks (e.g., mass population displacements). At the same time, decision makers must grapple with certain specific policy problems going forward, including inadequate financial resources and enduring institutional obstacles. More broadly, Michel argues, policymakers will need to reconcile the potential tensions between crafting holistic coastal strategies integrating multiple actors, uses, and demands at multiple scales and crafting policies adapted to local circumstances and priorities.

Coastal areas are dynamic regions where terrestrial and marine ecosystems intersect and interact with human socioeconomic systems. The analyses in this volume reflect that complexity. No single paper can encompass the whole of the relations between climate change and coastal zones, but each piece can help illuminate an important set of issues. Taken individually, we think that each paper, like the twist of a kaleidoscope, brings a new constellation of questions into focus. Taken together, we hope the papers provide a fuller picture of the environmental pressures and the policy choices and challenges that coastal managers and national and global decision makers will confront in a warming world.

Notes

1. Gordon McGranahan, Deborah Balk, and Bridget Anderson, "The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones," *Environment and Urbanization* 19, no. 1 (2007).

2. Susmita Dasgupta et al., "Sea-Level Rise and Storm Surges: A Comparative Analysis of Impacts in Developing Countries," Policy Research Working Paper 4901 (Washington, DC: World Bank, 2009).

3. R. J. Nicholls et al., "Coastal Systems and Low-Lying Areas," in M. L. Parry et al., eds., *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2007).

Perspectives from the Regions


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SEYCHELLES
COMOROS
MALAWI
ZAMBIA
MOZAMBIQUE
ZIMBABWE
MAURITIUS
MADAGASCAR
TAIWAN

Impacts of Climate Change on Coastal Ecosystems in the Indian Ocean Region

Nirmalie Pallewatta

The Indian Ocean region is highly diverse geomorphologically. It consists of littoral and island states and spans an area between the African, Asian, and Australian continents, reaching to the Antarctic landmass.[1] The Indian Ocean forms the natural border to the South Asian subcontinent (Bangladesh, India, and Pakistan) and encompasses many large islands, such as Java, Madagascar, Sri Lanka, and Sumatra; many smaller island groups, such as the Comoros islands, the Maldives, and Seychelles; and numerous atolls and archipelagos. The littoral countries of this vast ocean also include the Persian Gulf states; the East African coast states from Somalia, Kenya, Tanzania, and Mozambique to South Africa; and the Southeast Asian nations of Brunei, Cambodia, Indonesia, Malaysia, Myanmar, the Philippines, Singapore, Thailand, East Timor, and Vietnam.

This paper provides a general account of the coastal zone ecology of the Indian Ocean region and the known and potential impacts of climate change on the region's ecosystems. Ecosystems are complex entities consisting of living beings, the physical environment they inhabit, and the interactions within and between these two components.[2] The three basic levels of biodiversity are genes, species, and ecosystems/communities/habitats. The goods and services that ecosystems provide, such as food, fuel, and materials, are essential for human survival. Oceans and their constituent ecosystems form essential elements of the chemical, biological, and physical processes of life on Earth. Climate, driven by the solar energy that warms the Earth and causes the circulation of the atmosphere and oceans, is defined according to meteorological parameters (e.g., air temperature, rainfall, and humidity); and exhibits natural variability. Climate is one of the two most important physical factors (the other being topography) determining the survival and nature of all living beings, from individuals and communities to populations and entire species, by heavily influencing the natural systems on which they depend.[3]

Two things need to be kept in mind. First, the characteristics of ecosystems vary over time and space. Scale is an important variable in the definition and measurement of any ecological system. Except in a very few instances, organisms and the environmental factors that

determine their survival are distributed as gradients that blend into one another at the edges of the space they occupy. Most coastal and marine ecosystems display important characteristics specific to the region; despite the common types of stresses exerted on coastal regions globally, the specific aspects of particular ecosystems should not be ignored, even as microclimates are exceptions to the effects of climate systems over very large scales. There is much we do not know about the interactions of ecosystems with their surroundings, especially in coastal and marine environments, and many indirect effects of global change on ecosystem functioning will likely reveal themselves as gradual impairments rather than as readily apparent losses of ecosystem integrity.

Second, ecology cannot deal only with nature. Humans are part of the ecology of any place on this planet. They and their constructed systems have to be included in any analysis of ecology. Thus the term *social-ecological system* is often applied in the analysis of human impacts on ecosystems. In this paper, only a few salient socioeconomic, cultural, and political factors relevant to coastal climate change can be highlighted.

What Is the Coastal Zone?

The coastal zone, where land meets ocean, is one of the most dynamic natural systems. Here, the three main components of our planet—the hydrosphere, the lithosphere, and the atmosphere—meet and interact, forming interconnected systems. Coastlines are formed by morphological changes governed by climatic and geological processes.[4] They constitute a transition zone where land and freshwater meet saline water, and across which the effects of land on the ocean, and vice versa, are transferred and modified. Coastal zones are a crucial battleground in the current fight against climate change.

This paper follows the definitions of coastal zones adopted in two key publications. For the Millennium Ecosystem Assessment (2005), "the inland extent of coastal ecosystems is defined as the line where land-based influences dominate up to a maximum of 100 kilometers from the coastline or 50-meter elevation (whichever is closer to the sea), and with the outward extent as the 50-meter depth contour. Marine ecosystems begin at the low water mark and encompass the high seas and deepwater habitats."[5] For the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), "coastal systems are considered as the interacting low-lying areas and shallow coastal waters, including their human components…This includes adjoining coastal lowlands, which have often developed through sedimentation during the Holocene (past 10,000 years), but excludes the continental shelf and ocean margins [and inland seas]."[6] Coastal systems also form part of the larger marine ecosystems that include coasts and open ocean areas.

Coasts are of great ecological and socioeconomic importance. They sustain economies and provide livelihoods through fisheries, ports, tourism, and other industries. They also provide ecosystem services such as regulating atmospheric composition, cycling of nutrients

and water, and waste removal.[7] These areas have been centers of human settlement since perhaps the dawn of civilization, and have cultural and aesthetic value as well. Coastal ecosystems are among the most productive because they are enriched by land-based nutrients and nutrients that well up into the coastal waters from deeper levels of the ocean. Coastlines are also among the most populated regions. Nearly half the world's major cities are located within 50 kilometers of a coast, and coastal population densities are 2.6 times greater than those of inland areas.[8]

Changing Coastal Zone Ecology

Coastal ecosystems are repositories of biological diversity and provide a wide range of goods and services. The major habitats of the coastal zone are coral reefs; seagrass beds/meadows; coastal or barrier islands; rocky coasts; cliffs; intertidal rocky, mud, or salt flats; rock pools; sandy, pebble, or rocky beaches; dune systems; saline, brackish, and freshwater lagoons; estuaries and coastal river floodplains; salt marshes; and mangrove forests—all of which have been highly modified over millennia by human activities. The Indian Ocean region is particularly rich in marine biodiversity. For example, the diversity of a number of marine taxa, including corals, fishes, lobsters, and snails, peaks in the so-called East Indies Triangle (Indonesia, Malaysia, New Guinea, and the Philippines) and (though declining in the central Indian Ocean) shows another lower peak in East Africa and Madagascar.[9]

Ecosystem services can be broadly grouped into three types:[10]

- *Provisioning*—e.g., food species, water for agricultural and industrial use, timber, fibers, fuel, and genes
- *Regulating*—e.g., climate regulation; influencing hydrological flows and cycles; regulation of erosion; removal of excess nutrients and wastes; and mitigation/amelioration of natural hazards such as floods, storm surges, landslides, and high winds
- *Cultural and religious*—e.g., recreational, aesthetic, educational, and scientific opportunities; and spiritual and symbolic values

The current widespread decline of regulating services is most worrying as, without these, the other two types of services are not possible.

Coasts are affected by two main types of influences, terrestrial and marine, that are considered external to the coastal zone. *Terrestrial influences* are mostly anthropogenic in nature. They include land use changes and all the consequences of changing hydrological regimes, and nutrient loading from sediment transport, runoff, and reduction of sediments through rivers (for example, from dam and channel construction and extraction of river sand upstream). *Marine influences* are mostly natural phenomena such as weather events (storms and cyclones), tsunamis, and wave patterns and coastal and ocean currents that affect the processes of nutrient, material, and heat transfer and mediate geomorphological changes.

Loss and degradation of ecosystems are affected by a suite of interacting factors that can be divided into two groups: direct drivers and indirect drivers. The *direct drivers* (also known as *proximate causes*) of loss and degradation of coastal zone ecosystems are as follows:

- *Loss, fragmentation, and degradation of habitats*, primarily by land use changes such as conversion to agriculture
- *Overexploitation of resources* for livelihoods and commercial purposes
- *Pollution*, mostly by nutrient enrichment by land-based use of chemical fertilizers and sewage but also from toxins such as pesticides and hazardous chemicals
- *Introduction of alien invasive species* and their rapid and uncontrolled spread (this is also considered a form of biological pollution)
- *Anthropogenic climate change*, which interacts with the previous factors listed, generally reinforcing their impacts

Following are the main *indirect drivers* (sometimes referred to as *ultimate or root causes*) that underlie the proximate causes:[11]

- *Population expansion*—increase of populations is followed by increased demands for resources
- *Distribution of wealth and social inequalities*—the poor often must emphasize survival over sustainability, while the wealthy are far removed from the consequences of overexploitation of resources, leading to degradation of natural systems
- *Policy failure*—policies that do not take into account the inherent characteristics of ecosystems permit their unsustainable exploitation (e.g., policies on land tenure are especially responsible for changing the manner in which land and biological resources are used)
- *Market failure/distortions*—ecosystem goods and services mostly bypass markets and thus are often undervalued and underpriced, so the costs of environmental destruction are not reflected in the market
- *Globalization*—trade and market liberalization have created a global system in which commodities and their prices are highly influenced by international pressures that do not usually take local and regional environmental impacts of production into account
- *Poor development model*—a development model that equates increased consumption rates with growth and advancement

These drivers, both direct and indirect, are also agents of global change. Their impacts contribute to widespread trends on local, regional, and global scales and across socioeconomic strata. These drivers do not operate singly but form an interacting and often synergistic complex. Coastal and marine ecosystem goods and services are highly undervalued, as

are ecosystems and biodiversity in general. This undervaluation results in unsustainable patterns of resource exploitation, highly degraded ecosystems, and weak attempts at conservation. Communities that directly depend on these goods and services bear the heaviest economic and social costs of such decline and loss. Often they are among the poorest segments of society.[12]

All told, human stressors have significant implications for coastal ecosystems and biodiversity. Anthropogenic pressures are leading to the disappearance, fragmentation, and outright destruction of habitats. Decreases in individual populations or in the number and types of species can result in decreasing ecological richness and degradation of communities and ecosystems. Loss or reduction of ecosystem goods and services or loss of biodiversity beyond certain limits can impair the natural functioning of ecosystems. Reduction of ecological resilience (the natural capacity to recover or revitalize from damage or disturbance) beyond certain levels may lead to ecosystem collapse. Ecosystems already highly affected by anthropogenic activities may in some cases prove unable to withstand the additional effects of climate change and may suffer irreversible loss of function.[13]

Global assessments of trends over the past century and the impacts of proximate drivers on coastal zone wetland biodiversity can be summarized as shown in table 1.[14]

Table 1: Assessment of Ecosystem Degradation

Driver	Degree of impact	Trend
Habitat change	Very high	Increasing impact
Overexploitation	High	Increasing impact
Pollution (nutrient loading by nitrogen and phosphorus)	Very high	Very rapidly increasing impact
Invasive species	High	Increasing impact
Climate change	Moderate	Very rapidly increasing impact

Climate Impacts on Ecosystems

Climate change is the predominant challenge of this century. Increased concentrations of greenhouse gases, mostly carbon dioxide (CO_2) in the atmosphere from anthropogenic influences, have led to increasing global mean surface air temperatures, increased climate and weather variability (including the occurrence of extreme events), and changes in precipitation patterns and seasonal cycles such as monsoons.[15] The main climate variables of interest to ecology are mean surface air temperature, rainfall, humidity, wind speeds, and the frequency and intensity of extreme climate/weather events such as storms and

droughts. These affect fundamental physiological processes and the survival of living systems. However, many other measures are used to study and monitor the consequences of climate change in oceans and coastal areas, including sea levels, sea surface temperatures, intrusion of saltwater into freshwater, rates of evapotranspiration from oceans and other water bodies, snow and ice cover, and changes to polar ice sheets and glaciers.

As living systems, ecosystems often exhibit nonlinear responses brought on by crossing thresholds that alter their composition and key processes—changes that in turn affect ecosystem stability, resilience, and functions. Studies of several types of ecosystems, including coral reefs, kelp forests, and oceans, show that pressures from human activities can bring about dramatic changes where functioning is severely impaired.[16] Once some critical threshold is passed, even relatively small stresses may trigger rapid ecosystem degradation and loss of integrity. Climate change may very likely be the factor pushing some ecosystems over the limit.

Climate change is a global change driver that interacts with and exacerbates the impacts of already existing environmental and human drivers on the natural world.[17] Changes in climate will affect biodiversity at all levels: genes, species, habitats, and ecosystems. Temperature increase, change in rainfall patterns, drought, sea level rise, coastal flooding, damage from cyclones, and change in salinity can affect habitat suitability. Populations and species can respond in several ways to large-scale environmental change. They may benefit or remain unchanged; they may continue in the original distribution range, adapt, disperse to new regions, decline in numbers, or become extinct. As species respond individually and collectively, chain reactions will take place in the food webs of coastal and marine areas. Changes in the physiology or survivorship and reproduction of a species will affect any other species—including humans—that depend on it.

There will be species loss if flora and fauna cannot adapt to climate change or migrate to suitable habitats fast enough. The species composition of communities and ecosystem services will be affected, which in turn risks severely reducing productive functions and diminishing ecosystem resilience. The implications for humans include negative impacts on food security; the spread of diseases and vectors into new regions; loss of productive agricultural lands and water bodies; changes in seasonal cycles; plant and animal life cycle variations; and changes in ecosystem functions that disturb the provision of food, water, and essential environmental services.

There may be some benefits from climate change. These include increased precipitation over some areas that are currently water scarce and increased production from some types of ecosystems as a result of increased temperatures. Some species that are currently restricted by temperature regimes may expand their range. Growing and breeding seasons for species of the higher latitudes may be longer. However, a climate variable that favors

one species or ecological community may be detrimental to another. While it is safe to say that all regions will experience the impact of climate change and that positive as well as negative effects will likely take place in the same large areas, the magnitude of any positive effects, the ways species might be able to adapt to them, and the possibility of unforeseen negative consequences are largely unknown at present.

Major Consequences of Climate Change and Ocean Acidification for Coastal Zone Ecosystems

The IPCC Fourth Assessment Report states with high confidence that, globally, coasts are undergoing adverse consequences from climate change, such as sea level rise, inundation, erosion, and ecosystem loss.[18] The report also states that coasts are highly vulnerable to extreme events such as cyclones, extreme waves, storm surges, altered rainfall and runoff patterns, and ocean acidification. The data show strong regional and local variations in the impacts of climate change on coasts as a result of nonclimate factors. Even so, the overall impacts of climate change are "virtually certain to be overwhelmingly negative."[19] Climate change and its associated effects pose serious risks to coastal biodiversity.[20]

Climate change contributes to accelerated sea level rise by the thermal expansion of near-surface ocean waters and the increased melting of glaciers and ice sheets. Sea level rise in turn has numerous impacts. Flooding of coasts, estuaries, and river deltas can alter the physical structure of habitats and lower habitat availability and suitability, compromising the biota on which organisms higher up on food webs depend. Increased coastal erosion can reduce or remove beach areas and protective barrier islands and interfere with near-shore currents and their physical transport patterns. Subsequent changes in drainage and irrigation patterns and modifications of fluvial flows can reroute sediment transport nutrient runoff into coastal waters. Saltwater intrusion into coastal wetlands, especially estuaries, can negatively affect these ecosystems and contaminate groundwater and other inland freshwater sources. Higher sea levels can also intensify storm surges.

The IPCC predicts a sea level rise of 0.6 meters or more by 2100 and an increase of sea surface temperature by 3°C, but recent work suggests that these may be underestimates. It is important to note that there is significant regional variation in the coastal impacts of sea level rise. Sea levels can also vary naturally through the geological processes of subsidence and uplift or through human processes such as extraction of water, oil, and gas. Similarly, shoreline retreat, flooding, and saltwater intrusion can occur through natural phenomena such as changes in ocean currents, transport of sediments to coasts, and wind patterns.

Climate change is projected to affect climate variability, increasing the frequency and severity of storm/tidal surges, tropical cyclones, hurricanes, etc. These phenomena also cause coastal flooding, erosion, saltwater intrusion into freshwaterways, salinization of

soils, and destruction of coastal infrastructure. Global warming will also increase sea surface temperatures as surface waters absorb heat from higher air temperatures. Such altered temperature regimes can significantly affect the reproduction and survival of species unless they can adapt quickly enough.[21]

In addition to heat, the oceans absorb CO_2 from the atmosphere. Approximately a quarter of all the CO_2 released into the atmosphere by human activities is absorbed by the oceans.[22] This process also creates carbonic acid in the seawater. Ocean acidification has a corrosive effect on the corals and shelled organisms that form the basis of marine and coastal food webs. In a glimpse of the potential future implications of ocean acidification, Orr et al. report that coastal and marine locations with naturally occurring high CO_2 levels show a high number of invasive species and low biodiversity.[23]

Climate Change Impacts on the Coastal Zone Ecosystems of the Indian Ocean Region

The Indian Ocean coastal region is a key area of vulnerability. Several of its component subregions have consistently been identified as among the most vulnerable to climate change now and in the future.[24] All coastal areas in Asia and Africa are facing an increasing range of stresses and shocks, the scale of which now poses a threat to the resilience of both human and environmental coastal systems, and which are likely to be exacerbated by climate change. Summaries of the ecosystems of major concern follow, along with the known and predicted impacts of climate change.

Coral Reefs

Coral reefs support nearly 25 percent of all marine species.[25] They are among the world's most diverse and productive ecosystems. Yet they are also among the most threatened and perhaps the most high-profile "ecosystem victims" of climate change in the oceans.[26] Coral reefs occur mainly in the relatively nutrient-poor waters of the tropics, but because very efficient nutrient cycling and complex biological interactions transfer energy through the system, their ecological productivity is high. Cold-water, deep-sea corals are important breeding grounds for many species of marine organisms, including commercially important fish. Reefs provide food to humans, habitat to plants and animals, and protection of coasts from storm and wave damage by acting as natural breakwaters. They are also important for tourism, particularly in developing countries.

When coral, already threatened by overexploitation and coastal development, suffers from bleaching (a process attributed to increasing ocean temperature), the zooxanthellae that live within the coral in a symbiotic arrangement die—and finally, in turn, so does the coral. Over 34 percent of the vast and diverse coral reefs of Asia are reported to have been lost in

1998, largely as a result of coral bleaching induced by the 1997–98 El Niño event. Further increases in sea temperature are predicted to cause widespread coral collapse. The final blow to corals may yet come from the ocean acidification that is corrosive to coral growth. Recent data indicate that, by the middle of the next century, the process of coral calcification will decrease to the level where erosion will be greater than new growth.[27]

The 2008 report of the Global Coral Reef Monitoring Network sums up the status of, threats to, and trends concerning the coral reefs of the Indian Ocean.[28] Around the Indian Ocean, reefs are either highly degraded or degraded to a medium degree. Loss of habitat, sedimentation, overfishing, and pollution remain major threats for all coral reefs. A few that are highly protected as nature preserves of French territory islands remain relatively intact, but even they have undergone some amount of coral bleaching over the past 10 years. Reefs in South Asia were subject to the massive bleaching event of 1998, with attendant dramatic reduction of coral cover, but are recovering, albeit patchily. Reefs of the western atoll chain of the Maldives and the Bar Reef of Sri Lanka show relatively good recovery, but there is little or no recovery in other reefs near Sri Lanka and the eastern atoll chain of the Maldives.

Seagrass Beds

Seagrass beds are formed by unique groups of species of flowering plants that grow completely submerged in shallow coastal waters. These beds are very productive and provide a host of ecosystem services, ranging from filtering and trapping sediments to nutrient cycling. They are an important nursery habitat for fish and invertebrates and a source of food for many coastal organisms in tropical areas. In tropical waters, seagrasses often occur in proximity to coral reefs or mangroves, suggesting interactions that benefit the organisms inhabiting both types of habitat. Seagrasses can be considered "coastal canaries." Because they need high levels of light, they reflect changes in turbidity and water depth far more rapidly than comparable species in coastal waters. In all regions, sediment or nutrient inflows are the greatest stressors leading to seagrass loss and degradation.[29] Climate change factors such as increased coastal water temperatures, sea level rise, and extreme events such as storms and storm surges can contribute to increasing these stresses on seagrass meadows.

Mangroves and Coastal Wetlands

Asian wetlands have been increasingly threatened by a warmer climate in recent decades. Droughts and declining precipitation in most delta regions of Bangladesh, China, India, and Pakistan have caused wetlands to dry up and have severely degraded their ecosystems.[30] Reduction of freshwater flows and saltwater intrusion in the Indus Delta and Bangladesh have seriously compromised these regions' mangrove forests. About one-third of the world's mangroves have reportedly been lost during the last 50 years of the 20th century, likely as a result of human activities. Mangroves in developing countries are projected

to decline another 25 percent by 2025, with key countries such as Indonesia estimated to lose 90 percent or more of their mangroves in some areas.[31]

Wetlands, such as intertidal zones and floodplains, and vegetated ecosystems, such as mangroves, can be critical to the buffering of flooding and erosion arising from climate change. Maintaining these ecosystems' integrity is an important adaptation strategy. Coastal wetlands, including mangroves, are likely to respond to climate change and sea level rise through accretion, migration inland, or else habitat loss.[32] Reconstructions of ancient coastal geomorphological changes indicate that mangroves can respond to shifts in sea level. Vertical accretion by sediment accumulation may allow mangroves to keep up with mounting sea levels up to some limits. Where sea level rise exceeds the rate of accretion, habitat loss can result, but the wetland types can also migrate or shift inland. Where migration is not possible or is prevented by human interventions such as converting coastal zones to other types of land use, habitat loss will be the inevitable result. This phenomenon is called "coastal squeeze," the restriction of coastal ecosystems to ever-decreasing zones between advancing seas and inland development. Many mangrove localities are experiencing subsidence and therefore higher relative rates of sea level rise. Other climate change drivers, such as shifts in rainfall patterns, increased CO_2 levels, and changes in storm and wave actions, will affect mangroves in different ways, sometimes positively.[33] It is also possible that mangroves may not respond as a single entity, but that constituent species will adapt in different ways, leading to changes in distribution as well as composition of forest community and structure.

Challenges and Opportunities

The key challenge in addressing the climate threat to coastal zones is timely adaptation to global warming, for too much delay means that the option of adaptation no longer exists. Nevertheless, serious socioeconomic, technical, political, and ecological problems hamper the planning and implementation of adaptive strategies. Governments of the Indian Ocean region have joined the international treaty regime, produced National Communications required under the UN Framework Convention on Climate Change, and taken some steps toward addressing the issues of climate change, but there is little real national-scale action. In contrast to more developed regions of the world, national-scale awareness of the impending climate risks, special vulnerabilities of particular populations, and responsibilities of individuals and groups in mitigating climate change and reducing vulnerability remain very low. Forecast patterns for energy needs, water use, and natural resource consumption suggest pressures on ecosystems and ecosystem services in the Indian Ocean region will be exacerbated by climate change, yet a survey of the literature shows that interest in economic development of the coastal zone has overridden concerns regarding climate change, natural disasters, or environmental quality.

The Asian and African regions of the Indian Ocean share characteristics that make them more likely to be affected by climate change. In many countries, lack of effective governance structures, high rates of population growth and urbanization, poor land use planning, and myriad other development pressures add to the challenges posed by environmental degradation. A significant proportion of the population is either poor or low income and already vulnerable to malnutrition, ill health, and limited access to drinking water and sanitation. Climate change tends to disproportionately affect the more vulnerable segments of society, such as the poor and the marginalized, as they are already living in locations that have high vulnerability.[34] At the same time, developing countries have comparatively little capacity to adapt, given the speed with which climate change is taking place. Indeed, poverty has been identified as the most significant barrier to adaptation to climate change.[35] The costs of adaptive responses will be highly site-specific within a country, but will be greater in low-income economies in coastal zones of developing countries.

Both policymakers and the public display a lack of willingness to act, which is partly fueled by a lack of sufficient awareness of the effects of national-scale climate change. Insufficient regional models are available for analyses and vulnerability assessments, and downscaling from global scenarios remains problematic. Only a few global and crude regional-scale analyses are available for Indian Ocean coastal zones, with the exception of the megadeltas and a few selected localities of the Indian subcontinent, Southeast Asia, and East Asia. The uncertainties associated with climate change projections, and a general perception that climate change is of such overwhelming reach that it is beyond the capacity of individual countries to make a difference, further impede policy efforts. Despite slowly increasing levels of awareness among the general public, the level of debate and discussion is woefully inadequate.

Several difficulties beset attempts to gather information on how climate change affects the ecology of the Indian Ocean coastal zone. First, there is insufficient published information of the required type and quality on these ecosystems (with the status of coral reefs being an exception) and on economic, social, and other aspects of climate change. The underlying causes for this lack are mostly underresourced institutions and insufficient numbers of professional scientists. Second, there is a mismatch between the scales at which scientists typically study individual ecosystems and the conceptual scales of understanding needed to connect climate change with ecologically meaningful changes in populations and communities. Present understanding of most ecological processes largely derives from individual species, sites, or smaller regions studied over shorter time scales (a few decades), whereas many important climatological processes take place at global or regional scales and evolve over longer time frames. This makes it difficult to connect specific processes taking place in populations and communities with broader climate changes affecting whole regions and their constituent ecosystems.[36]

Another barrier to action arises from the problem of multiple scales across the natural, administrative, socioeconomic, and political realms. Political considerations at one level—local, regional, national—often ignore effects on other levels and in other domains, such as the social or environmental. This contributes to conflicts over governance, management, and responsibilities for adaptive responses. To protect the integrity of ecosystems, remedial action has to take place at several scales, often simultaneously.

More generally, governments in Asia and Africa are already overburdened trying to address pressing socioeconomic issues such as poverty, inequality in access to health care and education, the need for infrastructure development, and security issues such as terrorism. It will be very difficult or impossible for most developing countries to divert resources from these problems to combat global warming. Many will focus on climate change only when it causes natural disasters and emergencies. Governments and the public alike seem ready to respond to sudden, large-scale catastrophes but will ignore slow, cumulative processes such as climate change and sea level rise. Although the ultimate impacts of climate change could be calamitous, they are not easily recognizable over short periods and are frequently indistinguishable from the natural pattern of climatic events.

The Indian Ocean tsunami of December 2004 is a case in point. It caused unprecedented loss of human lives and damage to coastal infrastructure, but its aftermath created awareness of the power of natural events, especially in societies where tsunamis were very rare, such as Sri Lanka and southern India. Most Sri Lankans previously did not even know the term "tsunami." Since then, there has been a large increase in awareness, and the potential hazards of living in the coastal zone are better recognized. Responses by the affected governments included establishing tsunami early-warning systems, community-level programs to reduce risks, and national disaster management policies. These programs will also serve to reduce loss of life from flooding and other types of climate-related events affecting coastal zones. Assessments of the environmental vulnerabilities of coastal areas after the tsunami highlighted the importance of maintaining the integrity of coastal ecosystems. Mangroves and coral reefs buffered the impact of the waves that hit the coastlines. Nevertheless, the potential lessons to be drawn from the tsunami for undertaking better coastal zone management appear not to have been learned, except in some countries such as India. There, authorities seized the opportunity to develop coastal zone management guidelines that include reducing the risks of coastal flooding from climate change–related drivers.

Perhaps governments will prove able to leverage such opportunities to take action on climate risks. Numerous studies demonstrate the vulnerability of coastal zones in the region. At the same time, maintenance of coastal ecosystems is growing in importance as buffers against climate impacts and for sustaining coastal livelihoods. Indeed, multilateral donor agencies such as the World Bank, the Asian Development Bank, and the African Development Bank

increasingly include climate change in their development lending strategies. As public understanding of the consequences of environmental degradation rises, some governments have begun to take steps—however small—toward reducing greenhouse gas emissions. Sri Lanka, for example, has ended the use of chlorofluorocarbons (CFCs) in its refrigeration and tea industries. It would be far better if popular awareness and political foresight could engender timely and effective measures to avert the high human costs of global warming than for society to respond only belatedly to climate calamity.

We are just beginning to understand the changes that we have wrought on the massive and highly complex system that is the climate of our planet. We do not completely understand its workings and therefore are beset with the uncertainties of climate science, specifically how accurate our climate projections will prove. Even though it is commonly agreed that more accurate regional climate models would enable better decision making, dissenting views insist that we do not have to wait to adopt meaningful strategies to cope with climate change.[37] For most countries of the Indian Ocean region, there seems little choice but to attempt to reduce the exposure to climate risks of the most vulnerable populations, build resilience where possible, and salvage what we can of our ecosystems to prevent further degradation and extinction.

Notes

1. Vivian L. Forbes, *Maritime Boundaries of the Indian Ocean Region* (Singapore: Singapore University Press, 1995).
2. Robert E. Ricklefs, *Ecology*, 3rd ed. (New York: W. H. Freeman and Company, 1990).
3. Ibid.
4. Jentje Van der Weide, "A systems view of Integrated Coastal Zone Management," *Ocean and Coastal Management* 21, nos. 1–3 (1993).
5. Millennium Ecosystem Assessment, *Ecosystems and Human Well-Being: Current State and Trends* (Washington, DC: Island Press, 2005), p. 516.
6. Robert J. Nicholls et al., "Coastal Systems and Low-Lying Areas," in M. L. Parry et al., eds., *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2007), p. 318.
7. S. Curran et al., "Interactions between coastal and marine ecosystems and human population systems: perspectives on how consumption mediates this interaction," *Ambio* 31, no. 4 (2002).
8. Millennium Ecosystem Assessment, *Marine and Coastal Ecosystems and Human Well-Being: Synthesis* (Nairobi: United Nations Environment Programme, 2006), p. 40.
9. M. L. Reaka, P. J. Rodgers, and A. U. Kudla, "Patterns of biodiversity and endemism on Indo-West Pacific coral reefs," *Proceedings of the National Academy of Sciences* 105, suppl. 1 (2008):11474–81.
10. Modified from Millennium Ecosystem Assessment, 2005, op. cit.; and J. C. Avise, S. P. Hubbell, and F. J. Ayala eds., *In the Light of Evolution, Volume II: Biodiversity and Extinction* (Washington, DC: National Academies Press, 2008).
11. Adapted from Gretchen C. Daily and Pamela A. Matson, "Ecosystem services: from theory to implementation," *Proceedings of the National Academy of Sciences* 105, no. 28 (2008): 9455–56; National Research Council, *Valuing Ecosystem Services: Toward Better Environmental Decision-Making* (Washington, DC: National Academies Press, 2005); D. Tilman, "Global environmental impacts of agricultural expansion:

the need for sustainable and efficient practices," *Proceedings of the National Academy of Sciences* 96, no. 11 (1999): 5995–6000; Jeffery R. Vincent and Theodore Panayotou, "Consumption: challenge to sustainable development or distraction," *Science* 276, no. 5309 (1997).

12. R. Costanza et al., "The value of the world's ecosystem services and natural capital," *Nature* 387 (1997): 253–60; S. Pagiola, K. von Ritter, and J. Bishop, *How Much Is an Ecosystem Worth? Assessing the Economic Value of Conservation* (Washington DC: World Bank/IUCN/The Nature Conservancy, 2004).

13. E. L. Tompkins and W. Neil Adger, "Building Resilience to Climate Change through Adaptive Management of Natural Resources," Tyndall Center Working Paper No. 27 (Norwich, UK: University of East Anglia, 2003); Millennium Ecosystem Assessment, 2005, op. cit.

14. Adapted from Millennium Ecosystem Assessment, 2006, op. cit.

15. M. L. Parry et al., eds., *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2007).

16. M. Scheffer et al., "Catastrophic shifts in ecosystems," *Nature* 413, no. 6856 (2001); R. S. Steneck et al., "Kelp forest ecosystems: biodiversity, stability, resilience and future," *Environmental Conservation* 29, no. 4 (2002): 436–59.

17. Parry et al., op. cit.

18. Nicholls et al., op. cit.

19. Ibid.

20. A. R. Watkinson, J. A. Gill, and M. Hulme, "Flying in the face of climate change: a review of climate change, past, present and future," *Ibis* 146, Suppl. 1 (2004).

21. Nicholls et al., op. cit.; Nicholas Harvey and Robert Nicholls, "Global sea-level rise and coastal vulnerability," *Sustainability Science* 3, no. 1 (2008).

22. J. G. Canadell et al., "Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks," *Proceedings of the National Academy of Sciences* 104, no. 47 (2007): 18866–70.

23. J. C. Orr et al., "Research Priorities for Ocean Acidification," report from the Second Symposium on the Ocean in a High-CO_2 World (2009), http://ioc3.unesco.org/oanet/HighCO2World.html (accessed March 5, 2010).

24. Nicholls et al., op. cit.

25. Marjorie Mulhall, "Saving the rainforests of the sea: an analysis of international efforts to conserve coral reefs," *Duke Environmental Law and Policy Forum* 19, no. 2 (2009).

26. D. R. Bellwood et al., "Confronting the coral reef crisis," *Nature* 429 (2004): 827–33.

27. Orr et al., op. cit.

28. C. Wilkinson ed., *Status of Coral Reefs of the World* (Townsville, Australia: Global Reef Monitoring Network/Reef and Rainforest Research Center, 2008).

29. Orr et al., op. cit.

30. Parry et al., op. cit.

31. Elizabeth Macleod and Rodney V. Salm, *Managing Mangroves for Resilience to Climate Change* (Gland, Switzerland: IUCN, 2006).

32. Millennium Ecosystem Assessment, 2006, op. cit.

33. Macleod and Salm, op. cit.

34. B. L. Turner et al., "A framework for vulnerability analysis in sustainablility science," *Proceedings of the National Academy of Sciences* 100, no. 14 (2003): 8074–79.

35. United Nations Framework Convention on Climate Change (UNFCCC), *Climate Change: Impacts, Vulnerabilities and Adaptation in Developing Countries* (Bonn: UNFCCC Secretariat, 2007).

36. G. R. Walther et al., "Ecological responses to recent climate change," *Nature* 416 (2002): 389–95.

37. Suraje Dessai et al., "Do we need better predictions to adapt to a changing climate?" *Eos* 90, no. 13 (2009): 111–12.

Climate Change and Sea Level Rise: Issues and Challenges for Coastal Communities in the Indian Ocean Region

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Climate change is one of the greatest threats to human lives and livelihoods in coastal regions all over the world. It will significantly aggravate existing hazards such as flooding from cyclones and storm surges. Other climate-induced risks, including sea level rise, salinity intrusion, drought, and temperature and rainfall variations, are becoming serious threats to food, water, energy, and health security for humankind.

The coastal countries of the Indian Ocean region from East Africa to Southeast Asia are highly vulnerable to climate change. Many are especially endangered because of their geographic location and topography. Bangladesh and Vietnam, for example, are predicted to be among the most substantially affected countries in the world because of the large portion of their populations living in major river deltas exposed to sea level rise.[1] In Bangladesh, the shallow and funnel-shaped Bay of Bengal intensifies cyclones and storm surges, increasing their impact on the country's low-lying coastal plains. Tropical cyclones hit Bangladesh some 29 times in the second half of the last century, with one of the most devastating taking 138,000 lives in April 1991.[2]

Additional factors—including excessive population growth, poverty, lack of awareness of climate risks, and unplanned urbanization—make the region all the more susceptible to climate-induced extreme events. Currently, about 20 percent of South Asia's population lacks access to water services,[3] and more than 27 percent are without adequate food. Climate change and climate variability threaten to push these figures even higher in a number of countries in the region. A 5-meter rise in sea level, for instance, would submerge 11 percent of the productive land of Bangladesh and displace over 30 million people. Even at lesser amounts of sea level rise, saline intrusion into both soil and freshwater could force millions of people from their homes in search of safe water for drinking and other uses.

This paper looks at climate change and sea level rise in the Indian Ocean region. The first section provides a brief overview of the topic. The second examines the vulnerabilities

of natural ecosystems, urban areas, and social systems in the coastal zones. The third and fourth discuss the coastal management strategies, institutional arrangements, and policy challenges in Bangladesh and Sri Lanka, respectively, as case studies. The paper concludes with some recommendations.

The Problem: Climate Change, Sea Level Rise, and Extreme Events

Climate Change and Sea Level Rise

Sea level rise is caused by a number of factors including thermal expansion of the ocean, the melting of the Greenland and Antarctic ice caps, and inflow into the seas from melting glaciers on land. As increased radiative force causes the atmosphere to warm, the ocean absorbs more than 80 percent of the heat added to the climate system, causing the water to expand.[4] This thermal expansion accounted for between 0.30 and 0.54 millimeters in average annual sea level rise between 1961 and 2003. Higher average atmospheric temperatures contribute to the melting of the ice sheets of Greenland, Antarctica, and other continental glaciers, resulting in additional water flowing into the seas. Melting of glaciers and ice caps accounts for the highest contribution to sea level rise—an estimated 0.32 to 0.68 millimeters per year.[5]

Other factors, such as land subsidence, can affect the amount of sea level rise occurring in particular locations. For example, the North Indian Ocean sea level shows a linear increasing trend of 0.31 millimeters per year between 1958 and 2000.[6] But one recent report has found a trend of increasing sea level rise at Hiron Point near Sundarban of 5.3 millimeters per year between 1977 and 2002; some of the other stations along the Bangladesh coastline also show increasing trends of sea level rise.[7]

In 2007, the Intergovernmental Panel on Climate Change (IPCC) estimated that climate change would cause 0.6 meters or more of global sea level rise by 2100.[8] Newer estimates suggest that the global sea level rise due to climate change will top 1 meter or more by 2100.[9] The most recent sources indicate that the current global mean sea level rise has reached 3.1 millimeters per year.[10]

Extreme Events: Cyclones and Storm Surges

Tropical cyclones pose considerable risks to Indian Ocean countries. Most recently, in Bangladesh in 2007, Cyclone Sidr killed more than 3,000 people and affected over 6 million people. Nearly 0.3 million homes were destroyed, and about 0.9 million were damaged. Some 0.35 million hectares of cropland were also destroyed. According to an assessment made by the International Labour Organization and the Ministry of Labour and

Employment of Bangladesh, some 567,000 people saw their livelihoods temporarily or permanently disrupted, mainly due to employment losses and damage to income-generating assets. This figure corresponds to 436,000 households, or 14 percent of all households in the affected areas.[11] Another "super cyclone" which struck the Indian state of Orissa in 1999 generated a storm surge of 8 meters traveling up to 20 kilometers inland. The Orissa cyclone killed 10,000 people, destroyed 275,000 homes and 17,110 square kilometers of crops, and uprooted or snapped 90 million trees.[12]

The IPCC Fourth Assessment Report predicts climate change will intensify extreme weather events such as cyclones and associated storm surges, especially along the Bay of Bengal. Some evidence already indicates a decreasing frequency but increasing intensity of cyclone formation in the bay since 1970.[13] Higher wind velocity from such storms is expected to cause greater losses to vulnerable communities and ecosystems in South Asia.

Vulnerability to Climate Change and Sea Level Rise

The effects of sea level rise go beyond the gradual inundation of coastal land areas to include the intrusion of saline water into freshwater rivers and aquifers and the intensification of impacts from cyclones and storm surges. As sea levels rise, saline water will intrude directly into rivers and streams, advancing not only as a function of the water level but also according to changes in river discharge that may result from climate change. (In Bangladesh, for example, saline water starts to penetrate inland during winter months when the flow of water in rivers is much less.) Sea level rise also puts upward pressure on the saline-freshwater interface in groundwater aquifers.[14] Similarly, sea level rise raises the base on which storm surges build, making storm waves higher and carrying them farther inland.

Impacts of Sea Level Rise on Natural Ecosystems

Saline intrusion from sea level rise will degrade water quality in coastal rivers, lakes, ponds, and aquifers in different countries of the region. This degradation will in turn put stress on the existing drinking water sources—which is already a problem affecting Bangladesh, India, the Maldives, and Sri Lanka to varying extents. Sea level rise would also aggravate the water quality impacts of cyclones and storm surges, which can spread pollution from contaminated sources. In fact, these extreme events can act as vehicles for transferring water quality risk. For example, over 6,000 ponds were tainted with saline water from Cyclone Sidr in 2007 in Bangladesh. More pollution will lead to more waterborne illnesses such as cholera and diarrheal diseases. Sea level rise may also bring additional risks such as lower agricultural yields causing malnutrition along the coastal areas in the region.

In addition to effects on water quality for drinking and farming, climate impacts on surface water temperatures, sea level rise, and salinity intrusion may significantly damage aquatic

ecosystems in the region, facilitating the growth of algal blooms and eutrophication, which might have adverse impacts on sensitive species.

Impacts of Sea Level Rise on Coastal Settlements

Sea level rise will tend to worsen coastal erosion.[15] In some coastal areas, a 30-centimeter rise in sea level can result in 45 meters of landward retreat. Coastal erosion, cyclones, and storm surges will place coastal infrastructure—housing, industrial facilities, energy and sanitation systems, transportation and communication networks, and tourist and cultural sites—increasingly at risk.

Projected sea level rise could flood the homes of millions of people living in the low-lying areas of South Asia. The IPCC estimates that almost 60 percent of the projected increase in the annual number of people flooded in coastal populations will occur in South Asia, along the coasts from Pakistan, India, Sri Lanka, and Bangladesh through to Myanmar. The potential impacts of a 1-meter sea level rise include inundation of 5,763 square kilometers in India; a 45-centimeter sea level rise in Bangladesh may dislocate about 35 million people from 20 coastal districts by 2050.[16]

The repercussions from such population displacements could spread well beyond the coastal regions. Environmental migration within or between countries could create severe problems for regional and sectoral development as well as generate new sociopolitical instabilities from increased competition over scarce resources such as land, water, forests, and fisheries in many parts of the world. Around the Indian Ocean rim, millions of people are already living in urban slums without adequate employment or shelter. Climate migrants seeking refuge from more exposed regions could put enormous pressure on urban economies and infrastructure as well as on basic services such as water supply, power, health, and sanitation.

Bangladesh, for example, is already experiencing higher levels of tidal inundation in its coastal districts, with troubling implications. The country's Sundarban region, the largest continuous mangrove area in the world, provides direct employment to some 500,000 to 600,000 people for at least half the year, many of whom are engaged in harvesting the region's natural resources through fishing; woodcutting; and collecting thatching materials, honey, beeswax, and shells.[17] By some estimates, just 10 centimeters of sea level rise would submerge 15 percent of the region, and the Sundarban would disappear altogether if the sea level rose 60 centimeters.[18]

Case Study: Bangladesh

Bangladesh has a coastline of 710 kilometers along the Bay of Bengal. As defined by criteria including the reach of tidal waters, salinity intrusion, and the landward influence of cyclones and storm surges, fully one-third of the country is categorized as belonging to

the coastal zone. The outer boundary of the Exclusive Economic Zone delimits the seaward coastal zone. The coast of Bangladesh constitutes a region of both vulnerabilities and opportunities. It possesses a great diversity of natural resources including coastal fisheries, forests, salt, and minerals, as well as high potential for exploitation of both onshore and offshore natural gas. It also offers sites for harbors, airports, tourism facilities, and other development opportunities.

Increasing population, competition for limited resources, natural and anthropogenic hazards, lack of economic opportunities in some areas, and important ecological hotspots call for targeted coastal management strategies. The government of Bangladesh realizes that climate change poses a serious threat for development and acknowledges the need to protect coastal ecosystems and optimize the utilization of coastal resources. The state's forthcoming second Poverty Reduction Strategy Paper recognizes the risks of sea level rise and associated vulnerabilities in coastal areas and suggests possible adaptation actions and short-term measures (2009–11) for improving climate-resilient infrastructure, especially in the country's coastal districts.[19]

Bangladesh has designated the Ministry of Environment and Forests as its focal point for the United Nations Framework Convention on Climate Change (UNFCCC). Recently, the Ministry of Finance allocated resources from the annual budget to address climate change and, to this end, has formed a national-level committee. Additionally, the Economic Relations Department has established a multidonor trust fund to deal with climate impacts in Bangladesh.

Coastal Management and Climate Policy

In 2005, the government formulated a national coastal zone policy (CZP) to guide coastal management and ensure sustainable development of coastal communities without impairing the integrity of the natural environment. In seeking to facilitate harmonized policies across sectors, the policy established processes and mechanisms that commit different relevant ministries, departments, and agencies to coordinate their activities in the coastal zone, and to engage national and local government institutions as well as NGOs, the private sector, and civil society.

Recognizing the need to implement adaptive measures in the face of climate change, the CZP advanced a number of steps, including continuous management of sea dikes to protect the coastline from sea level rise, floods, cyclones, and storm surges. The CZP also proposed an institutional framework for detecting and monitoring sea level rise and for formulating contingency plans to cope with the resulting impacts.

For its part in addressing climate change and its impacts, the Ministry of Environment and Forests formulated a National Adaptation Program of Action (NAPA) under the guidance

of the UNFCCC in 2005. National and local government policymakers, scientific experts, and representatives from many sectors of civil society—including NGOs, indigenous groups, and the media—contributed to the action plan's development. The NAPA identified the immediate and urgent climate adaptation needs of the country and listed priority activities; those specific to the coastal zone are the following:

- Promoting adaptation of coastal crop agriculture to combat increasing salinity through maize production under the wet bed no-tillage method and "Sorjan" systems of cropping in tidally flooded agro-ecosystems
- Promoting adaptation of coastal fisheries through aquaculture of salt-tolerant fish species in coastal areas of Bangladesh
- Reducing climate change hazards through coastal afforestation with community participation
- Promoting research on saline-tolerant crop varieties to facilitate further adaptation in the future
- Providing drinking water to coastal communities to combat increased salinity in freshwater sources due to sea level rise
- Enhancing resilience of urban infrastructure and industries to the impacts of climate change
- Exploring options for insurance and other emergency preparedness measures to cope with increased climatic disasters (e.g., floods, cyclones)

In 2008, the Ministry of Environment and Forests formulated the Bangladesh Climate Change Strategy and Action Plan (BCCSAP), which aims to promote climate-resilient development in Bangladesh based on the Bali Action Plan of the UNFCCC. The BCCSAP covers adaptation to climate change, technology transfer, and adequate and timely flow of funds for investment within a framework of food, energy, water, and livelihood security. Developed in close consultation with civil society, the BCCSAP builds on the country's NAPA and is intended to be reviewed and revised as experience and knowledge are gained from implementing adaptation activities and from related research.

The BCCSAP consists of six pillars, comprising 37 programs and 128 projects. The individual programs are implemented by the relevant ministries or their agencies, with the involvement—as appropriate—of civil society and the private sector. The programs specific to coastal areas are as follows:

- *Comprehensive Disaster Management*—improvement of cyclone and storm surge warning
- *Infrastructure*—repair and maintenance of cyclone shelters, repair and maintenance of existing coastal polders, adaptation against tropical cyclones and storm surges

- *Research and Knowledge Management*—preparatory studies for adaptation against sea level rise

Policy Challenges

Despite increasing recognition of the need for Integrated Coastal Zone Management (ICZM) strategies, individual coastal policies in Bangladesh are still mainly formulated with narrow sector-oriented objectives in mind and are not part of an overall framework. Similarly, although many sectoral policies have clear implications for coastal development, in most cases they do not have specific sections on coastal areas and often fail to capture the distinctive combinations of vulnerabilities and opportunities that characterize the coast.

The coast remains an area of institutional weakness. Though several government agencies and NGOs are working in the coastal region, there are limited linkages between them and institutional fragmentation is common. Further, many of the government agencies responsible for coastal policies have hardly any presence at the local level. Insufficient coordination—compounded by a lack of institutional, financial, and human capacities for implementation and monitoring—impedes effective policy action. Consequently, sectoral development policies, the NAPA, and the BCCSAP all suffer from inadequate execution and follow-up. Too often, policy efforts aim at formulating master plans rather than at creating flexible planning and implementation procedures that can be adapted to changing situations and priorities based on performance monitoring and continuous feedback from stakeholders.

Practice and experience developed over the years suggest that successful ICZM strategies should

- be in accord with nationally accepted criteria for the development of the coastal zone, taking into account poverty alleviation and economic growth, environmental quality, empowerment of local communities and local participation in planning and implementation, disaster preparedness and mitigation, and international cooperation;
- stimulate and facilitate operational interactions among agencies needed to implement sector policies (e.g., land use planning, agriculture and irrigation, fisheries, forestry, water supply and sanitation, industrialization, and tourism);
- create a national platform to facilitate implementation and monitor corresponding progress.

The key to ICZM is to empower timely decision making at the appropriate levels, providing the flexibility to respond to evolving circumstances and cope with persistent uncertainties. When this has been achieved, the great range of opportunities offered by the coastal zone—including marine resources; the accretion of new land, oil and gas resources; the

potential productivity of mangroves and other coastal ecosystems; and tourism and leisure activities—can be judiciously developed. The major challenge to ICZM is to realize these potentials while mitigating or adapting to vulnerabilities through a process that enhances the livelihoods of the inhabitants and provides communities with avenues for input to, and support from, external institutions.

For Bangladesh, the political institutional barrier is the largest obstacle to overcome, requiring awareness and capacity building at the highest political and policy levels. Increased funding would help, but must be channeled toward the most climate-vulnerable communities through appropriate structures to maintain accountability and transparency. A coherent, dynamic national action plan is needed to prioritize adaptation measures, regularly review implementation, and eventually revise and reprioritize policy actions. Such a plan should facilitate more comprehensive evaluation of adaptation options, providing a framework for assessing social and environmental as well as economic costs and benefits across all relevant sectors and stakeholders. Formulating this plan would force decision makers to think beyond the short-term, politically expedient horizons of three to five years. A shift to long-term planning will enable the long-term effects of climate change—with predicted rises in sea levels, possible increases in the frequency of major storms, and changes in rainfall patterns over the whole Ganges-Brahmaputra basin—to be taken into account.

Case Study: Sri Lanka

Sri Lanka is an island country with some 2,825 kilometers of coastline and 500,750 square kilometers of surrounding waters in its Exclusive Economic Zone. Given the island's relatively small land area of 65,000 square kilometers, the entire population lives within 100 kilometers of the coast.[20] The coastal zone consists of diverse shoreline and near-shore habitats and an important resource base in the marine environment surrounding the island. In their natural state, these ecosystems not only support marine life but also provide a buffer against the erosive forces of the ocean. The physical and ecological characteristics of many of Sri Lanka's coastal ecosystems—particularly the lagoons—make them susceptible to degradation. They lack resilience and have a low threshold for irreversible damage. Once degradation exceeds this point, rehabilitation becomes prohibitively expensive or environmentally impossible. Population growth has increased human settlements and raised the development demands on coastal zone resources, augmenting the stresses on these unique ecosystems.

To control unregulated development of coastal areas, the government has put a number of regulations and policies in place. The first steps in this direction were taken in 1978 when responsibility for coastal conservation was assigned to a separate Coast Conservation Division within the Ministry of Fisheries; this division was upgraded a few years later to become a government department. Parliament passed the country's first Coast Conservation Act in

1981. This act, which became operational in 1983, shifted policy emphasis from coastal *protection* to coastal zone *management*. To best enable the Coast Conservation Department's effective control, the act provides a very narrow geographic definition of the coastal zone.

Coastal Zone Management

As required by the Coast Conservation Act, the first national coastal zone management plan (CZMP) was formulated and approved by the government in 1990; full responsibility for the plan's implementation was assigned to the Coast Conservation Department. The CZMP addressed the problems of erosion, exacerbated by human activities such as beach and river sand mining, collection of coral, and removal of coastal vegetation; loss and degradation of natural coastal habitats; and loss and degradation of archaeological, historical, religious, and cultural sites and of recreational and scenic areas. It described the nature, scope, severity, and causes associated with each of these problems and identified objectives and policies for each, along with specific management techniques and implementing actions in the areas of development, research, coordination, education, planning, and policy development.

The CZMP is legislatively required to be revised every four years to incorporate emerging challenges and current and projected development trends for refining policies and guidelines. Since its inception, the plan has evolved to include greater levels of community participation, particularly through the introduction of special area management in the early 1990s in recognition of the need for locally based collaborative management between residents and government departments. Formally incorporated into the 1997 CZMP revision, special area management is a practical strategy for increasing community participation in resource management within a relatively small geographic area.[21] Its purpose is to address problems that can arise from the accumulated impact of hundreds of individual resource use decisions both in and outside the narrowly defined coastal zone.[22] New focuses in more recent planning include the reduction of coastal water pollution as increasing urbanization, industrialization, and irrigation, coupled with inadequate waste management and treatment, are threatening the functioning of lagoons, estuaries, and marine coastal waters as well as livelihoods.

Policy Challenges

Although Sri Lanka is one of the few island states to have fully developed and implemented a CZMP on a national scale, its existing coastal policies and regulations suffer from numerous shortcomings. Several factors contribute to this lack of success, including communication problems, with many stakeholders being unaware of the regulations; and a lack of clarity over responsibilities shared among different levels of government. Most

importantly, however, there is a lack of consistent application and enforcement. Often, regulations seem to be implemented selectively when they affect economically weak actors such as fishermen. One measure that has received considerable scrutiny in this regard is the vulnerability zoning or "100-meter rule" enacted following the December 2004 tsunami. To provide a buffer against the recurrence of such catastrophes, new construction was forbidden within 100 meters of the mean sea level. Though well intentioned, this regulation had the perverse result of dispossessing many poor coastal residents and prohibiting them from rebuilding on their land, while effectively exempting many privileged actors such as tourist hotels. Many experts question whether such blanket rules applied across all coastal communities are practicable or effective. A better option may be to base such zoning regulations on a coastal vulnerability index that takes into account variable coastal geomorphology as well as the size and density of human settlements. The main challenge is to ensure compliance. In this regard, economic instruments are needed that provide the correct incentives. Another consideration is whether implementation of more place-specific coastal regulations can be devolved to local governments. Decentralization in resource management is an important trend worldwide, but there are concerns about whether local authorities can manage delicate coastal ecosystems of national or global importance.

Implementing the CZMP has imposed major challenges and constraints on government authorities. Significant environmental degradation of many coasts had already occurred by the time the plan was enacted. Government authorities had to educate and convince coastal populations of the causes of the degradation and the need for some measure of regulation of development activity. A lack of funding for implementation remains a major impediment, while strong and often conflicting pressures for exploiting the coastal region persist, with crucial economic and social implications.

Thus, coastal erosion continues to be a severe problem in Sri Lanka which will only be aggravated by climate change and sea level rise. In economic terms, the public and private costs of coastal erosion are enormous. Erosion has already led to damage or loss of infrastructure, undermining roads and rail track; loss or degradation of valuable land; and the disruption of fishing, recreation, and other activities. The Coast Conservation Department has committed substantial funding over the years to erect coastal defense structures. These have sheltered specific areas but contributed little to the overall protection of the coastline. Much less effort has been directed toward reducing activities that contribute to coastal erosion, particularly through education or creation of other employment options. In the limited locations where efforts have been made to stop shell and coral mining, for example, they have had serious negative impacts on household welfare, primarily because of the failure to provide meaningful alternative income-generating activities.

Experience gained in coastal zone management in Sri Lanka during the past decade and more has shown that approaches to resource management focused on regulation alone tend

to alienate the affected residents. Collaborative efforts on the part of government agencies, NGOs, and local communities are needed to address the root causes of environmental degradation in the coastal zone. Local communities can be organized to manage their natural resources only if they perceive that they will derive tangible benefits from so doing. Policy and decision making must be adopted to accommodate their participation and inputs.

Along these lines, there is now increasing demand for the Coast Conservation Department to transform itself from primarily a regulatory agency to a service-oriented organization. The department should provide the leadership, coordination, technical assistance, and training needed for successful implementation of a scientifically based coastal planning and management strategy. Such an expanded agency must become more proactive in its approach to coastal zone management to cover a wider area and scope of coastal-related activities and facilitate locally based planning and implementation efforts. As many responses to sea level rise are very similar to those required to address existing coastal zone management problems, such a framework would serve Sri Lanka well in adapting to global climate change.

Conclusion and Recommendations

Adaptation to climate change and sea level rise is especially critical for countries such as Sri Lanka and Bangladesh. Coastal industries and infrastructures (e.g., ports, communication networks, tourist facilities) and coastal ecologies and ecosystem services (e.g., fisheries, wetlands, barrier islands) represent important assets not only for coastal communities but for all who count on these resources. Despite the vulnerability of coastal areas, a number of measures can be taken to meet the challenges of climate change and sea level rise. Analyses of coastal vulnerabilities and responses in Sri Lanka and Bangladesh suggest the following recommendations.

1. Effective institutional arrangements must foster consistent coordination and communication on climate change, sea level rise, and coastal management aspects.
   - Special institutions should be established to handle coastal zone problems and possible solutions related to climate change and sea level rise. These institutions can be mandated to implement ICZM/CZP with support from relevant government agencies and NGOs.
   - Both government agencies and NGOs should work in a collaborative and integrated manner. Lack of coordination between various sectors is now the major hurdle in the path of mitigation and adaptation to climate change and development.

2. Climate change should be integrated into the development planning and design process.

- All present and future development projects should include climate change and sea level rise issues in their planning and design.

3. Resources should be devoted to implement climate change projects at the grassroots level.
   - Special funds need to be allocated to climate change and sea level rise adaptation projects in the coastal regions.
   - A separate fund should be established to address climate change–related impacts on the implementation of development projects in the coastal areas.

4. Climate change policies should support sustainable development.
   - Both adaptation and mitigation measures are needed to support sustainable development in coastal regions.
   - Pro-poor adaptation requires pro-poor governance at the grassroots level.
   - Women and children comprise the most vulnerable sectors of the population to sea level rise, so their needs merit special consideration in any sustainable development policy.

5. Awareness of climate change issues must be increased at policy and community levels.
   - Raising the level of awareness is crucial for proper design and implementation of projects and programs in the coastal areas.

6. In-depth research is needed on different sectors including agriculture, forestry, water, and health, as well as indigenous knowledge and coping mechanisms.
   - Measures should be put in place to increase biodiversity in agriculture and fisheries and to promote indigenous varieties of seed production.
   - Use of saline-tolerant crop varieties should be increased in the coastal regions.
   - Deforestation should be halted, and reforestation and afforestation encouraged, in coastal areas.
   - Research on specific health hazards to specific climate parameters is critical.

7. Government agencies, international organizations, and NGOs should collaborate on climate issues.
   - Policy actors and stakeholders should share information and experiences to draw lessons for best practices.
   - Effective networking, lobbying, and policy and advocacy at national, regional, and international levels are required.

Notes

1. Susmita Dasgupta et al., *The Impact of Sea Level Rise on Developing Countries: A Comparative Analysis*, Policy Research Working Paper 4136 (Washington, DC: World Bank, 2007).
2. Ranaa Haider et al., *Cyclone '91: An Environmental and Perceptional Study* (Dhaka: Bangladesh Centre for Advanced Studies, 1991).
3. World Bank, "Water in South Asia" (2010), http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/SOUTHASIAEXT/0,,contentMDK:21652275~pagePK:146736~piPK:146830~theSitePK:223547,00.html (accessed March 3, 2010).
4. United Nations Environment Programme (UNEP), *Global Environmental Outlook: Environment for Development* (Nairobi: UNEP, 2007).
5. P. Lemke et al., "Observations: Changes in Snow, Ice and Frozen Ground," in S. Solomon et al., eds., *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2007).
6. Keith R. Thompson et al., "Suppressing bias and drift of coastal circulation models through the assimilation of seasonal climatologies of temperature and salinity," *Continental Shelf Research* 27, no. 9 (2007).
7. A. Atiq Rahman et al., *Risks, Vulnerability and Adaptation in Bangladesh, Human Development Report 2007/2008*, Occasional Paper 2007/13 (New York: United Nations Development Programme, 2007).
8. Robert J. Nicholls et al., "Coastal Systems and Low-Lying Areas," in M. L. Parry et al., eds., *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2007).
9. Catherine P. McMullen and Jason Jabbour, eds., *Climate Change 2009 Science Compendium* (Nairobi: United Nations Environment Programme, 2009).
10. B. Wouters, D. Chambers, and E. J. O. Schrama, "GRACE observes small-scale mass loss in Greenland," *Geophysical Research Letters* 35 (2008).
11. International Labour Organization (ILO), "Cyclone Sidr: Preliminary Assessment of the Impact on Decent Employment and Proposed Recovery Strategy" (Geneva: ILO, 2008).
12. Neelesh Misra, "Weary survivors of cyclone ready for the worst," *Toronto Star*, November 6, 1999; BAPS Charities, "1999 Supercyclone of Orissa," www.bapscharities.org/services/disaster/1990/1999supercyclone.htm (accessed March 3, 2010).
13. R. V. Cruz et al., "Asia," in M. L. Parry et al., eds., *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2007).
14. M. R. Islam, ed., *Where Land Meets the Sea: A Profile of the Coastal Zone of Bangladesh* (Dhaka: University Press Limited, 2004).
15. Z. G. Huang and X. D. Xie, *Sea Level Changes in Guangdong and Its Impacts and Strategies* (Guangzhou, China: Guangdong Science and Technology Press, 2000).
16. R. Wassmann et al., "Sea level rise affecting the Vietnamese Mekong Delta: water elevation in the flood season and implications for rice production," *Climatic Change* 66, nos. 1–2 (2004); Nicholas Stern, *The Economics of Climate Change: The Stern Review* (Cambridge: Cambridge University Press, 2007).
17. India Resource Center, "Climate Change and the Indian Subcontinent" (2002), www.indiaresource.org/issues/energycc/2003/clmateindiansubcont.html (accessed March 3, 2010).
18. William Hare, *Assessment of Knowledge on Impacts of Climate Change—Contribution to the Specification of Article 2 of the UNFCCC: Impacts on Ecosystems, Food Production, Water and Socio-economic Systems* (Berlin: German Advisory Council on Global Change, 2003).
19. See also International Monetary Fund (IMF), "Bangladesh Poverty Reduction Strategy Paper," IMF Country Report No. 05/410 (IMF, 2005).
20. World Resources Institute (WRI), *Earth Trends Country Profiles, Coastal and Marine Ecosystems—Sri Lanka* (Washington, DC: WRI, 2003), http://earthtrends.wri.org/pdf_library/country_profiles/coa_cou_144.pdf (accessed March 3, 2010).
21. K. Lowry et al., *Special Area Management Interim Assessment Report* (Colombo, Sri Lanka: Coast Conservation Department and USAID, 1997).
22. Coast Conservation Department, Part I Sec (I) Gazette Extraordinary of the Democratic Socialist Republic of Sri Lanka 2006, p. 1, www.coastal.gov.lk/czmp english.pdf (accessed March 3, 2010).

Impacts and Implications of Climate Change for the Coastal Zones of Egypt

Mohamed El Raey

Egypt is considered one of the countries most vulnerable to the potential impacts of climate change. High population density, high population growth, and the rapid spread of unplanned urbanization place considerable pressures on the country's land and water resources. Egypt already suffers from low technical capacity and low community resilience to cope with extreme weather events. Global warming is expected to further exacerbate water shortages in Egypt's arid to semiarid environment and lead to a rise in both heat waves and the severity and frequency of sand and dust storms.

Climate change will affect all sectors of development in Egypt, but particularly water supplies, coastal and agricultural resources, tourism, and public health. Downscaled General Circulation Models differ as to the projected increase or decrease of the Nile water budget, but the Nile's flow is known to be particularly sensitive to changes in temperature and precipitation in the upstream catchment regions that feed the river. The Nile Delta region is also highly vulnerable to inundation and saltwater intrusion from expected sea level rise.

Tourism and agriculture are sensitive to changes in temperature and the frequency of extreme events and heat waves. Both sectors contribute significantly to Egypt's economy. Tourism currently represents 11.3 percent of Egypt's GDP, 40 percent of total noncommodity exports, and 19.3 percent of foreign currency revenues. Even though Egypt does not produce enough food to feed its population, the agricultural sector in Egypt accounts for about 14.8 percent of GDP and about 30 percent of commodity exports, which makes it a major revenue generator. Of Egypt's overall labor force, 35 percent work in the agricultural sector, mostly in the Nile Delta region.[1]

This paper describes prevailing conditions in the coastal zones of Egypt and details the contributions of these regions to the national economy. It surveys coastal vulnerabilities to the potential impacts of climate change and assesses the risks to Egypt's economic and social well-being. Finally, it considers mitigation measures in progress and discusses the institutional systems necessary for the government and the private sector to respond proactively to the looming adaptation challenge.

The Coastal Zone of Egypt: Resources and Problems

Egyptian coasts extend over 3,500 kilometers, with one-third of this distance running along the Mediterranean Sea from Rafeh Town in the east to Salloum Town in the west, and two-thirds along the Red Sea and the coasts of the Sinai Peninsula. An estimated 53 percent of Egypt's population lives within 100 kilometers of the coast. Egypt's territorial area and claimed Exclusive Economic Zone represent about 9 percent of that of the Middle East and North Africa. In addition, Egypt has a large number of inland lakes, the largest of which are the freshwater Lake Nasser and the saline Lake Qarun in Fayyoum. The coastal zone is home to several highly populated economic centers, such as the cities of Alexandria, Damietta, Hurghada, Port Said, Suez, and Sharm El Sheikh. Many industrial activities, including petroleum and chemical production, and important tourism centers are located along the coasts. Trading and transportation networks and a large number of harbors are also found on the coasts. The coastal zone is an important source for fisheries, providing income and food security. Egypt's overall annual production of fish, according to 2004 statistics, is about 875,990 tons, of which 116,560 tons (13.3 percent of the overall production) are from the coastal waters.[2]

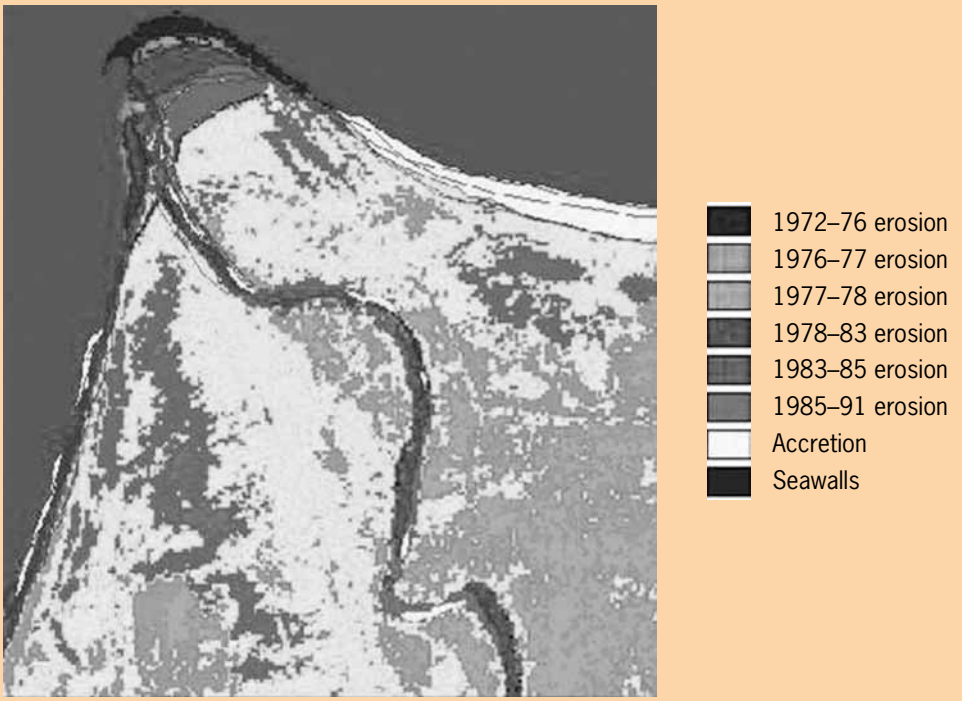
The Mediterranean Coastal Zone

The Mediterranean coastal shoreline of Egypt includes five large lakes, which constitute about 25 percent of the total wetlands in the Mediterranean region. This coastal zone has a large number of economic and industrial centers, as well as important beaches and tourist resorts. Precipitation along the Mediterranean coast varies between 130 and 170 millimeters yearly and decreases gradually to the south. The tidal range is about 30 to 40 centimeters.[3]

The Mediterranean coastal zone suffers from a high rate of population growth, land subsidence in the Delta region, excessive erosion rates (figure 1), saltwater intrusion, soil salinization, land use interference, ecosystem pollution and degradation, and lack of appropriate institutional management systems.

The Mediterranean coastal zone is the site of Egypt's second largest city, Alexandria, which is the country's main harbor. Located on the western side of the Nile Delta, the city sits partly on low-elevation land. Alexandria is home to about 40 percent of the country's industrial capacity, in addition to being a prominent summer resort. Other large cities in the northern low-lying Delta region include Rosetta and Damietta. Port Said is an important regional trading center on the Suez Canal to the eastern side of the delta. The coastal zone of the Nile Delta also has many small towns and villages with major populations of fishermen.

Figure 1: Overlaid Satellite Imagery of the Rosetta Promontory, Northwestern Nile Delta Coast, over 40 Years, Indicating Successive Erosion



Source: M. El Raey, S. M. Nasr, M. M. El Hattab, and O. E. Frihy, "Change Detection of Rosetta Promontory Over the Last Forty Years," *International Journal of Remote Sensing* 16, no. 5 (1995).

Note: Depicts Landsat MSS data for 1972, 1976, 1977, 1978, 1983, 1985, and 1991.

The Red Sea Coastal Zone

The coastal zone of the Red Sea on the Egyptian side is generally narrow because a mountain chain runs relatively close to the shoreline. The coast is composed of a large number of embayments, small gulfs, and small beaches. Fragmented and extended coral reef communities, with their rich marine life, extend over large areas of the coast. The tidal range varies between 110 and 130 centimeters.

The population is concentrated in a number of cities along the coast and a few scattered villages in between them. In the north, the Suez Canal connects the Red Sea with the Mediterranean, providing a vital international waterway and important source of income to Egypt. Farther south, the area has a large number of well-known diving sites because of its rich and highly diversified coral and mangrove communities. Major resort cities such as Dhahab, Hurghada, Nuweiba, and Sharm on the Red Sea employ a significant portion of the local population. Indeed, tourism along the coastal zone of Sinai and eastern Egypt on the

Red Sea accounts for a substantial part of Egypt's GNP and represents about 90 percent of the country's total income from tourism.[4]

The Red Sea coast has very limited freshwater resources as a result of its geographical location in the arid subtropical zone. The region also suffers from increasing habitat loss due to growing unplanned urbanization, pollution, coastal land filling, flash flooding, and the negative effects of tourism. The impacts of climate change on the Red Sea's world-famous coral communities include coral bleaching from rising seawater temperatures, loss of habitats, and loss of biodiversity, which can be expected to cause declines in tourism.[5] Egypt's lack of institutional capabilities to monitor and control these pressures will further exacerbate the impacts.

The Nile Delta Coastal Zone

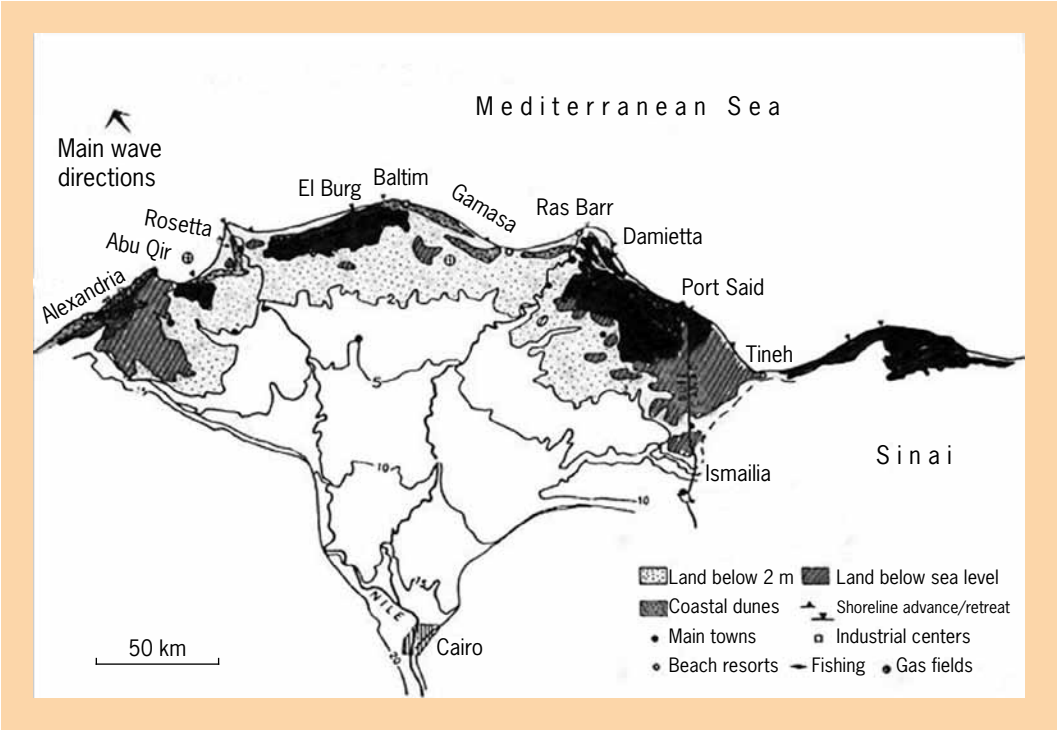
The Nile Delta region in the Mediterranean coastal zone represents the major industrial, agricultural, and economic resource of the country. It is home to over 50 percent of Egypt's population of 80 million and to about 70 percent of the nation's industrial and commercial activities.[6] The region is characterized by relatively low land elevation, which leaves it severely exposed to rising sea levels. In addition, it suffers from local land subsidence, compounding the effects of rising seas. Some estimates indicate that the northern delta region is subsiding at a rate that varies from about 2 millimeters annually at Alexandria to about 2.5 millimeters annually at Port Said.[7]

The Nile Delta shoreline extends from Alexandria in the west to Port Said in the east, with a total length of about 240 kilometers. This zone consists of sandy and silty shores of greatly varying lateral configurations, depending on where the old branches of the Nile have had their outlets. The coastline has two promontories, Rosetta and Damietta, and three brackish lakes—Idku, Burullus, and Manzala—are connected to the sea. There are five harbors located on the coast: Idku, New Burullus, and El Gamil are for fishing; and Damietta and Port Said are commercial ports.

Alexandria and Port Said are the main economic centers of the coastal zone. These cities are vulnerable to sea level rise as a result of the low elevation of adjacent land. Figure 2 illustrates the topography of the delta, showing that a large portion already lies below sea level. The Mohamed Ali Seawall, built in 1830, protects the lowland area southeast of Alexandria against inundation by water from Abu Qir Bay, and narrow strips of elevated land protect the southern area of Port Said. Many smaller towns and villages on the northern coast are also vulnerable to sea level rise and saltwater intrusion.

Like other deltaic regions worldwide, the Nile Delta is subject to shoreline changes resulting from erosion and accretion, subsidence, and sea level rise resulting from climate change. Since early studies by Sestini, various analyses have evaluated the impacts of

Figure 2: Topography of the Nile Delta Region



Source: M. El Raey, A. Nasser Hassan, R. J. Nicholls, and A. C. de la Vega-Leinert, eds., *Proceedings of SURVAS Expert Workshop on African Vulnerability and Adaptation to Impacts of Accelerated Sea-Level Rise (ASLR)*, Cairo, November 5–8, 2000.

climate change on the Nile Delta using various sea level rise scenarios (figure 3), concluding that a large percentage of the Nile Delta is directly vulnerable to inundation and saltwater intrusion that could drive millions from their homes.[8]

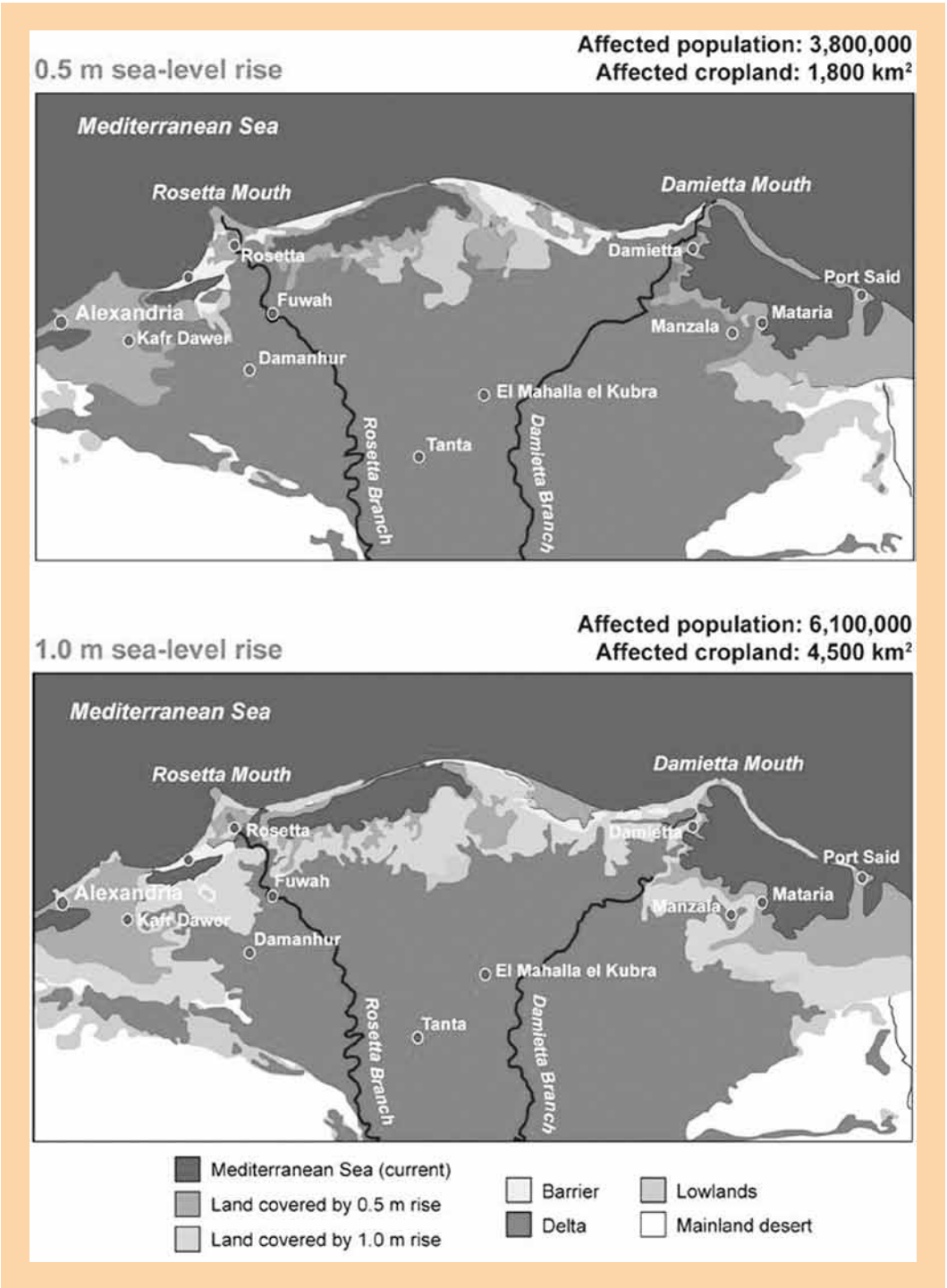
Consequences of Climate Change for Coastal Areas

Climate change will have serious repercussions for all sectors of development in the country. The most important general consequences include impacts on the water resources of the Nile River, agricultural productivity, and coastal resources and tourism.

Sea Level Rise

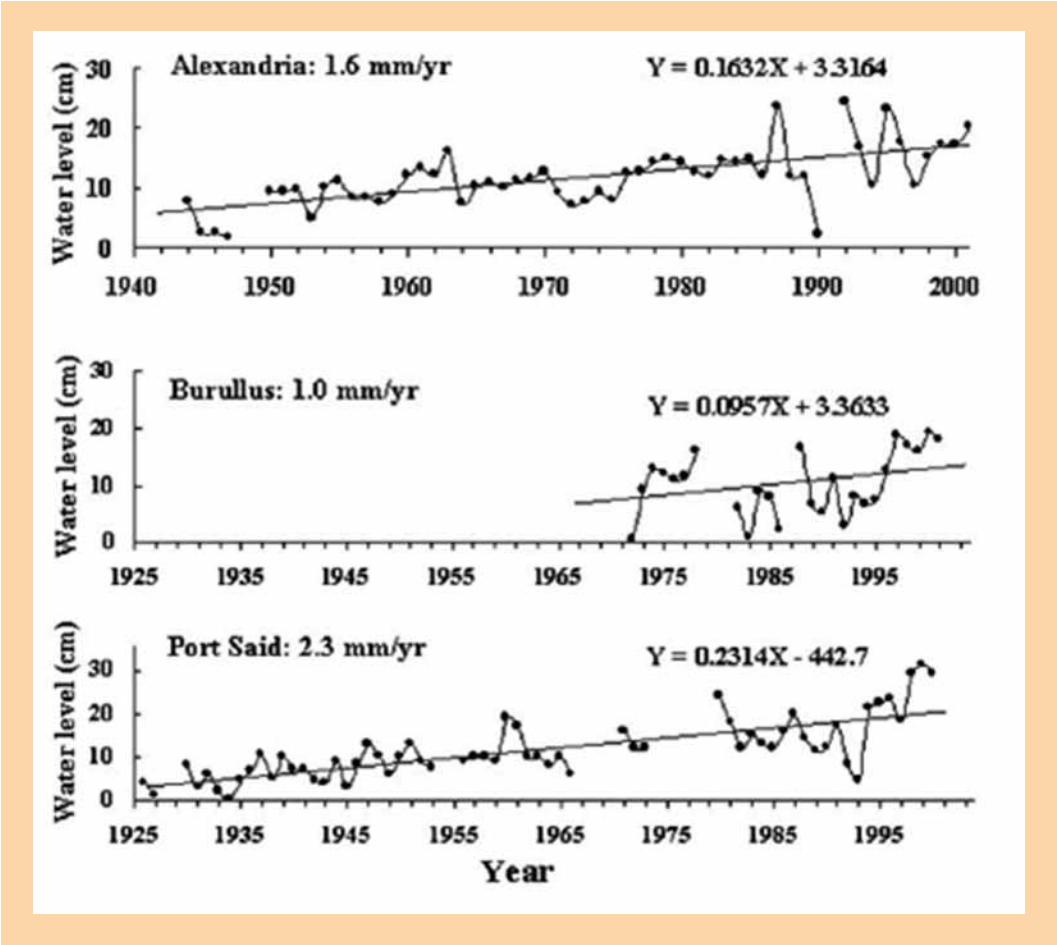
Results from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report indicate that a global sea level rise of 18 to 59 centimeters is expected by the end of this century.[9] In Egypt, local land subsidence in the Nile Delta would exacerbate the impacts of rising seas. Figure 4 represents the observed time variation of sea level and indicates the rates of land subsidence of the Nile Delta calculated by one study.

Figure 3: Expected Impacts of Sea Level Rise for Two Scenarios on the Nile Delta Region



Source: D. M. FitzGerald, M. S. Fenster, B. A. Argow, and I. V. Buynevich, "Coastal Impacts Due to Sea-Level Rise," *Annual Review of Earth and Planetary Sciences* 36 (2008).

Figure 4: Land Subsidence Rates as Estimated at Alexandria, Burullus, and Port Said



Source: O. Frihy, "The Nile Delta-Alexandria Coast: Vulnerability to Sea-Level Rise, Consequences and Adaptation," *Mitigation and Adaptation Strategies for Global Change* 8, no. 2 (2003).

The study area includes the entire coastal zone of the Nile Delta between Alexandria and Port Said. The inland boundary of the study area extends from the shoreline to the contour line of 3 meters above mean sea level. Tide gauge measurements at Alexandria, Burullus, and Port Said have been collected and statistically analyzed to estimate land subsidence over the last three decades at each of these regions. Results indicate that sea level rise varies from one region to another because of the difference in the land subsidence effect. Observed measures reveal that land subsidence is at least 1.6 millimeters per year at Alexandria and 1.0 millimeter per year at Burullus, while at Port Said the value is 2.3 millimeters per year.[10] These local estimates should be added to the IPCC global estimates over the current century to obtain final estimates of sea level rise.

The potential impacts of sea level rise will affect many sectors of development, including tourism, cultural and natural heritage, agricultural quality and productivity, freshwater availability, public health, and socioeconomic welfare.

Increased Soil Salinity from Saltwater Intrusion

Sea level rise is expected to exacerbate intrusion of saline water into the fresh groundwater aquifers in the coastal zone. Increasing temperature is also expected to enhance soil evaporation, hence increasing soil salinity. One early soil survey indicated that the amount of salt-affected soil relative to total cultivated land was 60 percent in the Lower Delta, 25 percent in the Middle Delta, 20 percent in the Upper Delta and Middle Egypt, and 25 percent in Upper Egypt.[11] A later survey concluded that almost 35 percent of the agricultural lands in Egypt suffer from salinity.[12] The current situation threatens not only agricultural sustainability but the entire ecological system as well.[13]

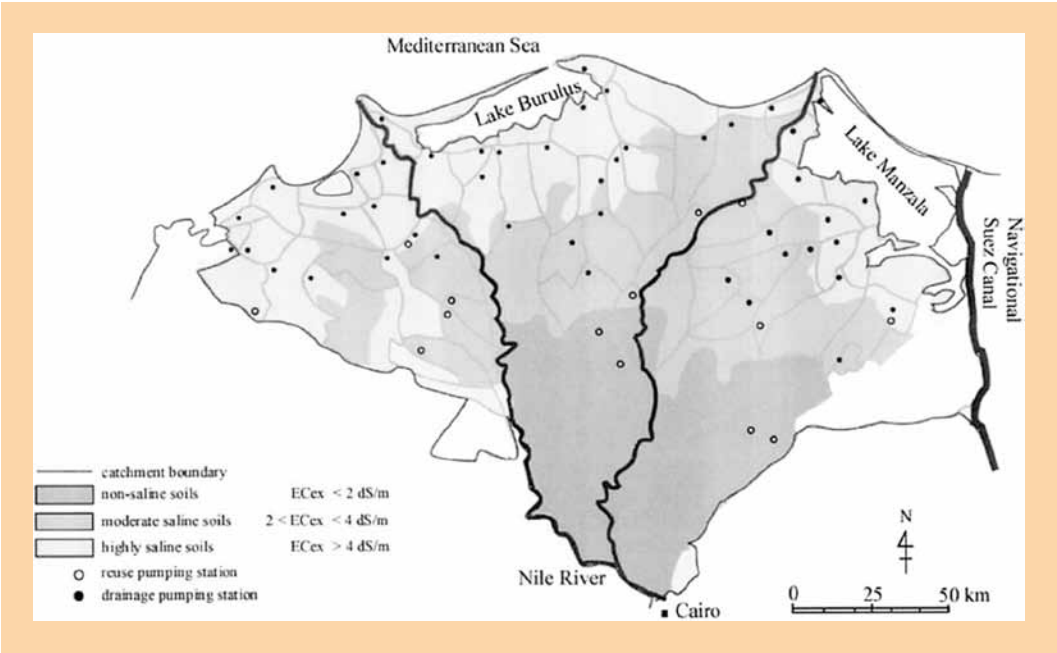
The majority of the salt-affected lands are in the Lower Nile, in the northern part of the delta, especially in low areas to the southeast of Alexandria. In the Mediterranean coastal plains and lower delta, excessive rates of groundwater withdrawal have resulted in a large drop in the water table. Consequently, seawater has intruded into the aquifers. The main reasons for soil salinity in these areas include seawater intrusion, irrigation with low-quality (saline) water, and inadequate field drainage. Figure 5 presents a classification of salt-affected soils in the Nile Delta.

Saltwater intrusion and its potential impacts on groundwater quality in the Nile Delta cannot be overlooked, especially in lowland areas along the Mediterranean coast. In addition to waterlogging and water-bogging problems, it is expected that increasing soil salinization will lead to deterioration of crop quality and lower productivity, which will have significant socioeconomic consequences and serious implications for food security and public health.

Extreme Events: Droughts, Heat Waves, and Storm Surges

The Middle East and North African countries are subject to a number of extreme events that recur more or less on seasonal cycles. Egypt is no exception. Sandstorms and flash floods occur regularly across Egypt. In recent years, severe sandstorms, dense haze, and flooding have occurred with increased severity and frequency.[14] They have had negative socioeconomic impacts on almost all sectors, including agricultural productivity, livestock, public health, the environment, and tourism. The causes of these events are linked to anomalies in global surface temperature, jet stream location and strength, and the location of the Intertropical Convergence Zone (ITCZ). Most of these anomalies are affected by global warming, and the increase in sandstorms, haze, thunderstorms, and flash flooding phenomena in Egypt is taken as an indicator of climatic changes.[15]

Figure 5: Soil Salinity Distribution over the Nile Delta



Source: T. H. S. Kotb, T. Watanabe, Y. Ogino, and K. Tanji, "Soil Salinization in the Nile Delta and Related Policy Issues in Egypt," *Agricultural Water Management* 43, no. 2 (2000).

Flooding and Storms

Flash floods are common in some areas of the coastal zone of Egypt, especially on the Red Sea and Sinai coasts. Flooding events normally prevail when rainfall intensity exceeds 1 millimeter per minute and the duration exceeds 10 minutes. In Port Said on the eastern coast, thunderstorm days rose from 0 to 18 to 41 days in the last 10 years. The increased number of thunderstorm days during the past decade compared with the two previous decades could be an indicator of the extensive northward intrusion of the southerly warm air, or the wide northward oscillations of the ITCZ influenced by global warming.[16]

The Mediterranean coast of Egypt experienced a successive increase in the amount of annual rainfall during the last three decades. The mean trend over the area is 0.76 millimeters per year. Rainfall has increased over the western coast of Egypt by up to 3 millimeters per year. The changes in the general circulation of the atmosphere and effects of some incidents, such as the North Atlantic Oscillation phenomenon, seem responsible for this change. Increased intensity and frequency of marine storms will necessarily increase the risks of transportation accidents and health risks in the coastal zone.[17]

Dust Storms

Saharan dust and heat waves are known to have serious effects on agricultural productivity, materials lifetime, and public health. Egypt is subject to severe sandstorms (Khamasin), which persist over a period of about 50 days during the months of March and April, afflicting coastal areas of North Africa (figure 6). Observed increases in the rates and frequencies of dust storms and temperature inversions over the Nile Delta region have resulted in the well-known "black cloud" phenomenon over coastal and noncoastal cities in September and October of each of the past 10 years (figure 7).

Figure 6: Trajectory of Khamasin Sandstorms along the North African Coast

Source: A. M. Abed, M. Al Kuisia, and H. A. Khaira, "Characterization of the Khamaseen (Spring) Dust in Jordan," *Atmospheric Environment* 43, no. 18 (2009).

Figure 7: Saharan Dust over the Eastern Mediterranean

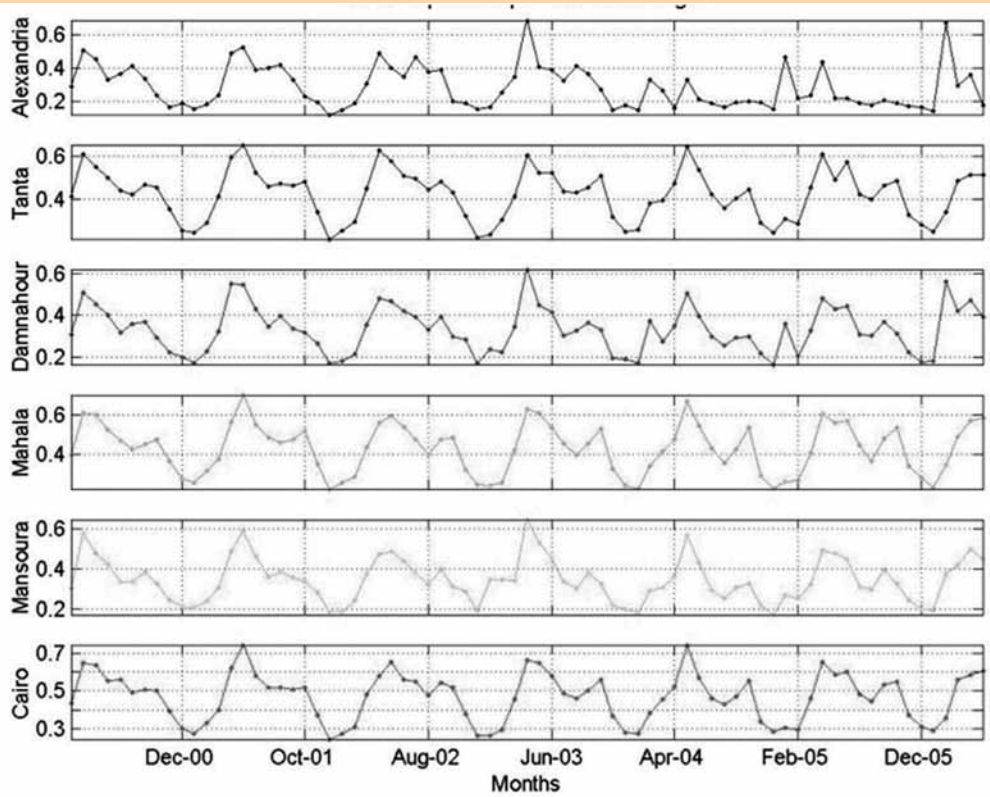
Source: Jeff Schmaltz, MODIS Rapid Response Team, National Aeronautics and Space Administration/Goddard Space Flight Center (2003).

Figure 8 presents a time series of the aerosol optical depth of the atmosphere as observed by MODIS satellite from 2000 to 2005 over cities in the Nile Delta region. In addition to the high peak of April due to the Khamasin of each year, a buildup of a smaller peak in September and October of each year is also observed. This has been attributed to temperature inversions which now prevail over the region.

Change of Acidity and Circulation Patterns in Coastal Waters

It is expected that increased water temperature, evaporation, and increasing levels of carbon dioxide absorbed into the sea will lead to changes in ocean acidity and the distribution of water salinity—changes likely to affect marine life and coral reefs. It is also expected that the coastal circulation patterns will change because of changes in temperatures, wind speed, and currents in the coastal zone. Altered coastal circulation

Figure 8: Aerosol Depth Variation as Observed by MODIS Satellite over Cairo and the Nile Delta Coastal Cities



Source: H. El Askary and M. El Raey, in preparation.

patterns will likely cause changes in fisheries catch, coastal recreation areas, and coastal navigation.

Potential Socioeconomic Risks of Climate Impacts

Tourism

Tourism is an important resource in Egypt. Coastal and marine ecosystems are the *raison d'être* for recreational tourism in the Red Sea and Sinai Peninsula resorts. In addition to international tourism, the coastal cities of Alexandria, Bulteem, Gamasa, Port Said, and Ras El Bar are popular destinations for local tourists, and many middle- and low-income Egyptians spend their summers in these towns.

The impact of climate change on coastal tourism is considered serious. Sea level rise threatens the infrastructure on which coastal tourism depends. Global warming also risks

diminishing the aesthetic quality of the marine environment that attracts vacationers. Bleaching could destroy the coral reefs that draw visitors for diving and snorkeling. Tourism development itself often damages these already fragile ecosystems, overwhelming their limited carrying capacities and abilities to regenerate.

Coral Reefs

Coral reefs have great environmental and economic value. They provide several ecosystem services, among them protecting the coastline, encouraging biodiversity, and providing fish breeding grounds and habitat. In this latter role, corals reefs support both large-scale commercial fisheries and smaller-scale artisanal fishing. They also provide tourists with opportunities for diving, snorkeling, and recreational fishing. In Egypt, coral reefs extend along most of the southern part of Sinai, particularly at Ras El Tor and the area between Ras Nasrani to Ras Mohammed. In the Red Sea, there are important reefs around Hurghada and near Gebal Elba, at Egypt's extreme southern border.

Human activities along these coastlines are highly varied, with some areas of intensive use at risk for considerable reef degradation. Some remote reefs remain relatively inaccessible and largely unharmed by humans. Egypt currently has five marine protected areas, established around the Sinai Peninsula and Red Sea coasts at sites where recreational scuba diving is common and the threat from anchor and flipper damage is high. Seven additional areas, including coral reefs, have been proposed to the government for protection status.

Coral reefs are among the most vulnerable ecosystems to climate change. Corals are especially sensitive to elevated sea surface temperatures. When physiologically stressed, corals may lose much symbiotic algae, which supply nutrients and colors. In this stage, corals appear white and are considered "bleached." Corals can recover from short-term bleaching, but prolonged bleaching can cause irreversible damage and subsequent mortality.

Monuments and Cultural Heritage

Cultural tourism in Egypt depends on the beauty and preservation of ancient monuments and historic sites. Climate changes may affect these cultural treasures in sometimes subtle ways. The most fragile elements of the country's heritage are the wall paintings in ancient tombs and temples. Strong shifts in temperature and in the moisture content of the air—the result in part of climate change—may degrade the paintings' stability over time. More dramatically, climate change affects the Nile and the water cycle. This in turn may affect cruising activities on the river, and rising groundwater tables and storm surges may damage cultural sites in coastal areas.

Public Health

Global climate change is expected to have multiple adverse impacts on human health.[18] More intense and frequent heat waves, for example, are projected to increase the rates of heat stress mortality, particularly for vulnerable populations such as children, the elderly, the infirm, and the poor. Global warming is also expected to alter the prevalence of certain disease vectors. Thus, in coastal regions, waterlogged areas in the lowlands could provide increasing breeding grounds for mosquitos carrying malaria. Climate impacts on agriculture will also likely have considerable consequences for population nutrition. Comprehensive studies of these potential risks are still lacking for Egypt, largely due to the dearth of data.

Food Security

With a rapidly growing population and limited arable land, Egypt is expected to continue importing most of its food. Table 1 indicates the self-sufficiency ratios for some major food commodities, showing that the country is a major net importer of all important commodities.

Table 1: Self-Sufficiency Ratios for Some Major Food Commodities in Egypt

Commodity	Ratio
Meat	0.84
Sugar	0.61
Vegetable oils	0.15
Cereals	0.60

Source: Food and Agriculture Organization of the United Nations, Economic and Social Development Department, "WTO Agreement on Agriculture: The Implementation Experience," www.fao.org/docrep/005/Y4632E/y4632e06.htm (accessed March 4, 2010).

Note: Data are for 1985–2000.

Numerous studies have been conducted in the agriculture and food areas. Modeling that examined the potential effects of climate change on three field crops—wheat, maize, and cotton—in three main agro-climatological regions projected productivity declines of 15 to 20 percent for wheat and maize. Only cotton is expected to increase by about 15 to 17 percent. Saltwater intrusion is projected to reduce land productivity generally in the Nile Delta region. Declines in fish catches resulting from ecosystem changes in the northern lakes are also expected.[19]

Suez Canal Revenues

Tariffs and fees generated from ships using the Suez Canal constitute a growing source of national income in Egypt. Revenues from the canal reached $4.6 billion in 2007, or about 3 to 4 percent of national GDP, compared with $2 billion in 2002. With the melting of the ice cap over the Northern Arctic, however, a new and shorter route for shipping between Europe and East Asia could open up (figure 9). Shipping cargo via the Arctic route would cut about 4,450 miles off of the voyage from Rotterdam to Yokohama, Japan, for example, compared to passing through the Suez Canal.[20] This alternative route is expected to cause a loss of not less than 20 percent of annual revenue for the Suez Canal.

Figure 9: Potential Alternative Shipping Routes between Europe and East Asia

Source: Stimson Center 2010.

A Vulnerability Hotspot: Climate Risks in the Nile Delta

Because of its high population density and exposure to both land subsidence and accentuated sea level rise, the Nile Delta is regarded by the IPCC as an extreme hotspot of climate vulnerability.[21] To evaluate the risks to the Delta region, a detailed assessment of potential climate impacts on the coastal cities of Alexandria, Marina, Matruh, Port Said, and Rosetta was conducted using remote sensing techniques, field visits, and geographic information systems (GIS).

In Alexandria, for a scenario involving a sea level rise of 0.5 meters over the next century, about 30 percent of the city would be lost to inundation and saltwater intrusion if no countermeasures were taken. For Rosetta, the damages from sea level rise of 0.5 meters would include $2.9 billion in lost land over the next century and could lead to the elimination of a third of the city's jobs. In Port Said, for sea level rise of 0.5 meters, the lost beach area alone would amount to more than $2 billion.

Alexandria

Alexandria is the second largest city in Egypt after Cairo. It is a major tourist attraction for both Egyptians and foreigners. In order to assess vulnerability to potential impacts of sea level rise, remote sensing techniques were used to produce land use maps. These maps were combined with digital elevation models and GIS data to identify the size and location of

vulnerable lowland areas based on three scenarios for sea level rise of 25 centimeters, 50 centimeters, and 1.0 meter. An estimated 45 percent of the population of Alexandria currently lives on land situated below sea level. Tables 2 and 3 show that a sea level rise of 50 centimeters would inundate two-thirds of the city's population, submerge nearly 32 square kilometers of its land area, and displace more than 1.5 million people.

Table 2: Percentage of the Population and Areas of Various Land Uses Currently Below Sea Level and Under Three Scenarios of Sea Level Rise for Alexandria

Sector	Below sea level (%)	% of areas affected under each scenario		
		0.25 m rise	0.5 m rise	1.0 m rise
Population	45.0	60.0	67.0	76.0
Beaches	1.3	11.0	47.8	64.0
Residential	26.2	27.5	39.3	52.0
Industrial	53.9	56.1	65.9	72.2
Services	45.1	55.2	75.9	82.2
Tourism	28.0	31.0	49.0	62.0
Restricted area	20.0	21.0	25.0	27.0
Urban	38.0	44.0	56.0	67.0
Vegetation	55.0	59.0	63.0	75.0
Wetland	47.0	49.0	58.0	98.0
Bare soil	15.0	24.0	29.0	31.0

Source: S. Agrawala, A. Moehner, M. El Raey, D. Conway, M. van Aalst, and M. Hagenstad, *Development and Climate Change in Egypt, Focus on Coastal Resources and the Nile*, Working Party on Global and Structural Policies (Paris: Organisation for Economic Co-operation and Development, 2004).

Table 3: Area Loss, Population Displaced, and Loss of Employment under Different Sea Level Rise Scenarios in Alexandria

Parameter	Sea level rise scenarios (meters)		
	0.18	0.30	0.50
Area loss (km^2)	11.4	19.0	31.7
Population displaced (thousands)	252.0	545.0	1512.0
Loss of employment (total)	32,507.0	70,465.0	195,443.0
Agriculture	1,370.0	3,205.0	8,812.0
Tourism	5,737.0	12,323.0	23,919.0
Industry	24,400.0	54,936.0	151,200.0

Source: Agrawala et al., op. cit.

Port Said

Port Said lies on the Mediterranean at the entrance of the Suez Canal. Manufacturing, transportation, and the residential sector are at the greatest risk from sea level rise. Agriculture is not affected because it is mainly found in the El Dawahy district, which is beyond the areas touched by sea level rise. If sea level rise reaches 50 centimeters, modeling that extrapolates from present population levels and takes into consideration the statistical distribution of employment over various sectors projects that the city would lose almost 7,000 jobs. Table 4 shows physical and socioeconomic losses for a sea level rise of 0.5 meters in the Governorate of Port Said.

Table 4: Physical and Socioeconomic Losses Associated with a 0.5-Meter Sea Level Rise in Port Said

Parameter	El Shark	El Arab	El Monakh	Port Fouad	Total	%	Million US$
Beach area (km^2)	0.426	0.377	7.419	13.039	21.26	1.6	2,126
Urban area (km^2)	0.034	0.044	0.339	0.046	0.46	7.8	92
Industrial area (km^2)	0.015	0.002	0.018	0.016	0.05	12.5	25
Aquacultural area (km^2)	0	0	0	0.024	0.024	0.12	2.4
Transport network (km^2)	10	7	3	3	23	11.7	4.6
Affected population	3,968	16,699	6,503	1,021	28,191	5.3	—
Employment loss	953	4,000	1,558	248	6,759	5.3	—

Source: Agrawala et al., op. cit.

Note: No data are available for El Dawahy.

Responses

Institutional Systems

As early as the 1990s, the Egyptian authorities realized the vulnerability of the country's coastal zone to the potential impacts of climate change. In response, the government has established a National Center for Land Use and a National Committee for Integrated Coastal Zone Management, staffed by selected representatives from various ministries and charged with coordinating and implementing integrated planning among relevant agencies.

In its efforts to upgrade environmental laws and regulations, the National Assembly approved an addition (Law 9/2009) to Environmental Law 4/1994, which enforces Integrated Coastal Zone Management. Similarly, to promote scientific research and technical coordination among concerned authorities and to help disseminate policies and measures

for adaptation, a prime ministerial decree established an institutional capability for climate change adaptation at the Information and Decision Support Center, the think tank for Egypt's cabinet.

Policy Strategies and Challenges

The policy strategies implemented so far concern greenhouse emissions reduction measures and projects under the Clean Development Mechanism (CDM). So far, only very limited policies for adaptation have been undertaken in any of the vulnerable sectors.

Clean Development Mechanism

A designated national authority for CDM has been established with a focal point in Egypt. The national authority has been successful in implementing a large number of CDM energy projects, with the objective of reducing greenhouse gas emissions, conserving energy, and enabling the country to participate in the global emissions trading market. In addition to establishing an institutional framework for CDM and creating a pipeline of CDM projects, the national authority has also conducted information and awareness-raising campaigns and strengthened policymaking capabilities and capacities for public-private partnerships.[22]

Adaptation Measures and Options

Developing the necessary adaptation strategies for Egypt will be a complex process. Adaptation opportunities are site-dependent and selecting the most effective measures necessarily entails multicriteria analysis to assess available technology options, maintenance requirements, environmental impacts, and equity and cost issues. The government will need to shape an integrated adaptation framework and supporting policies and processes to protect the vulnerable areas identified in the current study. As a first step, it should activate the National Integrated Coastal Zone Management Committee initiated several years ago and charge it to formulate and implement a strategic integrated coastal zone management plan.

The following adaptation measures are among those now under way or under consideration by Egyptian authorities:

- Protective structures are being constructed by the Shore Protection Authority at many sites along the Mediterranean.
- Natural sand dune systems constitute an important natural protection. Work by NGOs is in progress to upgrade awareness and protect and repair sand dunes.
- As a first line of defense, the Shore Protection Authority is considering protecting and reinforcing the Mohamed Ali Wall that protects lowland areas south of Abu Qir Bay.

- As the second line of defense, Egyptian authorities are considering reinforcing the embankment of the International Coastal Road (the coastal highway running from Libya to Palestine) to protect the northern zone of the delta. The northern side of the international road could be redesigned as a seawall.
- The banks of Al Salam Canal, which runs to the south of Lake Manzala and provides water to Sinai, sit more than 2 meters above the lake's water level. If the northern banks are properly designed and maintained, they could be used for protection.
- Existing wetlands should be preserved or new ones created to serve as buffers in areas vulnerable to sea level rise in low-lying deltas. Lake Manzala and Lake Burullus are two examples of areas suited for such adaptation processes.

International Support for Adaptation

To date, only limited financing has been made available at the regional and international levels to address climate problems. An infusion of international funds is needed to help countries like Egypt with capacity building and technology transfer for coastal adaptation, protection, and management. Particular issues on which international assistance should focus include the following:

- Developing regional circulation models and fostering "home-grown" model-building capacity (as opposed to importing models developed elsewhere) to enable decision makers to better project, assess, and understand prospective climate changes and risks at scales relevant for national policymaking
- Carrying out vulnerability assessment for potential climate impacts, including extreme events and adaptation strategies
- Testing options for environmentally friendly technologies for protection of the Mediterranean coast in general and low elevation areas in the delta in particular
- Developing public awareness programs targeting stakeholders and officials of the coastal governorates about the impacts of climate change on coastal zones
- Establishing proper observation systems, monitoring networks, and geographic databases of key indicators on sea level rise to support decision making
- Building cooperative approaches and integrated institutional structures to coordinate the efforts of all concerned actors and institutions in Egypt

Conclusions and Recommendations

The coastal zone of Egypt is highly exposed to the potential impacts of climate change. In particular, the Nile Delta region is acutely vulnerable to sea level rise and saltwater intrusion. The potential effects include significant socioeconomic implications, which may involve mass population displacement from the delta. It is therefore necessary to consider

accommodating possible environmental migrants elsewhere in the country and developing employment opportunities in safe areas.

Other vulnerable coastal zones include the Mediterranean and Red Sea, which could suffer considerable damage to coral reef communities, shortages of water resources, loss of biodiversity, and loss of natural and cultural heritage. Such consequences would seriously affect coastal tourism and quality of life in this region. Extreme weather events and increasingly frequent and intense dust storms in the coastal region are expected to detrimentally affect economic productivity, public health, and the quality of life, but their full repercussions are not well understood.

The government and the private sector must be proactive in establishing adaptation policies and measures to minimize potential impacts. These should include establishing institutional coastal monitoring capabilities, enforcing laws and regulations, enacting integrated coastal zone management, and raising awareness of climate risks and adaptation responses.

Notes

1. Egyptian Environmental Affairs Agency (EEAA), *The Arab Republic of Egypt: Initial National Communication on Climate Change. Prepared for the United Nations Framework Convention on Climate Change UNFCCC* (Cairo: EEAA, 1999).
2. EEAA, *Egypt State of the Environment Report 2005* (Cairo: EEAA, 2006), p. 88.
3. EEAA, *National Environmental Action Plan* (Cairo: EEAA, 2001).
4. Heba Handoussa et al., *Egypt Human Development Report 2005* (Cairo: National Planning Institute and United Nations Development Programme, 2006), http://hdr.undp.org/en/reports/nationalreports/arabstates/egypt/egypt_2005_en.pdf.
5. M. Fouda, *Implication of Climate Change on the Coral Reefs of the Red Sea* (Cairo: EEAA, 2001).
6. EEAA, *National Circumstances. Egypt Second National Communication on Climate Change* (Cairo: EEAA, 2009).
7. D. J. Stanley and A. G. Warne, "Nile Delta: recent geological evolution and human impacts," *Science* 260, no. 5108 (1993); O. Frihy, "The Nile Delta-Alexandria coast: vulnerability to sea-level rise, consequences and adaptation," *Mitigation and Adaptation Strategies for Global Change* 8, no. 2 (2003): 115–38.
8. G. Sestini, "Implication of Climatic Changes for the Nile Delta," in L. Jefic, J. D. Milliman, and G. Sestini, eds., *Climate Change and the Mediterranean, Vol. 1. Environmental and Societal Impacts of Climate Changes and Sea Level Rise in the Mediterranean Sea Region* (London: Hodder Arnold, 1993); S. Agrawala, A. Moehner, M. El Raey, D. Conway, M. van Aalst, and M. Hagenstad, *Development and Climate Change in Egypt, Focus on Coastal Resources and the Nile, Working Party on Global and Structural Policies* (Paris: Organisation for Economic Co-operation and Development, 2004); D. M. FitzGerald, M. S. Fenster, B. A. Argow, and I. V. Buynevich, "Coastal Impacts Due to Sea-Level Rise," *Annual Review of Earth and Planetary Sciences* 36 (2008): 601–47).
9. R. B. Alley et al., "Summary for Policymakers," in S. Solomon et al., eds., *Climate Change 2007: The Physical Science Basis*. *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2007), p. 327.
10. Frihy, op. cit.

11. A. Aboukhaled et al., *Research on Crop Water Use, Salt Affected Soils and Drainage in the Arab Republic of Egypt* (Cairo: Food and Agriculture Organization of the United Nations, Near East Regional Office, 1975).

12. Government of the Arab Republic of Egypt, *Environmental Action Plan* (Cairo: Government of the Arab Republic of Egypt, 1992).

13. T. H. S. Kotb, T. Watanabe, Y. Ogino, and K. Tanji, "Soil Salinization in the Nile Delta and Related Policy Issues in Egypt," *Agricultural Water Management* 43, no. 2 (2000): 239–61.

14. EEAA, 2009, op. cit.

15. M. El Shahawy, "Contribution to Egypt Second National Communication," Special Report (New York: United Nations Development Programme, 2009).

16. Ibid.

17. D. Susmita et al., *Sea-Level Rise and Storm Surges; A Comparative Analysis of Impacts in Developing Countries*, Policy Research Working Paper 4901 (Washington, DC: World Bank Development Research Group Environment and Energy Team, 2009).

18. U. Confalonieri et al., "Human Health," in M. L. Parry et al., eds., *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2007).

19. A. F. Abou-Hadid, "Assessment of Impacts, Adaptation and Vulnerability to Climate Change in North Africa: Food Production and Water Resources," Final Report Submitted to Assessments of Impacts and Adaptations to Climate Change (AIACC), Project No. AF 90 (Washington, DC: International START Secretariat, 2006); S. M. El Marsafawy, "Impact of Climate Change on Sunflower Crop Production in Egypt," 2nd International Conference on Water Resources & Arid Environment Proceedings, Riyadh, 2006.

20. Andrew E. Kremer and Andrew C. Revkin, "Arctic shortcut beckons shippers as ice thaws," *New York Times*, September 10, 2009.

21. Robert J. Nicholls et al., "Coastal Systems and Low-Lying Areas," in M. L. Parry et al., eds., *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2007), p. 327.

22. EEAA, 2009, op. cit.

Small Island Developing States: Incubators of Innovative Adaptation and Sustainable Technologies?

Alain De Comarmond and Rolph Payet

Small island developing states (SIDS) form a distinctive group. Spread across the Atlantic, Pacific, and Indian Oceans and the Caribbean and Mediterranean Seas, each island possesses its own unique characteristics, but they all share similar challenges to their development. This was the conclusion of the United Nations General Assembly in 2001 when it recognized

> that within the context of the challenges of development, small island developing States can experience specific problems arising from small size, remoteness, geographical dispersion, vulnerability to natural disasters, fragile ecosystems, constraints on transport and communication, isolation from markets, vulnerability to exogenous economic and financial shocks, limited internal markets, lack of natural resources, limited freshwater supply, heavy dependence on imports and limited commodities, depletion of non-renewable resources and migration.[1]

One strategy to overcome these challenges is to work toward the transfer of appropriate technologies. Indeed, the international community, through such instruments as the 1992 Earth Summit and Agenda 21, has long highlighted technology transfer as a key determinant of sustainable development. SIDS governments have similarly embraced the goal of technology transfer, as reflected in the 1994 Barbados Programme of Action adopted at the First Global Conference on the Sustainable Development of SIDS and its 10-year follow-up report, the 2005 Mauritius Strategy of Implementation.[2] Nevertheless, a 2004 preparatory meeting on the 10-year review of the Barbados Programme of Action implementation noted that although technology transfer in SIDS remains an issue, no separate funding mechanism to support this aim had been made available.[3] Also, regional clearinghouses to enable access to appropriate technologies by SIDS have yet to materialize, leading the Mauritius Strategy of Implementation to reiterate the need to build resilience in SIDS through technology transfer. According to the Organisation for Economic Co-operation and Development (OECD), investments in R&D are crucial for economic growth, job creation, and improved living standards—which implies that R&D can play a significant role in sustainable development and resilience building.[4] Yet while the ratio of investment in knowledge (R&D,

higher education, and software) to GDP varies from 1.8 to 6.8 percent across OECD countries, it falls well below 1 percent in most SIDS and is even nonexistent in some.

SIDS are especially vulnerable to climate change, with serious risk of substantial economic and societal repercussions. To address these impacts, SIDS will need to implement a number of adaptation strategies requiring the development and transfer of appropriate technology. Such strategies may include purely technological options, such as engineered coastal protection works and water desalination plants; or they may entail a combination of community innovation, technology, and wise management, such as water harvesting and coastal beach dune conservation. Adoption of these measures will depend strongly on each country's capacity to innovate and implement adaptation solutions appropriate to its specific ecosystems and socioeconomic structures.

For example, in the Pacific, continuing expansion of the tourism sector and the demands of housing growing populations have led to poor planning and development in high-risk areas without adequate safety design considerations. Housing made with locally available materials and traditional methods, however, has typically proven able to survive extreme events and other natural calamities.[5] Similarly, SIDS depend almost entirely on imported fossil fuel for electricity generation and transport. Shifting to renewable energy technologies from sources such as the sun, wind, geothermal power, and the tides of the ocean could provide both environmental and economic benefits. Iceland, for instance, has succeeded in transforming its energy market by investing in the development of geothermal and hydroenergy, which in 2006 constituted 73.4 percent and 26.5 percent, respectively, of its total national energy supply.[6] Scotland has established a world center for ocean energy innovation and prototype testing facilities in the Orkney Islands, further demonstrating that islands can be important incubators for technology development and create significant opportunities for foreign direct investment, R&D, training, and employment.[7] To fund projects and facilitate technology transfer and capacity building in SIDS, the United Nations Framework Convention on Climate Change (UNFCCC) and the Global Environment Facility established the Special Climate Change Fund in 2001, but it has yet to be sufficiently financed.

Despite these challenges, the SIDS have made tremendous efforts in innovating and applying established technology to their context. This paper discusses the opportunities for and barriers to technology development in SIDS, with particular reference to the emerging issue of adapting to climate change. It presents three case studies that highlight efforts by SIDS to innovate and shows how SIDS can become technology incubators for climate change adaptation and mitigation.

Climate Change and Its Implications for SIDS

The Intergovernmental Panel on Climate Change has extensively examined the prospective impact of climate change on SIDS.[8] Rising sea levels present the biggest challenge for small

island states. Sea level rise is expected to exacerbate coastal inundation, increase erosion, and magnify the effect of storm surges, thus threatening vital infrastructure, settlements, and facilities that support the livelihoods of island communities. Changes in precipitation will alter water resource availability, which would in turn affect agriculture, biodiversity, and natural ecosystems dependent upon water supplies. Elevated sea surface temperatures and ocean acidification are already causing coral bleaching and may cause changes in fisheries distribution that would critically undermine commercial and subsistence fisheries in many SIDS. Climate change will also have a direct impact on other important economic sectors such as tourism, as well as on human health.

Adaptation based on innovative and existing management techniques and technologies is therefore a priority for SIDS. Historically, much attention has focused on using hard structures such as seawalls to protect coastlines susceptible to sea level rise. A number of feasible "soft" protection and adaptation options are also possible, however. Integrated coastal zone management and ecosystem-based adaptation are proven frameworks that can facilitate the implementation of appropriate accommodation strategies.[9] These strategies include measures such as coastal forest rehabilitation, beach dune restoration, and design structures that take the dynamic changes in the coastal zone into consideration.[*] In many cases, these accommodation strategies—such as constructing homes on stilts rather than surrounding them with barriers—may provide a more cost-effective and resilient approach for adaptation.[10] Where such measures are not possible, some communities may have to undertake a policy of retreat, relocating away from vulnerable areas. Needless to say, this alternative has serious implications for land ownership and compensation. In cases where an entire nation has to be relocated, sovereignty issues arise.[11] Unfortunately, mounting evidence suggests that if no effort is made to reverse dangerous climate change, many low-lying island nations face forced evacuation to another country.

Barriers to and Opportunities for Technology Development in SIDS

A SIDS expert meeting on Science and Technology for Sustainable Development, held in Singapore in August 2004, outlined the main barriers to science and technology in SIDS:

- Nonexistent or poor allocation of resources for science and technology
- Poor legal infrastructure
- Limited value given to protecting and expanding traditional knowledge
- Science and technology poorly mainstreamed into the development process

[*]For example, the Institute for Business and Home Safety in the United States found that losses following Hurricane Rita were more than fourfold greater in houses that had ignored the 1996 Florida building codes. See Institute for Business and Home Safety, "The Benefits of Modern Wind Resistant Building Codes on Hurricane Claim Frequency and Severity: A Summary Report" (2004), www.ibhs.org/newsroom/downloads/20070810_102941_10167.pdf (accessed March 4, 2010).

- "Brain drain"
- Limited investment in the development of professional capacity
- Poor enabling environment for technology transfer[12]

In general, the main constraints faced by SIDS lie in the area of capacity building and the lack of R&D platforms such as academic institutions. Recent advances in information communication technology can alleviate some of these difficulties, reducing barriers to knowledge sharing and institutional cooperation, for instance. Nonetheless, significant constraints in access and optimal use of such technology persist, including insufficient access to high-bandwidth Internet communication and poor knowledge of globally available knowledge networks.

The allocation of resources in SIDS is based on revenues generated from a relatively limited set of economic activities such as tourism, fisheries, and financial services. Revenue from such activities, which are highly susceptible to global fluctuations such as the recent financial crisis, have been dedicated to basic education and health care rather than to technology R&D. Jacob and Groizard, for example, have looked at the number and type of technologies transferred from large tourism multinationals to the Dominican Republic.[13] They found that technological innovations in the areas of information communication technology and environmental protection were among the most valuable to local economies because many of these innovations were highly dependent upon local training programs and the recruitment of skilled labor. Empirical evidence shows that quality education and training can stimulate technology transfer with substantial economic impacts. Economic models developed by Ho and Hoon calculate that the quality of education combined with technology transfer accounted for at least 52.1 percent of Singapore's real GDP growth per worker from 1970 to 2004.[14] Some closely linked island groups in the Caribbean and the Pacific have sought to capitalize on this dynamic by coming together to build regional universities. Many small island states, though, do not have national universities or access to such knowledge and research institutions.

The same natural resources that provide the basis for many traditional livelihoods could also supply new economic opportunities. SIDS are exceptionally rich in ocean resources and endemic biodiversity, making them potential candidates for mineral/oil exploration and bioprospecting.[15] (Bioprospecting is the search for wild species useful for the development of new products and processes such as crops and pharmaceuticals.) For example, malamala (*Homalanthus nutans*), a medicinal tree from Samoa, has been found to be effective against HIV.[16] Since 1979, a tissue culture program on the island of Barbados aimed at improving the yam species *Discorea allata* has resulted in a multimillion-US-dollar industry benefiting several Caribbean islands.[17] Jamaica exports more than 2,000 tons of this yam species to Canada each year.

Even so, the lack of appropriate legal frameworks and cost/benefit-sharing mechanisms has resulted in lost opportunities and revenue for a number of SIDS. The brain drain of mobile professionals leaving SIDS is another important barrier to technological innovation and development. Despite their being potentially fertile grounds for R&D, the dearth of appropriate infrastructure and market opportunities in SIDS frequently pushes professionals to more hospitable countries. Singapore offers one positive example of a small island state fostering innovation-driven start-ups associated with universities that has increased retention of highly skilled professionals in key areas.

Solving Climate Change: Sustainable Technologies for Adaptation and Mitigation in SIDS

While climate change now receives widespread political attention, the planet faces a number of profound technical and economic challenges to mitigate global emissions and stabilize greenhouse gas concentrations at safe levels (defined by the UNFCCC as "a level that would prevent dangerous anthropogenic interference with the climate system"), and to adapt to those climate changes that cannot be avoided. Many scientists now consider the planet to be on the brink of a global shift in climate.[18] Although the science is compelling and the economic rationale for action credible,[19] the international community is at an impasse regarding whether and how vigorously the larger economies will commit to mitigating greenhouse gas emissions and adapting proactively to their impacts. The knowledge and technological requirements needed to address these challenges are unprecedented. The complex and discernible impacts of climate change on a wide range of sectors from public health to human settlements will require review and reconsideration of the ways in which technology transfer is evaluated and implemented at all levels, from the local to the global.

A first issue concerns the international intellectual property rights system, which provides the regulatory framework for technology development and transfer. The UNFCCC calls for developed nations to assist the developing world with technologies to address climate change.[*] However, the World Trade Organization Agreement on Trade-Related Intellectual Property Rights makes no special consideration for technologies that contribute to the "common good of humanity"—an omission that may present obstacles for developing countries seeking to obtain and deploy certain technologies on those grounds. In practice, the possibilities and constraints for technology transfer and technology development in the SIDS vary from case to case. A study commissioned by the International Centre for Trade and Sustainable Development evaluated numerous perspectives on intellectual property

[*]Article 4.5 of the UNFCCC states that "The developed country Parties and other developed Parties included in Annex II shall take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies and know-how to other Parties, particularly developing country Parties, to enable them to implement the provisions of the Convention."

and the transfer of renewable energy technologies.[20] The report concluded that the possibilities for developing countries to enter the photovoltaic sector are still much higher than for wind energy, which is currently dominated by a small group of companies. Biofuel technology, on the other hand, is based upon biotechnological advances and may be subject to patents in the long term.

Second, a related study by the Global Climate Network highlighted the importance of domestic policy in the deployment of grid-connected renewable energy technologies. It concluded that a lack of sector-specific feed-in tariffs,* and of regulations and incentives to promote such technologies, "is one of the most profound barriers of all."[21] This is particularly true in SIDS. For example, the initiatives aimed at introducing low-carbon technologies in Seychelles face unnecessary regulatory and tariff hurdles in bringing these technologies to the islands at a cost that would minimize the investment risk.

Finally, effective technology transfer depends on the emergence of new markets and on firms and individuals developing the skills and know-how to deploy and service those technologies. SIDS need to consider the institutional, infrastructural, and capacity implications when considering technology solutions for climate change. For example, an ongoing project to install wind power in Seychelles requires a complete overhaul of the regulatory framework to accommodate distributed power generation; significant upgrading of the distribution network to handle the load from decentralized wind farms; and training of local engineers, operators, and maintenance personnel.

To illustrate some of the challenges and opportunities in implementing climate change technologies in SIDS, three case studies are presented here. The first focuses on the adoption of an accommodation adaptation technology in Seychelles. The second considers a retreat adaptation strategy by the Maldives. The third examines a mitigation biofuel project in Vanuatu.

Case Studies

Implementing Protection/Accommodation Adaptation Strategies in Seychelles

The Seychelles archipelago, located 4 degrees south of the equator, consists of 115 islands, 41 of which are granitic with mountainous peaks and narrow coastal strips, and the remaining 74 coralline low-lying islands comprised mostly of sand cay formations. More than

*A feed-in tariff is designed to promote adoption of renewable energy sources by providing grid access for producers using renewable technologies and for the utility company to purchase the electricity so generated. See M. Mendonça, *Feed-in Tariffs: Accelerating the Deployment of Renewable Energy* (London: Earthscan, 2007).

90 percent of the population and all economic activities are located on the narrow coastal plateau, where the average elevation is 2 meters above sea level. Because of steep land conditions, extensive areas have also been reclaimed on the east coast of Mahe Island, the largest inhabited island in the group. The economy continues to rely heavily on tourism as a foreign exchange earner, accounting for about 21 percent of GDP in 2006.

Seychelles is highly vulnerable to climate change. Output from the Individual Global Circulation Model shows a maximum increase in rainfall of 5.9 percent (19 millimeters) for the year 2025, 9.3 percent (25.4 millimeters) for 2050, and 12.4 percent (38.6 millimeters) for 2100.[22] The range of percentage change in annual rainfall, however, is -2.4 to +5.0 percent, -4.8 to +8.5 percent, and -8.6 to +16.3 percent, respectively, for the years 2025, 2050, and 2100. Based upon these results, Chang-Seng concludes that the rainy season is more likely than not to be wetter, while the dry season is more likely than not to be dryer, with the exception of the June-September season of the year 2050. On sea level rise, Church et al., using tide gauge data combined with TOPEX/Poseidon satellite altimetry data from 1950 to 2001, estimated a rate of relative sea level rise of 0.5 ± 0.5 millimeters per year for Seychelles.[23] Against the global mean sea level rise (from 1961 to 2003) of 1.8 ± 0.5 millimeters per year, these results appear to fall below the global average, but not low enough to minimize the risks involved.[24]

Observations of coastal erosion in naturally stable areas have been linked to this increase in sea level, combined with coral bleaching and storm surges.[25] Because coastal beach erosion in particular is linked to human activities, a proper assessment of the root causes of changes should be undertaken before implementing any adaptation technology. Most economic activities in SIDS, especially tourism, occur in coastal areas, and such development pressures and related human stresses can have detrimental impacts on natural ecosystems such as beaches, wetlands, and coral reefs. Often these damages occur when setback policies are not applied, natural vegetation is removed, and coral reef ecosystems are destroyed via processes such as siltation and dredging. One hotel developer in Seychelles installed offshore breakwaters parallel to one of its beaches to create a more sheltered bathing experience for its guests. Over the years, the developer has had to put additional coastal protection measures in place because the first breakwaters aggravated coastline instability.

Setback limits constitute one very effective means of controlling impacts of coastal development in the narrow coastal areas of SIDS. They are also a retreat strategy against climate change risks such as sea level rise, storm surge, and flooding. In Seychelles, a 25-meter minimum setback distance requirement (unlegislated) has been imposed on developers as a planning tool as well as an adaptation strategy for the future. Further legal and institutional frameworks will be needed to support the implementation of chosen policies and technologies. For instance, sand poaching and extraction in beaches are direct causes of

coastal erosion. In Seychelles, sand extraction from beaches was legal until 1982 when the Removal of Sand and Gravel Act prohibited the practice.

With the support of the Global Environment Facility and the Assessment of Impact and Adaptation to Climate Change project, Seychelles developed a pilot project aimed at demonstrating the potential value of soft engineering approaches to beach protection and restoration of dunes.[26] Beach tourism here as elsewhere hinges on the condition of the shores. Several Seychelles beaches are counted among the top 10 best tourist beaches in the world.[27] The economic value (in net present value terms) of one popular beach in Seychelles has been estimated at US$320 million.[28] Thus, loss of beaches from climate change or any other factor would directly affect the islands' economy.

Since most of the best beaches in Seychelles lie on windward coasts, it is reasonable to assume that wind-driven wave action is an important determinant of their stability and structure. Consequently, changes in wave action as a result of climate change will affect the nature of these beaches. The challenge has been to develop an adaptation technique based upon building the resilience of the beach to increased wave action, while maintaining the aesthetic appeal required by the tourism industry. Based upon these criteria, a research team evaluated various methods and technologies of beach protection and undertook a survey of the effectiveness of existing beach protection techniques. The team concluded that many of these efforts (ranging from seawalls, groins, rock armoring, and artificial sheet revetments) were not effective over the long term in maintaining beach formation and structure. Consequently, a modified version of a coastal protection method involving wooden logs of diameters not more than 20 centimeters driven into the sand was adopted. The modification entailed introducing a second layer of wooden logs, in the form of a sandwich, the middle of which is lined with geotextile and filled with medium-sized rocks for additional strength. This second layer would act as the ultimate barrier in the case of an extreme wave event and also create a topographic profile to enable the sand to cover the proposed structure.

After considering various alternative designs and discussions with engineers, contractors, and a few hotel operators, it was agreed that the model be tested in a real-life situation. A cost analysis was conducted, and a local contractor interested in implementing the technique jointly sponsored a pilot project in conjunction with the hotel concerned. After completing the construction phase, the next step involved restoring beach vegetation and the sand dune. Relatively mature seawater-resilient plants were acquired from a nursery and planted in the area just behind the wooden pillars, with the aim of further reinforcing the beach berm from potential wave spillovers. A number of beach-monitoring transects were set up along the restored part of the beach to determine the technique's effectiveness.

After one year of monitoring, an assessment was made. Because beaches in Seychelles are subject to varying wave action over two seasons, long-term monitoring is necessary. However, results from the first year were very encouraging, and several hotels located along the beach have since offered to implement the approach. Figure 1 shows the changes in the beach's appearance over time.

It must be noted that the method is not applicable to all erosion scenarios or intensities and wave environments, and no modeling of the dynamics and expected changes over time has been made.

Figure 1 shows that the chosen beach protection approach yields positive results in every possible wave regime at that location during different times of the year. The method has since been promoted nationally at several other hotels, as it met the original criteria under which the project was designed. A key consideration is the need for continuous coastal vegetation replanting to ensure long-term stability of the beach berm. As figure 1 reveals, this practice was not observed by the hotel because its management was more interested in providing a view of the sea for its clients than creating a natural coastal vegetation buffer to protect the infrastructure against storm surges and erosion.

Overall, the introduction of coastal adaptation technologies requires a thorough assessment of the coastal dynamics and close consideration of the various uses made of coastal zones. Nature-based approaches such as replanting can substantially increase the resilience of particular shorelines to extreme wave conditions, but such measures require constant attention and ongoing maintenance.

Figure 1: Seychelles Beach Before and After Installation of Coastal Protection

a: Erosion 2001 (before installation)

b: 2003, after installation

c: June 2009, during high wave conditions

Source: Alain De Comarmond.

Retreat and Relocation Adaptation Strategies in the Maldives

The Maldives consists of 1,192 islands on 26 natural atolls, forming a double chain on the Laccadive-Chagos submarine ridge in the Indian Ocean. All the islands are low lying and began forming between 3,000 and 5,500 years ago, primarily from reef-derived carbonate sediments deposited by ocean waves and currents. At least 80 percent of these islands are 1 meter or less above sea level, and only three have a surface area of more than 500 hectares. These characteristics make them highly vulnerable to sea level rise and extreme storm events (table 1).[29]

Table 1: Land Utilization in the Maldives Based on Island Size

Island size range (ha)	Total no. of islands	Land area (km^2)	Land area of utilized islands	No. of utilized islands	% of utilized islands	% of total area utilized
1–25	949	56.53	177	18.75	18.7	33.2
25–50	124	44.69	84	30.97	67.7	69.3
50–100	66	45.15	55	38.31	83.3	84.9
100–250	33	47.67	32	47.45	97.0	99.5
250–500	7	20.35	7	20.35	100.0	100.0
500+	3	16.4	3	16.4	100.0	100.0

Source: A. Shaig, *Climate Change Vulnerability and Adaptation Assessment of the Land and Beaches of Maldives*, Technical Papers to Maldives National Adaptation Plan of Action for Climate Change (Malé: Ministry of Environment, Energy and Water, 2006).

The population of 298,968 lives on 202 islands, presenting a communications and transport challenge.[30] Most of the islands have a population of not more than 1,000, and only 2 percent have a population exceeding 5,000.[31] Malé, the capital city-cum-island, houses 34 percent of the population, and is almost entirely occupied by infrastructure. With more than 53,000 people per square kilometer, Malé is one of the most densely populated cities in the world.[32] A report by the United Nations Development Programme estimated that nearly a quarter of the population lives in houses of 40 square feet or less.[33] Despite these physical and logistic challenges, the Maldives has been able to progress economically and socially in the last 30 years, primarily due to its tourism industry and social investment program. Tourism, which accounts for about 33 percent of GDP, creates employment for roughly half of the population and stimulates economic activity in other sectors such as agriculture, construction, and services. About 20 percent of the population depends on subsistence fisheries.[34]

With economic growth averaging 9 percent since 1978, the Maldives will graduate from least developed country status in 2010.[35] While a commendable achievement, this will

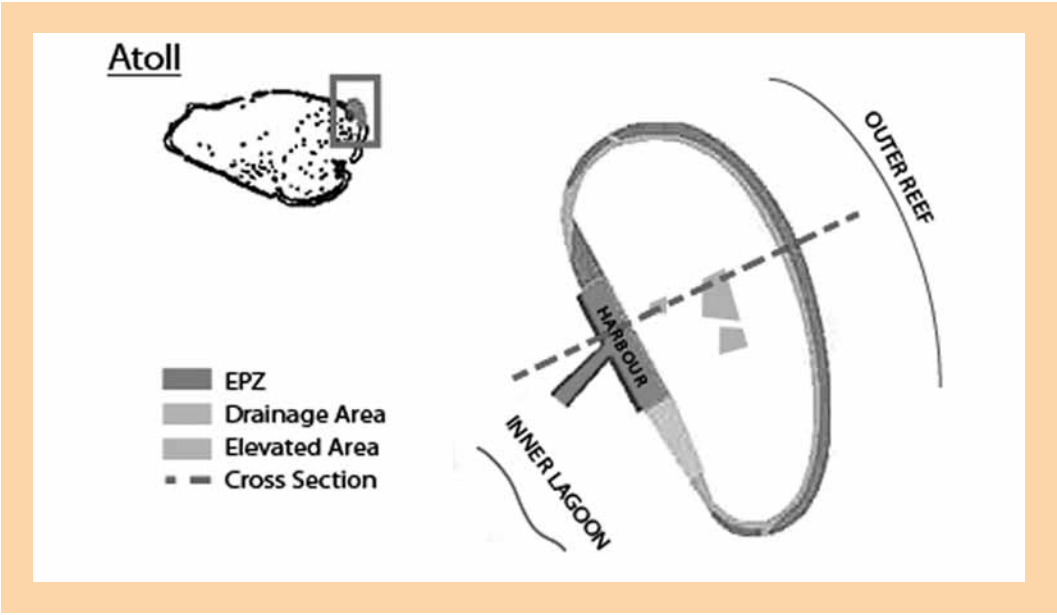
remove the Maldives from most official development assistance support, meaning that it will not be able to access development loans at grant or preferential interest rates. Research undertaken by the United Nations concludes that, irrespective of economic growth and GDP per capita improvements, SIDS remain extremely vulnerable to economic up- and downturns and thus require special consideration to ensure their continued sustainability.[36] Efforts to diversify away from traditional but volatile economic dependencies to sectors such as offshore financial and gambling centers have met with some opposition in developed countries.[37] The economic and survival challenges of the people of the Maldives were evident after the 2004 tsunami caused damage equivalent to 62 percent of national GDP.[38] As of 2009, the country still faced a deficit of more than US$150 million for reconstruction.[39]

The government of the Maldives has developed a National Implementation Strategy for Addressing Climate Change and submitted a National Adaptation Plan of Action in 2007.[40] A core component of this strategy is the development of one larger "focus island" or several "safe islands" per atoll. Such an approach will enable the establishment of more cost-effective and robust infrastructure, which will enhance the country's resilience to climate change and promote long-term environmental and social stability.

The Safe Island Program will involve the relocation from smaller and more vulnerable islands to these large islands (a retreat adaptation strategy). This strategy will enable the government to focus its adaptation efforts on a number of key large islands. Five focus islands have been identified: R. Dhuvaafaru, A. Sh. Maamigili, Dh. Kudahuvadhoo, Th. Vilifushi, and L. Gan. Some of the features planned for these islands include elevated areas for safe evacuation in case of storm surges (or another tsunami), raised buildings, appropriate drainage, and sand dune barriers (figures 2 and 3). A multipurpose safehouse system for about 1,000 people is currently under construction on the atolls of Muli and Meemu.[41] The shelter incorporates innovative designs such as an underground 45,000-liter rainwater tank, a storehouse for food and life-saving drugs, an operations center with communications equipment, and enough energy for up to three days. The building has also been designed to allow for vertical evacuation, which means people will be able to move upwards to a high central location in times of flooding. While the relocation policy will be voluntary, it is expected that inhabitants of smaller, more vulnerable islands will slowly move to those larger islands as economic centers are created.

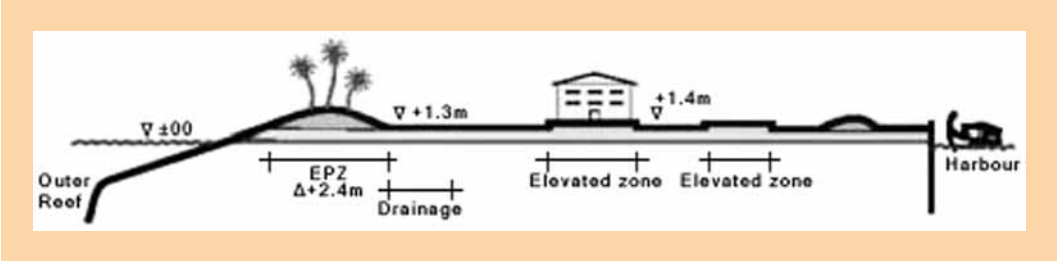
Historically in the Maldives, population movement between islands has been a means of overcoming stresses such as changes in resource availability and extreme weather conditions.[42] Modern progress and development, however, have resulted in significant investments in heavy infrastructure, which makes the relocation strategies of earlier times difficult and costly. Efforts at a more flexible approach to settlement development may provide some avenues for enhancing the resilience of island populations to coastal hazards and

Figure 2: Safe Atolls: A Retreat Adaptation Strategy Adopted by the Maldives



Source: United Nations Environment Programme (UNEP), *Maldives: Post-Tsunami Environmental Assessment* (Nairobi: UNEP, 2006), p. 24.

Figure 3. Cross-Section of an Atoll Showing Potential Adaptation Measures



Source: UNEP, op. cit., p. 24.

sea level rise. Such an approach should include the consideration of appropriate design to minimize waste and the use of energy and water, as well as built-in adaptation to future climate change.

Ultimately, the Maldives faces a far worse prospect—that of relocating the entire nation. It is estimated that sea level rise will eventually render the Maldives completely uninhabitable, although there is still some uncertainty as to whether the sea level in the Maldives region is rising at the same rate as the global average.[43] This issue has led to discussion of a number of relocation options: (1) individual or collective emigration to other countries, (2) purchasing land in another country for a mass relocation,[44] and (3) relocating to

alternative islands in other large archipelagos. Each alternative raises important questions of sovereignty and national identity (statehood). According to the United Nations Convention on the Law of the Sea, an island or archipelago would automatically lose its claim on an Exclusive Economic Zone following inundation by the sea.* Although there are previous examples of governments in exile, international law is not clear on the case of forced relocation as a result of environmental factors or climate change caused largely by the actions (emissions) of other states. International consensus on this issue is crucial for the future of the Maldives and other island states facing the same dilemma.

SIDS Mitigating Climate Change: Developing Biofuels in Vanuatu

Most SIDS are heavily dependent on fossil fuels and devote a high proportion of their foreign exchange resources to importing fuel. For example, the ratio of the value of petroleum imports to the value of total exports ranges from 10 percent for Papua New Guinea to more than 400 percent for the Marshall Islands. Most SIDS depend on high-cost fossil fuels to produce very expensive electricity. Electricity prices are generally between US$0.20 and US$0.35 per kilowatt hour, which is much higher than prices in America or Europe. SIDS energy systems are frequently inefficient as well as expensive, exacerbating national economic vulnerability. Secure supplies of affordable and reliable energy are an essential element of economic and social development. Electricity is vital to the delivery of social services such as health, education, water, and sanitation; further, it enables job creation and frees time for productive pursuits. At present, however, 70 percent of Pacific island residents do not have access to electricity and depend on a mix of fuelwood, kerosene, and batteries for their energy supply.[45]

The 2007–08 oil crisis placed unsustainable financial pressures on the economies of many SIDS, prompting investigations into alternative forms of energy. For SIDS, the benefits of renewable energy are at least fivefold:

- Renewable energy offers a clean, green, dynamic image and marketing tool for a country.
- It preserves natural resources.
- It provides economic benefits, including reducing imports, thus saving scarce foreign exchange.
- It creates employment and generates new income.
- It furnishes cheaper and more reliable energy for businesses and individuals.[46]

*The criteria defining a state are enshrined in Article I of the Montevideo Convention on the Rights and Duties of States of 1933. Article 56(1) of the UN Convention on the Law of the Sea outlines the sovereign rights of nations over the natural resources, whether living or nonliving, of the waters and seabed. See "Report of the Expert Meeting on Capacity Building for Renewable Energy and Energy Efficiency in Small Island Developing States" (2003), www.un.int/mauritius/Documents/AOSIS/Workshop%20Reports/Final%20Draft%20Energy%20Meeting%20Report%20revised.pdf (accessed March 4, 2010).

Historically, coconut oil was used for cooking and lighting in many island homes, but with the arrival of electricity supplied by centralized generators, these practices subsided. Recent advances in technologies such as coconut oil extraction, engine modifications, and blending have once again increased its potential as a source of fuel on the islands. Research on the calorific value of coconut oil has demonstrated its versatility and safety, making it an effective alternative to fossil fuel. Indeed, Virgin Airlines has successfully powered a 747 flight on a blend containing coconut biofuel.[47] Developing such biofuels offers a promising means of safeguarding the coconut oil industry, which remains a major source of income and is often the sole employment opportunity for large portions of rural island populations.

On the other hand, the biofuel industry has attracted much criticism, often linked to food security and environmental degradation. It is therefore imperative that SIDS adopt sustainable approaches throughout the life cycle of the biofuel process. Properly certified, coconut biofuels can be produced in climate-neutral fashion, thus effectively contributing to reducing the emissions that cause global warming. This is an important consideration, as it demonstrates that, despite their size, SIDS can contribute to global mitigation efforts.

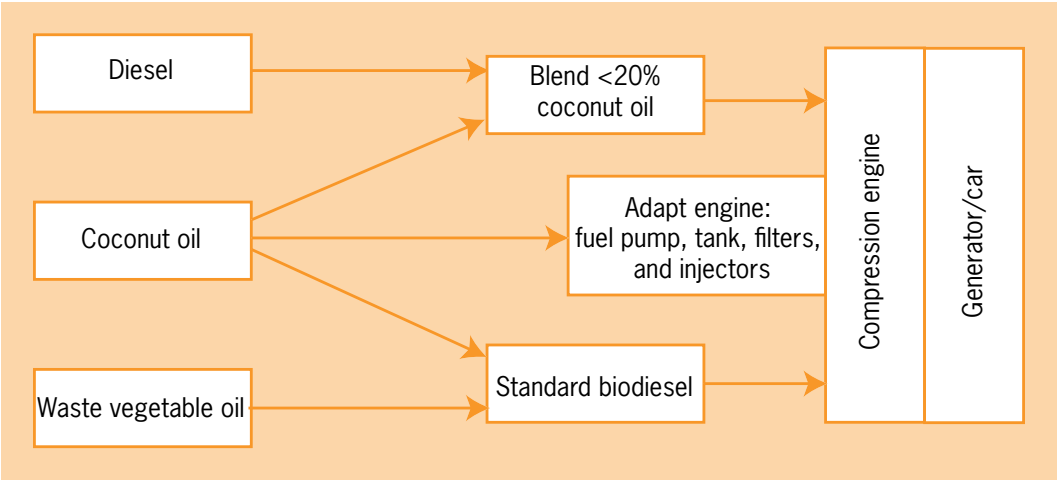
At the 2002 World Summit on Sustainable Development in Johannesburg, the Pacific island countries launched a regional energy sector umbrella initiative. Its goal is to increase the availability of adequate, affordable, and environmentally sound energy for the countries' sustainable development, and to accelerate the transfer and adoption of clean and renewable energy technologies. The Cook Islands, Fiji, Kiribati, the Marshall Islands, the Federated States of Micronesia, Palau, Papua New Guinea, Samoa, the Solomon Islands, Tonga, and Vanuatu together spend more than US$800 million a year on fuel imports. If the Pacific islands replaced half of their diesel imports with coconut oil, the region's average fuel import bill would be cut by 10 percent.

One small island state that has made significant strides in the development of coconut as a biofuel is Vanuatu. Agriculture—dominated by the production of copra (from coconut), kava, beef, cocoa, and timber—provides employment to about 65 percent of Vanuatu's population of 243,000.[48] Tourism, fisheries, and offshore financial services are growing sectors on the island.[49] In 2008, Vanuatu exported US$11 million of copra and US$8 million of coconut oil;[50] it imports more than 24 million liters of diesel oil annually. Although the government collects over 40 percent of its taxes from the importation of diesel, it believes that substituting biofuels for diesel will have a positive impact on the balance of payments and reduce its dependency on imported energy. To stimulate the development of biofuel, Vanuatu introduced an excise tax (specifically a value-added tax) on biodiesel, while providing for customs duty exemptions or reductions on raw materials and machinery for the production of biofuels. With the price of coconut oil ranging from US$0.30 to US$0.70 per liter, it can be a viable substitute for diesel fuel. Fostering biofuels markets

provides an outlet for local coconut plantations, which would otherwise be outcompeted by large coconut oil producers such as the Philippines.

Many studies have been undertaken in Vanuatu to determine the viability of coconut oil as a component of biodiesel or of fuel blends for electricity generation (figure 4).[51] As one outcome of these studies, a 2:1 coconut-diesel oil blend is currently being used in vehicles in Vanuatu. Although short-term results look promising, in the long term, the engines suffer from accumulation of deposits on internal engine parts, suggesting that substantial reliance on this fuel requires modifications to the standard engine. Additionally, Vanuatu is running its main generator in the city of Port Vila on a fuel blend containing 10 to 20 percent coconut oil with important financial benefits to the operators. Despite these promising successes, a number of challenges remain to be addressed, including price considerations, lack of public awareness of the fuel, and environmental concerns regarding the sustainability of the coconut plantations and risk of coconut palm diseases.

Figure 4: Overview of Biofuel Choices for Compression Engine



Source: J. Cloin, "Coconut Oil as a Fuel in Pacific Islands," *Natural Resources Forum* 31, no. 2 (2007).

Conclusions

SIDS can become effective incubators of sustainable technology. Despite the opportunities, technology development and transfer are often hampered by several key challenges. These constraints are not international or external in nature, but include a number of internal impediments that need urgent attention if SIDS are to adapt effectively to climate change. While the availability of external financing and opportunities remains an important concern, appropriate national frameworks and institutions to support technology development and transfer are imperative. At the same time, the examples discussed here demonstrate

that technology development and transfer do not entail only hard engineering solutions, but also innovative, sustainable, and integrated approaches to provide the greatest resilience to societies and ecosystems.

Action must be taken to reduce the impact of climate change in SIDS through appropriate technology transfer frameworks. Lack of an integrated approach can result in higher costs without achieving resilience. Evidence abounds demonstrating that, with an effective and proactive strategy, the initial high costs of adaptation can be avoided or reduced. In extreme situations where islands might have to be evacuated, specific adaptation measures need to be put in place after an assessment of risk and vulnerability. Finally, it is important to ensure that subsequent adaptation or mitigation technology transfer does not lead to environmental degradation, unsustainable practices, or climate change.

Notes

1. United Nations General Assembly, Fifty-Sixth Session, 2001, (A/RES/56/198), www.un.org/esa/sustdev/sids/res_56_198.htm (accessed March 3, 2010).

2. Both official UN decision documents can be accessed at www.sidsnet.org.

3. *Earth Negotiations Bulletin* 8, no. 41 (2004), www.iisd.ca/vol08/enb0841e.html (accessed March 5, 2010).

4. Organisation for Economic Co-operation and Development, "Science, Technology and Industry Scoreboard 2005," http://dx.doi.org/10.1787/480375180182 (accessed March 3, 2010).

5. United Nations Framework Convention on Climate Change, "Vulnerability and Adaptation to Climate Change in Small Island Developing States," background paper for the Expert Meeting on Adaptation for Small Island Developing States, Kingston, Jamaica, 2007.

6. National Energy Authority, *Iceland Energy Statistics 2007* (Reykjavik: National Energy Authority, 2007), www.os.is/page/energystatistics (accessed March 3, 2010).

7. Ocean Energy Council, "Harnessing the Power of the Ocean Creates Jobs in the Highland" (2008), www.oceanenergycouncil.com/index.php/Worldwide-Ocean-Energy-News/Harnessing-the-Power-of-the-Ocean-Creates-Jobs-in-the-Highland.html (accessed March 3, 2010).

8. N. Mimura et al. "Small Islands," in M. L. Parry et al., eds., *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2007).

9. R. F. McLean et al., "Coastal Zones and Marine Ecosystems," in J. J. McCarthy et al., eds., *Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2001).

10. See Lloyds, "Coastal Communities and Climate Change: Maintaining Future Insurability" (Lloyd's and Risk Management Solutions, 2008), www.rms.com/newspress/PR_090908_Lloyds.asp (accessed March 3, 2010). This case study by Lloyds (a global insurance service provider) in Grand Cayman Island showed that raising a property on stilts by up to 50 centimeters lessens the future average losses of storm surges by more than 60 percent; raising the structure by a further 150 centimeters lessens losses by up to 95 percent. These estimates are based on an increase in sea level rise of 30 centimeters, combined with a 5 percent increase in Category 3–5 hurricanes by 2030.

11. Discussed in J. Barnett and W. N. Adger, "Climate dangers and atoll countries," *Climatic Change* 61, no. 3 (2003).

12. "Report of the Expert Meeting on Science and Technology for Sustainable Development," Singapore, August 30–September 3, 2004, www.un.int/mauritius/Documents/AOSIS/Workshop%20Reports/Report%20

of%20the%20SIDS%20Expert%20Meeting%20on%20Science%20and%20Technology%20for%20Sustainable%20Development%20v2.pdf (accessed March 3, 2010).

13. M. Jacob and J. L. Groizard, "Technology transfer and multinationals: the case of Balearic hotel chains' investments in two developing economies," *Tourism Management* 28, no. 4 (2007): 976–92.

14. K. W. Ho and H. T. Hoon, "Growth accounting for a technology follower in a world of ideas: the case of Singapore," *Journal of Asian Economics* 20, no. 2 (2009): 156–73.

15. R. A. Payet and R. Lettington, "Access to Genetic Resources in Seychelles," in Kent Nnadozie et al., eds., *African Perspectives on Genetic Resources: A Handbook on Laws Policies and Institutions* (Washington, DC: Environment Law Institute, 2003).

16. Food and Agriculture Organization of the United Nations, "Bioprospecting in the Pacific region: who will benefit?," *Non-Wood News*, April 13, 2006.

17. E. J. Da Silva and M. Taylor, "Island communities and biotechnology," *Electronic Journal of Biotechnology* 1, no. 1 (1998).

18. T. M. Lenton et al., "Tipping elements in the Earth's climate system," *Proceedings of the National Academy of Sciences* 105, no. 6 (2008).

19. Nicholas Stern, *The Economics of Climate Change: The Stern Review* (Cambridge: Cambridge University Press, 2007).

20. John H. Barton, "Intellectual Property and Access to Clean Energy Technologies in Developing Countries: An Analysis of Solar Photovoltaic, Biofuels and Wind Technologies," ICTSD Trade and Sustainable Energy Series Issue Paper No. 2 (Geneva: International Centre for Trade and Sustainable Development, 2007).

21. Global Climate Network, *Breaking Through on Technology: Overcoming the Barriers to the Development and Wide Deployment of Low-Carbon Technology* (London: Center for American Progress and Global Climate Network, 2009).

22. S. D. Chang-Seng, "Climate Change Scenario Assessment for the Seychelles," Second National Communication under the United Nations Framework Convention on Climate Change (Seychelles: National Climate Change Committee, 2007).

23. J. A. Church, N. White, and J. Hunter, "Sea level rise at tropical Pacific and Indian Ocean islands," *Global Planetary Change* 53, no. 3 (2006): 155–68.

24. N. L. Bindoff et al., "Observations: Oceanic Climate Change and Sea Level," in S. Solomon et al., eds., *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2007).

25. C. Sheppard et al., "Coral mortality increases wave energy reaching shores protected by reef flats: examples from the Seychelles," *Journal of Estuarine, Coastal and Shelf Science* 64, nos. 2 and 3 (2005).

26. See R. Payet, *Impact of Climate Change on Tourism in Seychelles and Comoros*: *A Final Report Submitted to Assessments of Impacts and Adaptations to Climate Change (AIACC)*, Project No. SIS 90 (Washington, DC: International START Secretariat, 2007), at www.aiaccproject.org/Final%20Reports/Final%20Reports/FinalRept_AIACC_SIS90.pdf (accessed March 3, 2010).

27. See "The World's Ten Best Beaches for Luxury Travel," *Telegraph*, September 4, 2008, www.telegraph.co.uk/travel/ultratravel/2682093/The-worlds-ten-best-beaches-for-luxury-travel.html (accessed March 3, 2010).

28. See H. Cesar et al., "Evaluation of the Socio-economic Impacts of Marine Ecosystem Degradation in the Seychelles" (Netherlands: Cesar Environmental Economics Consulting, 2004).

29. A. Shaig, *Climate Change Vulnerability and Adaptation Assessment of the Land and Beaches of Maldives*, Technical Papers to Maldives National Adaptation Plan of Action for Climate Change (Malé: Ministry of Environment, Energy and Water, 2006).

30. Ministry of Planning and National Development, *Population and Housing Census of Maldives 2006*, Republic of Maldives, www.planning.gov.mv/publications/Population%20and%20Housing%20Census%202006/home.htm (accessed March 3, 2010).

31. From M. Faisal, "Living on a crowded island –urban transformation in the Maldives," www.globalfocus.org.nz/infoservices/downloads/MohammedFaisalMaldivesurban.pdf (accessed March 8, 2010).

32. Ibid.

33. Ibid.

34. Asian Development Bank (ADB), *Maldives Environment Assessment* (Manila: ADB, 2007).

35. United Nations General Assembly Resolution A/59/L.48 recommended graduation of Maldives from least developed country (LDC) status, providing that the country would be entitled to LDC status until December 20, 2007.

36. United Nations Conference on Trade and Development, "The Vulnerability of Small Island Developing States in the Context of Globalization: Common Issues and Remedies," discussion paper (United Nations Conference on Trade and Development, 1997).

37. See M. P. Hampton and J. Christensen, "Offshore pariahs? Small island economies, tax havens, and the re-configuration of global finance," *World Development* 30, no. 9 (2002); Antigua *v.* US WTO Internet Gambling Case, www.antiguawto.com/WTODispPg.html (accessed March 3, 2010).

38. United Nations Environment Programme (UNEP), *Maldives—Post-tsunami Environmental Assessment* (Nairobi: UNEP, 2005).

39. European Union, Maldives Multiannual Indicative Programme 2007–2010.

40. "Maldives Climate Change Thematic Assessment," report prepared for Ministry of Environment, Energy and Water (Malé, 2007).

41. See Maryam Omidi, "Safe shelter to protect against natural disasters," Minivan News, February 18, 2009, at www.reliefweb.int/rw/rwb.nsf/db900SID/MUMA-7SP4SV?OpenDocument (accessed March 3, 2010).

42. D. D. Paulson and S. Rogers, "Maintaining subsistence security in Western Samoa," *Geoforum* 28, no. 2 (2007): 173–87.

43. See P. S. Kencha, S. L. Nichol, and R. F. McLean, "Comment on 'New perspectives for the future of the Maldives' by Mörner, N. A., Tooley, M., Pössnert, G. [*Global and Planetary Change* 40 (2004): 177–82]," *Global and Planetary Change* 47, no. 1 (2005): 67–69.

44. See Nicholas Schmidle, "Wanted—a new home for my country," *New York Times*, May 8, 2009.

45. World Bank, "Global Environment Facility to fund renewable energy electricity supplies for rural communities in Papua New Guinea, the Solomon Islands, Vanuatu, Fiji and the Republic of the Marshall Islands," press release, June 2007.

46. T. Roper, "Small island states—setting an example on green energy use," *RECIEL* 14, no. 2 (2005).

47. See BBC, "Airline in first biofuel flight," February 24, 2008, http://news.bbc.co.uk/2/hi/uk_news/7261214.stm.

48. Vanuatu National Statistics Office, "Preliminary Report Agriculture Census 2007" (2008), www.spc.int/prism/country/VU/stats/Projects/Agcensus_census_report2008.pdf (accessed March 3, 2010).

49. ADB, "Asian Development Bank and Vanuatu—Fact Sheet" (2009), www.adb.org/documents/fact_sheets/van.asp (accessed March 3, 2010).

50. Vanuatu National Statistics Office, "External Trade Statistics (1999–2008)," www.spc.int/prism/country/VU/stats/economic/int-trade/exports-mcom.htm (accessed March 3, 2010).

51. J. Cloin, "Coconut Oil as a Fuel in Pacific Islands," *Natural Resources Forum* 31, no. 2 (2007).

Adaptation Policies in the Coastal Zones of the Indian Ocean Region: Challenges, Opportunities, and Strategies

Poh Poh Wong

This study spans the countries bordering the Indian Ocean from East Africa across South Asia and includes countries in Southeast Asia and island states in the Indian Ocean. Almost all are developing countries, and some are least developed countries (LDCs) where poverty is a serious problem. The coasts and coastal resources play significant roles in the region: a large percentage of the population lives in the coastal areas, and many people are dependent on coastal and marine resources as their primary protein source and for their livelihood. In many countries, it is often the poor—largely as squatters—who live in the most exposed, low-lying coastal areas. At the same time, many coasts have been degraded by exploitive activities such as the removal of mangroves, the destruction of coral reefs by blast fishing, erosion from coastal development, industrial pollution, and poor land management. Some coastal areas are subject to cyclones and flooding, which is common, for example, in Bangladesh and the Mekong Delta.

Climate change will exacerbate environmental and social problems in the coastal areas of the Indian Ocean basin.[1] In Southeast Asia, climate change poses a grave threat to agriculture and food security, water resources, natural ecosystems, forestry, biodiversity, and human health.[2] For East Africa, water resources, agriculture, forestry, and coastal zones are priority sectors.[3] Throughout the region, rising sea levels constitute the most serious risk for coastal nations, with Bangladesh, India, Indonesia, the Maldives, Myanmar, the Philippines, Tanzania, and Vietnam figuring among the most vulnerable. The LDCs, particularly the small island developing states (SIDS), will disproportionately bear the brunt of climate change impacts. They contribute little to world greenhouse gas emissions, yet they possess limited capacity to mitigate the impacts of global warming and face other natural hazards as well. Rising not more than 3 meters above sea level, the Maldives faces the grim prospect of being completely submerged by rapidly rising seas within the century.

Within the Indian Ocean region, the Intergovernmental Panel on Climate Change (IPCC) has identified megadeltas such as the Ganges-Brahmaputra and Mekong, low-lying coastal

cities, and small island states as climate change "hotspots"— areas particularly vulnerable to the impacts of rising sea levels.[4] Examples of vulnerabilities in the region include the following alarming scenarios:

- A sea level rise of 0.5 meters along Tanzania's 800-kilometer coastline would inundate 247 square kilometers of the country.
- A 1-meter sea level rise would result in the loss of 15 to 20 percent of Malaysia's mangroves—with serious consequences for fisheries and livelihoods—and would submerge more than 80 percent of the Maldives's land area, and displace 7.1 million people in India.[5]

In recent years, more extreme weather events and rising sea levels have increasingly affected the coastal areas of the Indian Ocean and Southeast Asia. For example, an average of 20 cyclones typically cross the Philippines each year, with 8 or 9 making landfall. In the period 1990–2003, the average annual frequency of cyclones entering the Philippines area increased by 4.2.[6] Of 15 cyclones and tropical storms that made landfall on the coast of Mozambique between 1980 and 2007, 4 occurred in 1980–93, and 11 in 1994–2007. Two cyclones in 1980–93 were in Categories 3–5 compared to seven in 1994–2007.[7] In recent years, Categories 4 and 5 tropical cyclones have become more intense, including in the northern Indian Ocean.[8]

While mitigation and adaptation are equally important strategies for meeting the climate change challenge, the focus of this paper is on adaptation for coastal zones. Adaptation is a complex topic, with a range of definitions and implications. This paper uses the broad definition employed by the IPCC, addressing adaptation as adjustments in natural or human systems to actual or expected climatic stimuli or their effects that moderate harm or exploit beneficial opportunities. Adaptation can be *reactive* (taking measures to respond to climate change impacts) or *anticipatory* (taking measures before impacts are observed). A related concept, *adaptive capacity*, refers to the ability to adapt to climate change and gives an indication of the differing capacities—technical, financial, institutional, etc.—of societies to respond to climate stresses.[9] Compared to developed countries, developing countries and LDCs have a lower adaptive capacity, and so require external support. Ultimately, the aim of an adaptation policy is to reduce exposure (e.g., move settlements to higher ground) and sensitivity (e.g., design coastal infrastructures to withstand storm surges) to climate change, or to increase adaptive capacity (e.g., disaster management planning) and resilience or coping ability.

This paper provides a brief overview of adaptation and coastal zone management in the Indian Ocean and Southeast Asian region, surveying the relevant challenges and obstacles, available opportunities, and effective strategies. It concludes by providing policy recommendations.

Regional Overview of Adaptation and Coastal Zone Management

Even before the advent of climate change concerns, many countries had adopted Integrated Coastal Zone Management (ICZM) strategies to address the complex challenges of sustainable coastal development. ICZM strives to balance environmental, economic, and social objectives within the limits set by natural dynamics. It aims to draw on the participation of all stakeholders to define and achieve these objectives and to resolve potential conflicts among competing interests. Intended to coordinate the relevant policy instruments and actors at multiple scales, and to guide planning that integrates short-term demands as well as medium- and long-range needs, ICZM is considered a suitable framework for climate change adaptation in coastal areas and forms an essential part of a national climate change plan. Thus, the National Communications formulated under the United Nations Framework Convention on Climate Change (UNFCCC) by many Indian Ocean states—including Bangladesh, Indonesia, Kenya, Malaysia, Mozambique, Seychelles, and Tanzania—envisage ICZM approaches. Sri Lanka has established a fully operational national coastal zone management (CZM) plan, though it lacks a sea level rise component.[10]

Other models have also come into use recently in coastal zone management and adaptation to climate change, including the following:

- Adaptation can take place at many different levels—global, national, regional, and local. *Community-based adaptation* (CBA) is an innovative approach enabling communities to enhance their own adaptive capacity, empowering them to increase their resilience to climate change impacts.[11] CBA focuses on activities carried out by highly vulnerable and poor communities, mostly in developing countries.
- Climate change will totally transform coastal and marine ecosystems in ways that today's management systems are often unprepared to accommodate. *Ecosystem-based management* takes a broader view of management decisions in order to understand the ecosystems themselves. Ecosystem-based management looks to take account of potential future changes that may be larger than those induced by present stresses, adopting a longer perspective that includes nonclimate issues.[12]

The IPCC identifies three standard strategies of coastal adaptation to sea level rise: (1) *managed retreat* (move landward to higher ground), (2) *accommodate* (stay in the same location but make adjustments, e.g., elevate buildings on piles), and (3) *protect* (employ various hard structures such as seawalls, bulkheads, groins, and breakwaters or use soft measures such as beach nourishment, mangrove replanting, and preservation of coral reefs).[13]

From an analysis of the National Communications of Asian countries, adaptation options differ from tropical to semiarid and arid regions. Tropical coasts tend to protect wetlands

and marine resources, improve preparedness for weather extremes, and implement CZM and contingency plans for migration in response to sea level rise. For semiarid and arid coasts, the priority is on water- and soil-saving technologies, measures to improve salinized soils, providing irrigation, and protection of settlements and infrastructure from sea level rise.[14] In Southeast Asia, several adaptation options and practices are now widely used, including upgrading existing coastal protection systems, conserving mangrove forests and planting new stands, relocating aquaculture farms and coastal infrastructure, improving the design of housing and infrastructure, monitoring sea level rise and mapping hazard and vulnerability risks, and providing information to stakeholders and the public.[15] In the Indian Ocean islands, coral conservation is particularly important. Successful adaptation, however, is expected to go beyond these technologies.

Compared to continental land masses or terrestrial ecosystems, climate change adaptation in coastal zones poses particular difficulties for coastal managers, decision makers, and stakeholders, for a variety of reasons. These reasons include increasing population pressures in coastal zones, complex natural-human interactions in frequently limited areas, the fragility of coastal ecologies, less leeway for adaptation—especially by retreat or relocation—in relatively narrow coastal bands, and the critical thresholds present in some coastal ecosystems. For example, coral reefs exhibit critical thresholds beyond which they may not be able to adapt to changing climate conditions without radically altering their function and role in the ecosystem.

Adaptation Obstacles and Challenges

Several adaptation policy challenges confront coastal managers, decision makers and stakeholders in the Indian Ocean region. According to one assessment conducted by the UNFCCC on adaptation measures in Asia, a lack of reliable and accurate data constitutes a major impediment. Wide variation in data collection methods, processing, and reporting of data for impacts and vulnerability assessments, as well as discrepancies and discontinuities in recorded data, frequently frustrate integrated policy development. Failure of monitoring equipment is also a common concern, and time-series data are often incomplete.[16] Consequently, for many coastal areas, systematic observations are lacking for a range of oceanographic and atmospheric variables needed to evaluate evolving trends and assess emerging policy needs.

A lack of funding is another major obstacle. Under the UNFCCC, international funding to support adaptation in developing countries is an obligation under the "polluter pays principle," but funding amounts have not been decided. While several funding sources are available, including the Global Environment Facility (GEF), the Least Developed Countries Fund (LDCF), the Special Climate Change Fund (SCCF), and the Adaptation Fund, current investment is incremental and still evolving.[17]

The GEF, for example, provides funds for vulnerability and adaptation assessments for specific projects and programs. From 2001 to 2006, GEF funds were allocated for coastal projects in Bangladesh, the Maldives, the Philippines, Seychelles, and Tanzania.[18] Funding provided by the LDCF hinges on country development of a National Adaptation Program of Action (NAPA). So far, countries in the Indian Ocean with NAPAs include Bangladesh, Cambodia, Comoros, Djibouti, Eritrea, Madagascar, the Maldives, Mozambique, Tanzania, and Yemen.[19] Myanmar and Timor Leste are eligible for LDCF funding but have yet to submit their NAPAs.

The NAPA provides a means by which LDCs can identify priority activities to respond to their urgent and immediate climate adaptation needs, but the system has several flaws that limit the effectiveness of adaptation planning and implementation. First, funding was initially limited to $200,000 per country for developing the NAPA—a sum that is a fraction of what some European cities spend on climate risk assessment. Second, adaptation costs are underestimated, because there are not enough funds in the LDCF to finance the requirements identified. Third, most NAPAs focused on small-scale projects cofinanced by donors that do not provide an adequate basis for implementing an effective adaptation strategy as they tended to focus on ”climate-proofing” measures with only weak links to human development criteria and no integration into national poverty reduction strategies.[20]

Overall, there is a significant difference between the funds pledged to and the money actually transferred by the LDCF and the SCCF. The current funding flows are largely insufficient to meet demand. The SCCF has funded one coastal CBA project for Bangladesh and coastal projects for the Maldives and Vietnam, but is now closed for new submissions until funding becomes available again.[21] The Adaptation Fund operates under the Kyoto Protocol and is based on a 2 percent surcharge on Clean Development Mechanism project financing, but is unlikely to generate sufficient capital flows. Instead, the main contributions to the fund are likely to come from development financing and private investment.[22]

According to an independent assessment, the UNFCCC has underestimated the global costs of coastal protection by a factor of 2 to 3.[23] The UNFCCC adaptation cost assessments are quite detailed and were based on extensive experience, which took into account traditional coastal engineering responses. Even so, these estimates failed to consider several key factors. For example, recent projections for future sea level rise have been substantially higher than the IPCC figures used by the UNFCCC. The UNFCCC estimates also neglected to take into account important climate changes such as extreme storms, as well as nonclimatic changes such as coastal subsidence (evident in the city of Bangkok, for example). Finally, the UNFCCC did not consider the protection of landscapes for their value as an amenity and in ecological recreation. As a result, the current level of international financial transfers to address adaptation challenges in the Indian Ocean and Southeast Asian region is far short of what is required.

Beyond the question of available funding, the complex and lengthy processes for accessing existing financial resources further complicate the implementation of adaptation measures. Moreover, the lack of coordination and cooperation among national agencies often leads to conflicting approaches and priorities. Climate change has not yet been fully appreciated as a national issue in development. The LDCs, especially those in Africa, face particular hurdles in overcoming these difficulties, since they generally possess low levels of the scientific expertise and administrative capacity needed to formulate and carry out integrated adaptation policies. For these countries, few resources are allocated at national levels to climate policy, which is seen as a lesser priority compared to other urgent needs. Indeed, international donors and other organizations sometimes contribute to the confusion of competing pressures, pushing countries to incorporate not only climate change, but also gender, HIV/AIDS, biodiversity, and other issues into their core development policies.[24] In Madagascar, for example, the conservation organizations prefer to address global warming within their own conservation agenda, instead of incorporating conservation programs as elements in an integrated climate adaptation strategy.

The UNFCCC synthesis of reports submitted by countries and organizations on adaptation technology revealed an important additional obstacle to adaptation in the Indian Ocean and Southeast Asian region.[25] Specifically, the private sector is not involved at a sufficiently early stage. Adaptation inherently suffers from several market failures, which arise because of uncertain information associated with the costs and benefits of large-scale and long-term investment such as coastal protection measures. As a result, the private sector underinvests in adaptation.[26]

Ultimately, developing countries—including the majority of those in the Indian Ocean and Southeast Asian region—will experience climate change differently depending more on their disparate vulnerabilities and adaptive capacities than on the differing environmental impacts projected to strike their coasts.[27]

Adaptation Opportunities

Technology transfer provides important opportunities in adaptation. It is a key component of the UNFCCC process, ensuring flows of expert know-how, practical experience, and technical equipment for climate change mitigation and adaptation among stakeholders.[28] Adaptation technologies for coastal zones are normally classified as "hard" or "soft," with the former relying on permanent concrete and rock constructions, and the latter on natural elements such as sand, dunes, and vegetation. These technologies can be further classified as traditional, modern, high, and future.[29] *Traditional/indigenous technologies* are those that were first developed in traditional societies to respond to specific local problems. *Modern technologies* are those created since the Industrial Revolution. *High technologies* are those created from recent scientific advances, including information and communication

technologies and computer monitoring and modeling. *Future technologies* do not yet exist in a commercially viable form. Some traditional, modern, and high technologies used in the coastal zones are listed in table 1. Traditional technologies are vital for adaptation, but the transfer of modern technology is also necessary.

Technology transfer is not an easy process in the Indian Ocean region. Its success depends on several factors, including the type of technology, the availability of appropriate financial vehicles, and a policy environment that supports technology. As was noted with regard to

Table 1: Traditional, Modern, and High Adaptation Technologies in the Coastal Zones

Technology	Traditional	Modern	High
Restoration of coastal forests and coral reefs	X		
Sand dune restoration and construction	X		
Community-based conservation and aquaculture	X		
Seawalls, revetments, and headlands	X		
Beach nourishment and dune restoration	X		
Protection and reconstruction of wetlands	X		
Littoral drift replenishment	X		
Afforestation	X		
Creation of drainage areas	X		
Dikes, dams, levees, nets, and dredging	X	X	
Dikes and groins	X	X	
Saltwater intrusion barriers	X	X	
Tidal barriers	X	X	
Reef protection	X	X	
Detached breakwaters		X	
Coastal and coral erosion monitoring	X	X	X
Sea level and tide monitoring			X
Coastal zone monitoring			X
Impact assessment studies			X
Light detection and ranging			X

Source: Adapted from United Nations Framework Convention Climate Change, "Advance Report on Recommendations on Future Financing Options for Enhancing the Development, Deployment, Diffusion and Transfer of Technologies Under the Convention" (2009), p. 79, http://unfccc.int/resource/docs/2009/sb/eng/inf02.pdf (accessed March 4, 2010).

one adaptation program, "It is not for lack of options that adaptation lags. It is lack of determination, lack of cooperation and lack of means that impede adaptation."[30]

Given that several countries around the Indian Ocean face extreme weather events—and that these events are already increasing in intensity—it makes sense to link existing disaster reduction and prevention to climate change adaptation. Both approaches reduce risks.

For example, Cyclone Nargis tore into southern Myanmar in early May 2007, leaving over 130,000 people dead or missing. In comparison, 3,300 people lost their lives when Cyclone Sidr struck Bangladesh in November 2007. Cyclone Sidr was more powerful than Nargis, but the death toll was much lower in part because Bangladesh has a well-tested disaster reduction program. A primary condition for the success of this program is that the disaster reduction and climate change communities within the government, private sector, civil society, and scientific agencies must cooperate. Involving people and institutions at the local level is vital.[31] The Mangrove for the Future initiative, established in the wake of the Indian Ocean tsunami of December 2004, was developed in part to address the challenges that climate change poses for the Indian Ocean region, offering an example of a program combining disaster reduction and adaptation. During its initial phase in 2006–11, the project is targeting the six worst-affected countries (India, Indonesia, the Maldives, Seychelles, Sri Lanka, and Thailand) as they recover from the tsunami. The project will emphasize protection of natural barriers to extreme weather events and the rehabilitation of degraded coastal areas.[32]

In addition to funding and technology transfer, insurance-related actions have been identified as another important component of climate change adaptation. Insurance provides a vehicle to spread and transfer risk and to engage the private sector. It can be a useful instrument for developing countries, particularly coastal communities exposed to climate hazards, and for the tourism industry, which is dependent on the continuing viability of the coasts.[33] For poor communities, microfinance can also be used in climate change adaptation.[34] The idea of an international insurance scheme is not new, as proposals have been made in the past. In recent years, political support has risen for assembling suitable insurance schemes to serve the poorer countries in particular. While insurance alone will not address all of the risks or adaptation challenges of climate change, it can be a strong component of a broad-based adaptation framework.[35]

The multilateral development banks are taking a more comprehensive approach to support strengthening adaptation and resilience. The World Bank has partnered with the United Nations International Strategy for Disaster Reduction to reduce vulnerability to natural hazards and extreme events (e.g., supporting Yemen's ICZM). It has also initiated sector-specific and regional studies, examining Asian coastal cities and floods in India, among

other topics.[36] The Asian Development Bank also funds several initiatives. These include increasing the climate resilience of vulnerable sectors, such as coasts in India and Ho Chi Minh City in Vietnam, and supporting the development of private sector–based instruments such as climate-oriented insurance products.[37]

The provision of technical and institutional capacity building through international cooperation plays an important role in overcoming some of the problems in adaptation, as seen in two examples, one completed and one now in its second phase. The first example is the Assessment of Impacts and Adaptations to Climate Change (AIACC), a global initiative developed in collaboration with the IPCC and funded by the GEF to advance scientific understanding of climate change vulnerabilities and adaptation options in developing countries. Technical and institutional capacity building were provided through three general workshops (on projects, scenarios, and vulnerability and adaptation) and a series of regional workshops. Of 24 regional assessments implemented in 2001–07 under the AIACC, two projects involved several countries in the Indian Ocean and were related to coastal areas.[38] In Project AS07 (Vulnerability to Climate Change–Related Water Resource Changes and Extreme Hydrological Events in Southeast Asia), the research helped enhance the capacity of Southeast Asian countries, particularly Laos and Thailand, in the study and assessment of climate impacts and vulnerability and adaptation to climate change. Project activities helped develop the research capacity of personnel as well as build networks among institutions in Laos, Thailand, and Vietnam. Project SIS90 (Impact of Climate Change on Tourism in Seychelles and Comoros) explored the problems of coastal erosion and risks to tourism in Seychelles. To build local capacity, the project supported advanced degree research that linked adaptation to climate change, training in geographic information systems, and monitoring of beaches and coral reefs.

The second example involves the Nairobi Work Program, carried out by the UNFCCC from 2005 to 2010 in two phases, with the first phase completed in June 2008.[39] The program assists all parties to the UNFCCC—particularly developing countries, including LDCs and SIDS—improve their abilities to assess impacts, vulnerability, and adaptation to climate change. It serves as a platform for dissemination of scientific information and to support implementation of adaptation. The program focuses on two main areas (impacts and vulnerability; and adaptation planning, measures, and actions) and carries out various activities in nine subareas (methods and tools; data and observations; climate modeling, scenarios, and downscaling; climate-related risks and extreme events; socioeconomic observation; adaptation planning and practices; research; technologies for adaptation; and economic diversification) to improve capacity at various levels and sectors. This work is being further developed in the second phase for implementation by countries, intergovernmental and nongovernmental organizations, the private sector, communities, and other stakeholders, especially for developing countries.

Effective Adaptation Strategies and Policy Recommendations

Several lessons can be drawn from an assessment of the AIACC regional projects that can be helpful to the countries of the Indian Ocean and Southeast Asian region in formulating their adaptation strategies:[40]

- Follow a policy of "adapt now and don't delay," as adaptation will cost more in the future.
- Create conditions or policies to enable adaptation by individuals, communities, and the nation as a whole.
- Integrate adaptation with development planning to advance both adaptation and development goals.
- Increase awareness of and knowledge on adaptation, as insufficient information is often a constraint to taking action.
- Strengthen the roles of local and national institutions with regard to adaptation issues.
- Rehabilitate and protect natural resources from damage from climate change.
- Provide financial assistance for adaptation.
- Involve at-risk stakeholders in adaptation planning and implementation.
- Use location-specific strategies that are appropriate to the individual contexts of particular areas.

Underlying these lessons are certain basic truths about adaptation:

- There is no silver bullet. Adaptation must be location-specific, and institutional capacities are important for community-based adaptation.[41]
- Local acceptance and cooperation is vital at all stages. For successful adaptation, it is crucial to involve all stakeholders; AIACC projects have tried to involve as many as possible.
- Policy recommendations for the future should address the question of political will. Although adaptation is usually in the hands of the public sector, the private sector, NGOs, and international organizations play important roles.

A close relationship between climate change and development means that adaptation is best mainstreamed into development practice and not developed as a stand-alone activity. "Mainstreaming" refers to the integration of climate change vulnerabilities or adaptation into a related government policy, such as disaster preparedness.[42] Although mainstreaming is an emerging process, it is now primarily donor-driven and does not necessarily consider climate change an important concern. For example, the first-generation poverty reduction strategy papers produced by the United Nations Environment Programme (UNEP)

made little reference to climate change.[43] Countries in the Indian Ocean and Southeast Asia regions must understand the need to incorporate adaptation into the planning process for sustainable development. Risk management and reduction can also be incorporated into adaptation planning at all levels. The UNFCCC has prepared a technical paper that explores this approach.[44] Mainstreaming tools for the coasts are also available, such as the US Agency for International Development's adaptation guidebook tailored for coastal areas.[45]

Although many Indian Ocean and Southeast Asian countries face common and interrelated challenges, they lack a regional policy framework for climate adaptation. Cyclones and storm surges, coral bleaching, fisheries, and even tsunamis (although these last are not related to climate change, they also affect the resilience of coastal communities) are all transboundary issues. Reducing such environmental and climate change risks requires information and early-warning systems from a regional or international network. Regional capacity building in data collection, monitoring, and evaluation are required for countries to understand the shared problems facing the region and to work toward framing policy strategies for cooperative solutions. For example, many of the region's coastal ecosystems cross national borders, making regional cooperation an effective means to deal with cross-boundary issues such as fisheries and marine protected areas.[46]

The need for a regional adaptation framework has been addressed in several forums. For example, the Medium-Term Strategy (2010–13) of the UNEP Regional Seas Programme incorporates an ecosystem management component. One element of this strategy aims to assess and address the effect of climate change on the marine and coastal environment and to promote cooperation for formulating regional adaptation strategies.[47] Such efforts are under way within the Regional Seas Programme for the Pacific and Mediterranean but not yet for the Indian Ocean or Southeast Asia. Similarly, strong regional entities are dealing with climate change in the Caribbean and South Pacific. The Caribbean Community Climate Change Centre, for example, acts as a key node for information and regional responses to managing and adapting to climate change.[48] The South Pacific Regional Environment Programme operates a climate change program intended in part to develop adaptation response measures.[49] Potential opportunities exist for a large-scale regional initiative, either by using the existing policy structures or going beyond the UNFCCC framework. Two possible implementation models could be used—a regional center or a regional project. The International Ocean Commission, or a similar regional organization with international support, could take the lead in implementing an action-oriented regional project in the Indian Ocean. The project could be part of scaling-up integrated climate change adaptation and disaster reduction policies using the existing United Nations International Strategy for Disaster Reduction Hyogo Framework for Action.[50]

Current UNFCCC provisions do not mainstream climate-friendly technology into the innovation and investment frameworks of developing countries. A regional center for the Indian Ocean might therefore also help facilitate technology transfer and knowledge sharing. It could take the form of a regional center of excellence and learning to assist vulnerable communities in adaptation mechanisms, exchanging best practices, capacity building, and fostering public-private partnerships. Disseminating best practices to a wider audience is especially important for low-cost adaptation actions and measures to achieve the links among policymakers, researchers, and users. Note, however, that regional structures do not negate the necessity for place-specific strategies adapted to local contexts.

A large-scale regional initiative could also help tackle the priority problem of the small island states and low-lying deltas of the Indian Ocean and Southeast Asia. Rising sea levels and stronger storm surges pose serious risks of flooding to the densely populated Asian megadeltas, while potential inundation not only threatens small island states with the loss of their Exclusive Economic Zones but raises the specter of mass population displacements from submerged atolls. Indeed, in November 2008, the Maldivian president-elect suggested buying a new homeland abroad if sea level rise continues—an adaptation strategy with obvious international ramifications.[51]

Given these risks, the SIDS and low-lying deltas may need to consider some bold adaptation measures for the future. For example, the success of artificial island reclamation in shallow waters off the coast of Dubai could be applied to the reclamation of SIDS threatened by rising sea levels and possible extinction. Perhaps wealthy countries that have gained this expertise might help finance island reclamation for SIDS. In this way, instead of abandoning its atolls within the next century, the Maldives could adopt a strategy of saving some islands by using them as "fill" for other islands now.[52] Similarly, in deltas with sediment-rich rivers, these sediments could be channeled into low areas to create land above sea level. Bangladesh has experimented with such sedimentation engineering. At Beel Bhaina, on the banks of one of the tributaries of the Ganges, silt brought by rivers across the low-lying delta has been channeled into low-lying, flood-prone depressions.[53] Over time, pieces of high ground are created and used for agriculture. Although this is not a technique designed to counter sea level rise, it should be evaluated for such use, as success in climate adaptation often stems from the resourcefulness of local people applying local methods.

Large-scale modular mangrove planting should be considered as another measure for protecting the coast against gradual sea level rise.[54] Mangroves grow on tidal mudflats but can also survive on various substrates and in nontidal areas. The coastal strip over which mangroves grow can be raised with the addition of a wide variety of sediments to serve as a protective barrier. Thus, replanting of mangroves and coastal forest belts can be readily

adapted to different shorelines depending on the level of exposure to erosion. Replanting typically costs less than hard protection measures, and has been carried out on a small scale by local coastal communities with varying levels of success. The Asian Development Bank's policy recommendation for Southeast Asia on adaptation for coastal sectors is to implement CZM plans, including mangrove conservation and planting.[55]

Finally, some bold adaptation measures may require conceptual innovations. ICZM remains the best framework for climate adaptation for coastal regions but must be modified to meet future needs. One promising area for improvement involves integrating climate change and tsunami adaptation measures. Although tsunamis are not the result of climate change, adaptation strategies should consider both threats. Measures taken to expand and strengthen livelihoods against an extreme event such as a tsunami can also serve to increase resilience against storm surges and sea level rise.[56] At the same time, policymakers should learn to consider rising sea level as not necessarily totally negative, but as offering opportunities as well. According to the ancient Chinese treatise, *The Art of War* by Sun Tzu, one fights water with water.[57] Thus, as sea levels rise, prepared communities may be able to exploit the situation for economic gain, turning submerged land into floating gardens for food or pools for fish farming.

Conclusion

Successful adaptation will require that developing countries receive sufficient assistance both with "hardware" (appropriate technologies) and "software" (finance, institutions, and the policy environment). More importantly, such measures should show demonstrable practical solutions, especially for SIDS.

Strong national or regional policy is also necessary for adaptation. Within each country, political will is paramount. For strong regional cooperation or development of a regional framework, an impetus from outside the region or international support is sometimes necessary. Both national and regional policy must drive adaptation strategies to meet future climate change issues and challenges, which will be increasingly of a transboundary nature.

Notes

1. For overall coverage of the region's vulnerabilities, see chapters 9 ("Africa"), 10 ("Asia"), and 16 ("Small Islands") in M. L. Parry et al., eds., *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2007).

2. M. Alam et al., "Background Paper—Impacts, Vulnerability and Adaptation to Climate Change in Asia," Beijing, China, April 11–13, 2007, http://unfccc.int/files/adaptation/methodologies_for/vulnerability_and_adaptation/application/pdf/unfccc_asian_workshop_background_paper.pdf (accessed March 3, 2010).

3. B. O. Elasha et al., "Background Paper on Impacts, Vulnerability and Adaptation to Climate Change in Africa for the African Workshop on Adaptation," Accra, Ghana, September 21–23, 2006, http://unfccc.int/files/adaptation/adverse_effects_and_response_measures_art_48/application/pdf/200609_background_african_wkshp.pdf (accessed March 3, 2010).

4. Intergovernmental Panel on Climate Change, "Summary for Policymakers," in Parry et al., op. cit., p. 12.

5. Details on the vulnerabilities of individual countries are available in each state's Initial National Communication submitted to the United Nations Framework Convention Climate Change (UNFCCC), listed under National Communications (Non-Annex I), at www.unfccc.int/national_reports/items/1408.php (accessed March 3, 2010).

6. R. V. Cruz et al., "Asia," in Parry et al., 2007, p. 476.

7. National Institute for Disaster Management, "Study on the Impact of Climate Change on Disaster Risk in Mozambique Synthesis Report—First Draft" (2009), p. 9, www.irinnews.org/pdf/Synthesis_Report_Final_Draft_March09.pdf (accessed March 3, 2010).

8. J. B. Elsner, J. P. Kossin, and T. H. Jagger, "The increasing intensity of the strongest tropical cyclones," *Nature* 455 (2008): 92–95.

9. E. L. F. Schipper, M. P. Cigarán, and M. M. Hedger, *Adaptation to Climate Change: The New Challenge for Development in the Developing World* (Nairobi: United Nations Environment Programme, 2008), www.undp.org/climatechange/docs/English/UNDP_Adaptation_final.pdf (accessed March 3, 2010).

10. See National Communications of individual countries at the UNFCCC website.

11. S. Huq and H. Reid, *Community Based Adaptation: An IIED Briefing* (London: International Institute for Environment and Development, 2007).

12. P. H. Taylor, "Climate changes everything: ecosystem-based management in the sea," *Gulf of Maine Times* 10, no. 2 (2006), www.gulfofmaine.org/times/summer2006/scienceinsights.html (accessed March 3, 2010).

13. R. F. McLean et al., "Coastal Zones and Marine Ecosystems," in J. J. McCarthy et al., eds., *Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2001), p. 367.

14. Alam et al., op. cit, pp. 24–26.

15. Asian Development Bank (ADB), *The Economics of Climate Change in Southeast Asia: A Regional Review* (Mandaluyong City, Philippines: ADB, 2009), pp. 115–16.

16. Alam et al., p. 19.

17. For updates and details on adaptation funds, see the Cooperation and Support page of the UNFCCC website, http://unfccc.int/cooperation_and_support/items/2664.php (accessed March 3, 2010).

18. Alam et al., op. cit., table 4.

19. Based on the 41 NAPAs received by the UNFCCC Secretariat, http://unfccc.int/cooperation_support/least_developed_countries_portal/submitted_napas/items/4585.php (accessed March 3, 2010).

20. United Nations Development Programme, *Human Development Report 2007/2008* (Basingstoke, UK: Palgrave MacMillan, 2007), p. 189.

21. Global Environment Facility, *Progress Report on the Least Developed Countries Fund (LDCF) and the Special Climate Change Fund (SCCF),* LDCF/SCCF Council Meeting, 13 November 2008, GEF/LDCF.SCCF.5/Inf.3 (October 21, 2008), www.gefweb.org/uploadedFiles/Documents/LDCFSCCF_Council_Documents/LDCF-SCCF5_November_2008/LDCF.SCCF.5.Inf.3%20Progress%20Report.pdf (accessed March 3, 2010).

22. M. Kok et al., "Integrating development and climate policies: national and international benefits," *Climate Policy* 8, no. 2 (2008): 103–18.

23. M. L. Parry et al., *Assessing the Costs of Adaptation to Climate Change* (London: International Institute for Environment and Development, 2009), www.iied.org/pubs/pdfs/11501IIED.pdf (accessed March 3, 2010).

24. Kok et al., op. cit.

25. UNFCCC, *Synthesis of Outcomes of the Regional Workshops and Expert Meeting on Adaptation under Decision 1/CP.10*, Subsidiary Body for Implementation, Twenty-sixth session, Bonn, May 7–18, 2007, FCCC/SBI/2007/14 (2007), http://unfccc.int/resource/docs/2007/sbi/eng/14.pdf (accessed July 28, 2009).

26. ADB, op. cit., pp. 214–15.

27. O. Mertz et al., "Adaptation to climate change in developing countries," *Environmental Management* 43, no. 5 (2009): 743–52.

28. UNFCCC, "Advance Report on Recommendations on Future Financing Options for Enhancing the Development, Deployment, Diffusion and Transfer of Technologies Under the Convention" (2009), p. 79, http://unfccc.int/resource/docs/2009/sb/eng/inf02.pdf (accessed March 4, 2010).

29. Ibid, p. 17.

30. N. Leary et al., eds., *Climate Change and Adaptation* (London: Earthscan, 2008), p. 17.

31. Kok et al., op. cit.

32. Mihoko Kumamoto and Bo Lim, "Climate change and the MDGs in Asia Pacific: challenges and opportunities," *Inside Asia Pacific* 2, no. 2 (2007).

33. United Nations Framework Convention on Climate Change (UNFCCC), *Climate Change: Impacts, Vulnerabilities and Adaptation in Developing Countries* (Bonn: UNFCCC Secretariat, 2007), pp. 39–41.

34. A. Hammill, R. Matthew, and E. McCarter, "Microfinance and climate change adaptation," *IDS Bulletin* 39, no. 4 (2008): 113–22.

35. S. Harmeling, *Adaptation Under the UNFCCC—The Road from Bonn to Poznan 2008, Version 1.0, August 2008* (Bonn: GermanWatch, 2008), p. 56, www.germanwatch.org/klima/bonnadapt08e.htm (accessed March 3, 2010).

36. World Bank, *Development and Climate Change—The World Bank Group at Work* (Washington, DC: World Bank, 2009).

37. See ADB, "Climate Change: Sample List of Projects by Sector," www.adb.org/Climate-Change/projects.asp#adaptation (accessed March 3, 2010).

38. N. Leary, J. Kulkarni, and C. Seipt, *Assessments of Impacts and Adaptation to Climate Change*, Final Report of the Assessments of Impacts and Adaptations to Climate Change (AIACC) Project (Washington, DC: International START Secretariat, 2007).

39. See the UNFCCC website for the Nairobi Work Programme, http://unfccc.int/adaptation/sbsta_agenda_item_adaptation/items/3633.php (accessed March 3, 2010).

40. Leary, Kulkarni, and Seipt, op. cit., pp. 33–36.

41. Alam et al., op. cit., p. 29.

42. UNFCCC, 2007, op. cit., p. 44

43. Mertz et al., op. cit.

44. UNFCCC, *Integrating Practices, Tools and Systems for Climate Risk Assessment and Management and Strategies for Disaster Risk Reduction into National Policies and Programmes*, Technical paper, FCCC/TP/2008/4 (2008), http://unfccc.int/resource/docs/2008/tp/04.pdf (accessed March 3, 2010).

45. US Agency for International Development (USAID), *Adapting to Climate Variability and Change: A Guidance Manual for Development Planning* (Washington, DC: USAID, 2007).

46. ADB, op. cit., p. 210.

47. See the United Nations Environment Programme website for the Regional Seas Programme, www.unep.org/regionalseas/about/strategy/default.asp (accessed March 3, 2010).

48. See the website for the Caribbean Community Climate Change Centre, http://caribbeanclimate.bz/news.php (accessed March 3, 2010).

49. See the website for the Pacific Regional Environment Programme, www.sprep.org/climate_change/index.asp (accessed March 3, 2010).

50. Kok et al., op. cit.; see also www.unisdr.org/eng/hfa/hfa.htm (accessed March 3, 2010).

51. "Paradise almost lost: Maldives seek to buy a new homeland," *Guardian*, November 10, 2008, www.guardian.co.uk/environment/2008/nov/10/maldives-climate-change (accessed March 3, 2010).

52. Based on P. P. Wong, "Climate Change Impacts on Coastal Infrastructures," unpublished presentation at Expert Consultation on Climate Change and Coastal Zones, Colombo, Sri Lanka, March 19–20, 2009.

53. Somini Sengupta, "In silt, Bangladesh sees potential shield against sea-level rise," *New York Times*, March 19, 2009.

54. Based on P. P. Wong, "Mangroves—Coastal Protection Measure for Tsunamis and Sea-Level Rise," unpublished presentation at Coastal Zone Management in Relation to Extreme Events, University of Twente, June 19, 2009.

55. ADB, op. cit., p. 215.

56. P. P. Wong, "Rethinking post-tsunami integrated coastal management for Asia-Pacific," *Ocean and Coastal Management* 52, no. 7 (2009): 405–10.

57. Sun Tzu, *The Art of War*, Thomas Cleary, trans. (Boston: Shambala, 1988).

Interpreting the Trends

The Policy Challenges: Looking Ahead

David Michel

The papers gathered in this volume present a rich variety of perspectives on the multifaceted challenges that climate change poses for coastal regions. Yet while each author takes a different angle of approach, certain shared issues run through their contributions. These salient threads trace several critical policy considerations that coastal managers will have to address. They also point to a number of unresolved questions for further research and analysis.

Climate Policy Mainstreaming and Integrated Coastal Zone Management

Coastal zones are complex geographic entities. They encompass diverse human activities and ecological processes in interconnected maritime and terrestrial spaces. Global warming poses potentially significant threats to these interdependent systems and to the natural and built environments that support them. Emerging climate stresses will increasingly endanger the food security, water security, health, and livelihoods of coastal populations. Consequently, climate considerations must be "mainstreamed" into all aspects of policy formulation for coastal areas. Policymakers will need to practice Integrated Coastal Zone Management (ICZM), incorporating holistic environmental risk assessments into sustainable development planning that balances economic and social objectives with the preservation of vital ecosystem services.

Currently, much coastal zone management falls well short of this ideal. Frequently, perceived economic priorities prevail at the expense of environmental considerations. For policymakers in developing countries across much of the Indian Ocean region, eventual climate impacts appear quite distant relative to more immediate poverty alleviation imperatives. In the Gulf countries, by contrast, spectacular wealth—not deprivation—has often overridden environmental concerns. Here, developers have built colossal artificial islands with little regard for the consequences to coastal ecologies.

Integrated policy planning requires decision makers to think across political boundaries as well as across functional fields. Climate change impacts ignore administrative and

jurisdictional borders. Data collection, monitoring, and policy design should therefore correspond to the scale of habitats, catchments, and ecological zones. Implementation should be defined by social and environmental rather than political parameters. Unfortunately, current policymaking too often restricts public deliberation and decision to particular stakeholders and policy elites. Local communities frequently find themselves excluded from centralized, state-level policy processes while ecosystem needs have no voice at all.

In addition to arguments from social equity, there is also a pragmatic political case to be made for more inclusive decision making. Policy treatments that are inappropriate, inapplicable, or politically unacceptable to local contexts will not likely deliver satisfactory results. Indeed, the practical success or failure of most policy intervention ultimately hinges on the commitment and conduct of local actors. Similar arguments apply in many cases to the private sector. Private firms, for instance, typically own the technologies that coastal communities will need to alleviate or adapt to climate impacts. Like other local constituencies, private firms can, by their behavior, either further or frustrate policymakers' broader objectives.

The Adaptation Imperative

Emissions mitigation remains essential to combating climate change. Adaptation efforts will be the more costly and extensive the greater the climate stresses to which societies must try to adjust. So too, beyond certain thresholds, adaptation measures may become fruitless or even counterproductive.* Nevertheless, even if the international community could halt all greenhouse emissions tomorrow, the accumulated inertial momentum of the climate system would still result in continuing global warming and centuries of rising sea levels. Indeed, evidence assembled since the Intergovernmental Panel on Climate Change released its Fourth Assessment Report in 2007 indicates that sea levels are already mounting more rapidly than previously predicted.[1] The countries most vulnerable to rising seas bear little historical responsibility for this trend and can do little to alter it, their emissions constituting a tiny portion of the world total. Consequently, policymakers must urgently undertake measures for adapting to climate changes that can no longer be avoided.

Much climate adaptation, though, will unfold beyond policymakers' control. Natural systems will move to adjust to changing climatic conditions regardless of—or sometimes despite—human actions. But they may (or may not) do so in ways conducive to human ends. Species may migrate; they may go extinct. Ecosystems, flora, and fauna can only adapt in

*Thus, for example, boreholes can supplement freshwater supplies during the dry season affecting small islands. Extensive reliance on pumping underground reservoirs to compensate for shifting precipitation patterns, however, can lead to surface subsidence of the land above, exacerbating the hazard small islands face from sea level rise.

reaction to global warming; they cannot adapt in ways that counter climate changes, and their adaptations may fail. Ironically then, humans may have to intervene most emphatically where they wish to preserve natural ecologies or sustain natural ecosystem services, such as to maintain protective coastal wetlands.

Climate change exposes coastal zones to both gradual, cumulative stresses such as sea level rise and episodic pressures from extreme events such as stronger cyclones. For the most part, policymakers evince considerably greater worry about the latter. Though it represents an incomplete assessment of the climate risk, this growing preoccupation with a potential increase in the frequency and severity of natural disasters may play a useful role. It supplies governments a sharper political catalyst than the remote motivation of prospective long-term threats. At the same time, moves to prepare early-warning systems, disaster management, and response strategies can serve more generally to build adaptive capacity and bolster resilience to the broad range of climate change impacts.[2] Yet, contrary to policymakers' present perceptions, a number of coastal regions face greater dangers from the more chronic risks of climbing sea levels against which they have less ready defense. Many coastal communities, particularly those habituated to monsoon cycles, have developed numerous coping strategies for the already existing peril of recurring storms. In Bangladesh, for instance, farmers have turned to floating gardens, called *baira*, in the face of seasonal flooding. But creeping saline contamination as rising sea levels carry saltwater into the river deltas gradually renders these gardens impracticable.

Adaptation Hardware and Software

Much of the current policy debates regarding climate change mitigation revolve around the challenges of developing new sustainable technologies and deploying them to developing countries. In the field of coastal adaptation, in contrast, myriad effective technologies are already in use across the developing world. Water desalination techniques for furnishing freshwater supplies are highly developed in the Gulf region and increasingly in the small island states. Bangladesh has built more than 12,000 kilometers (longer than the entire shoreline of Sri Lanka) of protective coastal embankments and hundreds of raised and reinforced storm shelters. Such technical options—what might be called "hardware" solutions—are available for numerous adaptation problems.

For many countries, securing the "software" of adaptation—financial resources, institutional structures, and social practices that support adaptation policies—has proven more problematic. Adaptation technologies are often costly, and the most vulnerable countries and communities frequently lack sufficient financial resources to acquire them. The parties to the international greenhouse regime established by the United Nations Framework Convention on Climate Change (UNFCCC) and the follow-on Kyoto Protocol have created a dedicated Adaptation Fund, but financing levels to date are sorely inadequate.

Current UNFCCC analyses report that financing adaptation measures in coastal zones will require additional annual investment flows of US$11 billion per year by 2030. But these estimates, like most such studies, consider only the incremental cost of adaptation—that is, they suppose that there is already good infrastructure in place to upgrade against climate change. In many places, however, particularly in the developing world, this is not the case. Consequently, many coasts face a preexisting "adaptation deficit" that most adaptation cost calculations miss. Two additional deficiencies further weaken the UNFCCC conclusions. First, the UNFCCC numbers rely on projections of future sea level rise that now appear too conservative. Second, the estimates fail to consider significant coastal impacts beyond sea level rise, such as the danger of more severe storms. As a result, one recent review suggests that actual coastal adaptation needs could plausibly reach three times the UNFCCC figures, while the costs of making up the coastal adaptation deficit likely exceed the US$11 billion per year the UNFCCC reckons future adaptation will demand.[3] At the most recent international negotiations, held in Copenhagen in December 2009, the developed country parties jointly pledged to mobilize US$100 billion annually in public and private financing by 2020 to help fund mitigation and adaptation in developing countries. (By comparison, the World Bank's *World Development Report 2010* put combined annual adaptation and mitigation requirements by 2030 at US$275 billion.[4]) But the Copenhagen accord is legally nonbinding. Moreover, several critical questions remain about where this money will come from, how much will be "new and additional" over existing development assistance, and whether developed countries will make the funding conditional on developing country mitigation policies or other obligations—a possibility the developing countries hotly reject.[5]

Establishing effective adaptation strategies also exacts substantial demands on policy institutions. Adaptation is necessarily site specific. Planning and implementation ought to engage the participation of local communities, incorporate local knowledge, and reflect the local specificities of the particular environments in which policies will be enacted. Yet policymakers often simply do not have the detailed local information (e.g., fine-grained climate models to project local impacts, empirical time-series records of climate indicators, etc.) to so tailor policy decisions. Similarly, policymakers frequently lack the financial and institutional resources and processes to effectively monitor, evaluate, and revise national policies, much less local measures.[6] Many policy declarations and action plans initiated by national governments and regional organizations rest unexecuted. They are not carried down through the ministries, to local levels, or to the point of technical application. Mechanisms for gathering and diffusing policy lessons and best practices across locales, countries, or regionally remain largely to be developed.

Finally, beyond technological strategies, meeting the climate challenge will demand behavioral changes from human society and conceptual shifts from decision makers. The persistent uncertainties and long time horizons characterizing climate risks create a novel

decision environment requiring the development of new cognitive paradigms for framing policy planning and choice.[7] As yet, however, these changes have still to be realized.

"Small Islands, Big Issues"

The small, low-lying island nations embody in concentrated form many of the thorniest challenges that climate change poses to coastal regions. They make virtually no contribution to the greenhouse gases that drive climate change, yet they will bear the full brunt of global warming's direst consequences. The small island states are essentially completely coastal; no point lies farther than a few kilometers from the sea. The coastal impacts of climate change will inevitably reverberate throughout these societies. To these countries, slow sea level rise and sudden storm surges alike represent existential threats that could potentially eradicate them entirely.

For the so-called small island developing states (SIDS), even more so than for other coastal countries, adaptation constitutes a vital national priority. To be sure, the small islands continue to press for vigorous mitigation targets, advocating more stringent emissions reductions than most other countries espouse. Nevertheless, the SIDS exhibit growing impatience with the slow pace of the international negotiations. The small island nations simply cannot wait. And indeed they have not.

Small island states now stand in the vanguard on many fronts of climate policy and integrated coastal management. Despite their own insignificant emissions, they have begun to move aggressively to curb their greenhouse gas production as well as build their adaptive capacities. Mauritius, for instance, has launched a "Sustainable Island" initiative, supported by the government of France, heavily devoted to developing wind and solar power. In 2009, the Maldives announced its intention to become fully carbon neutral within the decade by switching wholly to renewable fuels.[8] So too, Seychelles already mainstreams climate policy into crosscutting issues of coastal development through 10-year national environmental management plans. And all the island countries are partnering with the private sector to promote sustainable tourism. (Although, much as they champion adaptation strategies, the small island nations—and the developing countries in general—have announced more action than they have implemented.) Indeed, such is the policy commitment of the island countries that several observers suggest that the SIDS could serve as key proving grounds where adaptive policy measures can be field tested against emerging climate impacts.

Despite their avowed political will, geography condemns the SIDS to an inescapable policy bind. The small island nations can only *accommodate* or *protect* against so much climate change; they have no space to practice the third adaptation option of *retreat*. Without rigorous mitigation measures from the rest of the world—an eventuality over which they

exercise no control—countries such as the Maldives, Mauritius, and Seychelles, might be forced to abandon certain islands, or even evacuate their territory altogether.

Such population displacements would have multiple, tangled implications for the countries of origin, the destination countries, and the migrants themselves. For example, the first people to move would likely be those with the capacities—money, job skills, family ties—to do so, leaving behind the more vulnerable and those with lesser resources. What impacts would this have on the sending states? How would such migrants be received in countries that may already be poor and crowded? Where should climate migrants go? To the nearest country? To polluter countries that "caused" the migrants' plight? To countries with jobs? To countries with space, with the requisite environmental carrying capacity? What becomes of the citizenship of a people whose country has disappeared? What of the citizens of other countries now living in the small island nations? (In addition to its native population of some 300,000 people, the Maldives is home to an additional 67,000 expatriate workers who are not counted in the census.[9]) What becomes of the sovereignty—or of the Exclusive Economic Zones—of states swallowed under the waves? Should such migration be left to the choices of individual emigrants and the disparate decisions of various immigration authorities? Or should climate migration be prepared or planned for in some way? The presidents of the Maldives and Kiribati have spoken of buying land in other countries as a safe haven to which their compatriots could move if necessary.[10]

The same questions could be asked about potential population movements within climate-afflicted states, from the flood-prone Nile Delta to other regions of Egypt, for example. Is there a "right" to migrate under such circumstances? Is there a "right" *not* to be forced to migrate by such circumstances? The possibility that unchecked global warming could generate thousands, hundreds of thousands, even millions of climate refugees from island states and other countries as well poses tremendous political and ethical dilemmas with which the international community has barely begun to wrestle.

Unresolved Policy Questions

The policy problems and preoccupations tackled by the authors of this volume shed light on many significant issues but leave several important questions outstanding. Chief among these is a tension threaded throughout the papers linking policy process, actors, and substance. The goal of developing and implementing holistic coastal management strategies—integrating multiple actors, uses, and demands at multiple scales—may conflict with the objective of crafting policies to reflect local specificities. Holistic approaches must necessarily assimilate multiple competing considerations, eventually muddying or compromising some in favor of others, departing from unique contexts, and abstracting local particularities. Locally tailored strategies, on the other hand, depend on context; they cannot be abstracted without losing their specificity.

Integrated Coastal Zone Management represents the dominant policy approach for grappling with this dilemma. Indeed, some experts argue that ICZM needs to be applied globally to meet the myriad emerging challenges imposed by global environmental change.[11] The ICZM paradigm itself, however, rests on some unsettled foundations. At its core, ICZM proposes consultation among contending stakeholders and coordination among diverse interests and institutions in order to reach policy decisions. But ICZM offers no constant guide as to how such consultation and coordination are best organized. What stakeholders must be consulted and what decision rule should apply when their interests diverge or their needs conflict? Does policy coordination necessitate institutional integration? If so, then how much integration, formal or informal, involving which institutions, is required? ICZM has no definitive answers. Ultimately, opines one expert, "coastal management is an irreparably complex phenomenon…[T]he 'multi-layered political administrative system' notoriously criticised in the ICZM literature…is neither a temporary flaw in the system nor a short term administrative aberration; it is structurally inevitable."[12]

By the same token, to formulate policies integrating multiple sectors across multiple scales, decision makers must determine what sectors to include and what scales to balance. But ICZM has yet to define consistent parameters for delimiting its effective sectoral scope and appropriate geographic extent. Thus, for example, coastal managers well know how inland rivers influence the seaboard. The water runoff, mineral sediments, and organic materials draining from upland basins continually nourish estuaries, fertilize wetlands, renew and reconfigure shorelines, and shape and reshape coastal deltas. Human interventions weigh heavily on these processes. According to recent global studies, upstream dams and diversions now trap almost one-third of all the sediment flow that would otherwise have reached the coastal zone. Absent these sediments to replenish the land that river currents carry away, deltas will suffer greater relative sea level rise. One assessment found that this loss of river-borne sediment accounted for substantially more relative sea level rise than did mounting ocean levels in nearly 70 percent of 40 deltas surveyed around the world.[13] Water policymakers are keenly aware of these trends. And, ironically, water mangers widely employ techniques of Integrated Water Resources Management (IWRM) quite similar in approach to ICZM. Yet ICZM and IWRM have developed as largely separate disciplines, rarely linked in planning or in practice.[14]

The international climate negotiations provide a telling test case illustrating the difficulty for decision makers of keeping both the whole and the parts of the climate problem in view to structure an integrative policy vision. Despite years of deliberations, governments seem to have not yet reached satisfactory solutions. Where large delegations allow individual representatives to concentrate on particular topics in detail, the view of each authority is fragmented by specialization. Where smaller delegations oblige fewer diplomats to cover the broader field of issues, no authority can comprehend the whole in any depth. Resolving

these tensions, if indeed it can be done, will place significant demands on the financial, organizational, and human capacities of governing institutions. The organizing principles and institutional architectures—local, national, regional, and global—of the governance structures required to meet this policy puzzle remain to be established.

Notes

1. Catherine P. McMullen and Jason Jabbour, eds., *Climate Change 2009 Science Compendium* (Nairobi: United Nations Environment Programme, 2009).
2. International Strategy for Disaster Risk Reduction, *Global Assessment Report on Disaster Risk Reduction* (Geneva: United Nations, 2009).
3. M. L. Parry et al., *Assessing the Costs of Adaptation to Climate Change* (London: International Institute for Environment and Development, 2009), www.iied.org/pubs/pdfs/11501IIED.pdf (accessed March 3, 2010).
4. World Bank, *World Development Report 2010: Development and Climate Change* (Washington, DC: World Bank, 2009).
5. See Liane Schalatek, Neil Bird, and Jessica Brown, "Where's the Money? The Status of Climate Finance Post-Copenhagen" (Heinrich Böll Foundation and Overseas Development Institute, 2010), www.boell.org/downloads/HBF-ODI_ClimateFinace_Post-Copenhagen_WhereIsTheMoney.pdf (accessed March 10, 2010).
6. Ian Christoplos et al., *The Human Dimension of Climate Adaptation: The Importance of Local and Institutional Issues* (Stockholm: Commission on Climate Change and Development, 2009).
7. See, e.g., National Research Council, *Informing Decisions in a Changing Climate* (Washington, DC: National Academies Press, 2009).
8. Duncan Clark, "Maldives first to go carbon neutral," *Guardian*, March 15, 2009.
9. US Department of State, "Background Note: Maldives" (Bureau of South and Central Asian Affairs, 2009), www.state.gov/r/pa/ei/bgn/5476.htm (accessed March 10, 2010).
10. Andrew C. Revkin, "Maldives considers buying dry land if seas rise," *New York Times*, November 10, 2008; Subramanian Sharma, "Kiribati islanders seek to buy land as rising seas threaten," Bloomberg.com, February 8, 2009, www.bloomberg.com/apps/news?pid=20601090&sid=a0kuXMsICBhg (accessed March 10, 2010).
11. Peter J. Ricketts, "State of Fear or State of Oblivion? What Coastal Zones are Telling Us about Global Change and Why We Need Integrated Coastal and Ocean Management on a Global Scale," in Erlend Moksness, Einar Dahl, and Josianne G. Støttrup, eds., *Integrated Coastal Zone Management* (Chichester, UK: Wiley-Blackwell, 2009).
12. Raphaël Billé, "Integrated Coastal Zone Management: four entrenched illusions," *Sapiens* 1, no. 2 (2008): 6.
13. Charles J. Vörösmarty et al., "Battling to save the world's river deltas," *Bulletin of the Atomic Scientists* 65, no. 2 (2009).
14. P. S. Rasch et al., "Linking integrated water resources management and Integrated Coastal Zone Management," *Water Science and Technology* 15, no. 11 (2005).

Appendix 1:
Author Biographies

Alain De Comarmond is a Director in the Ministry of Environment, Natural Resources and Transport in Seychelles. Mr. De Comarmond joined the Department of Environment in 2001, where he now oversees coastal management issues and policies in Seychelles and administers environmental impact assessments. He is an active member of the Seychelles National Climate Change Committee responsible for coastal adaptation issues and has participated in the production of several of the country's national reports to the UN Framework Convention on Climate Change. Mr. De Comarmond was recently appointed to the Board of Trustees for the Sea Level Rise Foundation.

Mohamed El Raey is Professor of Environmental Physics and former Dean of the Institute of Graduate Studies and Research at the University of Alexandria, Egypt. He is also Chairman of the Environment Committee for the Supreme Council of Egyptian Universities; Vice President of Friends of the Environment, an Egyptian NGO; and a senior environmental consultant at the Arab Academy of Science, Technology and Maritime Transport. From 1995 to 2003, Dr. El Raey represented Egypt on the Intergovernmental Panel on Climate Change Working Group II on Impacts, Adaptation, and Vulnerability.

Nazria Islam is a Senior Research Officer at the Bangladesh Centre for Advanced Studies. Previously, she was a Program Officer at the International Federation of Red Cross and Red Crescent Societies, Bangladesh Delegation, and led assessment teams and relief operations following Cyclone Sidr in 2007. She has worked in the Dhaka office of the United Nations Development Programme and of the United Nations World Food Programme's Disaster Preparedness and Response Section.

David Michel is Senior Associate in the *Regional Voices: Transnational Challenges* project and Director of the Environmental Security program at the Stimson Center. He previously served as Senior Associate at the Center for Transatlantic Relations at the Johns Hopkins University's Paul H. Nitze School of Advanced International Studies. He has written widely on the human security and international governance challenges presented by global environmental change and has advised the US government and consulted with several NGOs on climate policy issues.

Nirmalie Pallewatta is a Senior Lecturer and Coordinator of the Environment Science master's degree program in the Department of Zoology at the University of Colombo, Sri Lanka. She previously served as a Program Officer for the International Union for Conservation of Nature (IUCN), Asia Regional Biodiversity Program, and was the team leader for environmental impact and assessment in the western coastal zone of Sri Lanka following the Indian Ocean tsunami of December 2004. A zoologist by training, Dr. Pallewatta received her Ph.D. in 1986 from the Imperial College of Science, Technology and Medicine at the University of London.

Rolph Payet is the President and Vice Chancellor of the University of Seychelles. In addition, he is special advisor to the President of the Republic of Seychelles on sustainable development, biodiversity, climate change, energy, and international environment policy. Dr. Payet has received numerous international awards and recognition for his work. In 2007, he shared in the Nobel Peace Prize as a lead author of the Intergovernmental Panel on Climate Change Fourth Assessment Report and was selected as a Young Global Leader by the World Economic Forum.

Golam Rabbani is a Senior Research Officer at the Bangladesh Centre for Advanced Studies. He has spent almost 10 years working on environment and climate change–related issues at the national and regional levels, mainly in the areas of vulnerability and risk assessment, risk management, adaptation and policy, and institutions. He is a member of Climate Action Network–International and has coordinated the Climate Change Development Forum in Bangladesh since 2005.

A. Atiq Rahman is the Executive Director of the Bangladesh Centre for Advanced Studies. He is the Chairman of the Climate Action Network–South Asia; current Chairperson of the International Union for Conservation of Nature (IUCN), Bangladesh; and a Visiting Professor of international diplomacy and sustainable development at the Fletcher School of Law and Diplomacy, Tufts University. Dr. Rahman was named Champion of the Earth 2008 by the United Nations Environment Programme for the Asia Pacific Region, and was a lead author of the Intergovernmental Panel of Climate Change Fourth Assessment Report, which received the Nobel Peace Prize in 2007.

Poh Poh Wong is an Associate Professor in the Department of Geography at the National University of Singapore. He was a coordinating lead author of the Intergovernmental Panel on Climate Change Fourth Assessment Report, sharing in the 2007 Nobel Peace Prize jointly awarded to the panel and Al Gore. He also contributed to the Millennium Ecosystem Assessment that won the Zayed International Prize for the Environment in 2005. Dr. Wong's research includes geomorphology and climate change relating to coasts and islands. He has conducted fieldwork on tsunami-impacted coasts in southern Thailand, Aceh, Tamil Nadu, and Sri Lanka. He holds a PhD from McGill University.

Appendix 2:
Experts Consulted

Colombo Meeting Participants

Amjad Abdulla, Ministry of Environment, Energy and Water, Republic of Maldives
Rajandranath Awotar, Mauritius Council for Development, Mauritius
Amrit Bart, Asian Institute of Technology Center in Vietnam, Vietnam
Mihir Bhatt, All India Disaster Mitigation Institute, India
Junaid Choudhury, Consultant, Bangladesh
Alain De Comarmond, Ministry of Environment, Republic of Seychelles
P. Ruchira T. Cumaranatunga, University of Ruhuna, Sri Lanka
Alfonse Dubi, Institute of Marine Sciences, University of Dar es Salaam, Tanzania
Dia El Din El Quosy, Advisor to the Ministry of Water Resources and Irrigation, Egypt
Lakshman W. Galagedara, University of Peradeniya, Sri Lanka
A. Hettiarachchi, International Union for Conservation of Nature (IUCN) Sri Lanka
S. S. L. Hettiarachchi, University of Moratuwa, Sri Lanka
Amal Jayawardane, Regional Centre for Strategic Studies, Sri Lanka
Edward Kimani, Kenya Marine and Fisheries Research Institute, Kenya
Deepti Mahajan, The Energy and Resources Institute, India
Gayathri Nanayakkara, Regional Centre for Strategic Studies, Sri Lanka
Samira Omar, Kuwait Institute for Scientific Research, Kuwait
Nirmalie Pallewatta, University of Colombo, Sri Lanka
Golam Rabbani, Bangladesh Centre for Advanced Studies, Bangladesh
Mohamed Abdel Raouf, Gulf Research Center, United Arab Emirates
Nihal Rodrigo, Honorary Advisor to the President of Sri Lanka, Sri Lanka
Jayampathy Samarakoon, consultant on Bangladesh, India, and Sri Lanka
Gunavi Samarasinghe, Sri Lanka Meteorology Department, Sri Lanka
Geetha de Silva, Regional Centre for Strategic Studies, Sri Lanka
Waduwawatte L. Sumathipala, Ministry of Environment and Natural Resources, Sri Lanka
R. Venkatesan, South Asia Co-operative Environment Programme, Sri Lanka
K. D. D. Wijewardena, Department of Coast Conservation, Sri Lanka
Poh Poh Wong, National University of Singapore, Singapore

Regional Experts Interviewed

Bahrain

Waleed K. Al-Zubari, Arabian Gulf University

Bangladesh

Emaduddin Ahmad, Institute of Water Modelling

Manjur Murshed Zahid Ahmed, Institute of Water Modelling

Raquibul Amin, Programme Coordinator, International Union for Conservation of Nature (IUCN)

Giasuddin Ahmed Choudhury, Center for Environmental and Geographic Information Services

Malik Fida A. Khan, Center for Environmental and Geographic Information Services

Ainun Nishat, International Union for Conservation of Nature (IUCN)

A. Atiq Rahman, Bangladesh Centre for Advanced Studies

Quamrul Islam Siddique, Bangladesh Water Partnership

Cambodia

Tep Bunnarith, Culture and Environment Preservation Association

Egypt

Dia El Din El Quosy, Advisor to the Ministry of Water Resources and Irrigation

Mohamed El Raey, University of Alexandria

India

Ram Chandra Khanal, International Union for Conservation of Nature (IUCN)

Chandan Mahanta, Indian Institute of Technology–Guwahati

Indonesia

I. Nyoman Suryadiputra, Wetlands International Indonesia Programme

Purbasari Surjadi, Sustainable Fisheries Partnership

Kenya

Justus Inonda Mwanje, Institute of Policy Analysis & Research

Malaysia

Mak Joon Num, Independent Maritime Analyst, Malaysia

Khairulmaini Osman Salleh, University of Malaya

Mauritius

Rezah Badal, Mauritius Oceanography Institute

Shyam Hurbungs, Mauritius Council for Development, Environmental Studies & Conservation

Soodursun Jugessur, Mauritius Research Council

Munesh Munbodh, Ministry of Agro Industry, Food Production and Security (Fisheries Division)

Shyama Rathacharen, Ministry of Agro Industries and Fisheries (Fisheries Division)

Arjoon Suddhoo, Mauritius Research Council

Oman

Hamood Al Maskry, Riyadh-Memorandum of Understanding for Port State Control Secretariat

Philippines

Nicolas Bailly, WorldFish Center

Rex Victor O. Cruz, University of the Philippines, Los Baños

Angela Consuelo S. Ibay, Manila Observatory

Len Garces, WorldFish Center

Rodel D. Lasco, World Agroforestry Centre

Antonia Yulo Loyzaga, Manila Observatory

Deanna Marie P. Olaguer, Manila Observatory

Juan Pulhin, College of Forestry and Natural Resources, University of the Philippines Los Baños

Ramon Faustino M. Sales, Jr., Philippine Rural Reconstruction Movement

Singapore

Fwa Tien Fang, National University of Singapore

Joshua Ho, Rajaratnam School of International Studies

Bernard Tan Tiong Gie, National University of Singapore

Tanzania

Prajesh Bhakta, African Development Bank Group Tanzania Country Office

Oswald Leo, African Development Bank Group Tanzania Country Office

Benjamin Peter Ngatunga, Tanzania Fisheries Research Institute

Ignatious Nhnyete, Tanzania Ports Authority

Sam Turay, African Development Bank Group Tanzania Country Office

Thailand

Rujarek Bumrasarinpai, Southeast Asian Fisheries Development Center

M. Zakir Hussain, International Union for Conservation of Nature (IUCN)

Javed Hussain Mir, Asian Development Bank

Patricia Moore, International Union for Conservation of Nature (IUCN)

Ganesh Pangare, International Union for Conservation of Nature (IUCN)

Somnuk Pornpatimakorn, Southeast Asian Fisheries Development Center

Anond Snidvongs, Southeast Asia START Global Change Regional Center

Nualanon Tongdee, Southeast Asian Fisheries Development Center

Vute Wangwacharukul, Kasetsart University

United Arab Emirates

Saif Mohammed Al-Ghais, Marine Environment Research Section, United Arab Emirates University

Mariam Al-Hammadee, Federal Environmental Agency, United Arab Emirates

Thabit Zahran Al Abdessalaam, Environment Agency, Abu Dhabi

Jaber Al Jaberi, Environment Agency, Abu Dhabi

Vietnam

Nguyen Viet Dung, PanNature

Nguyen Lanh, Institute of Strategy and Policy on Natural Resources and Environment

Ngo Tuan Nghia, Ho Chi Minh National Academy of Political and Public Administration

Kim Thi Thuy Ngoc, Institute of Strategy and Policy on Natural Resources and Environment

Nguyen Huu Ninh, Center for Environment Research, Education and Development

Ho Thi Yen Thu, Centre for Marinelife Conservation and Community Development

Nguyen Ngoc Thuy, Nong Lam University

Luu Anh Tuyet, Institute of World Economics and Politics

US Experts Consulted

Barbara Best, Bureau for Economic Growth, Agriculture, and Trade, US Agency for International Development

Appendix 3: Partner Institutions

Africa

Moi University, Centre for Refugee Studies (CRS). The Centre for Refugee Studies was conceived in 1991 as a program of the Department of Government and Public Administration in the School of Social, Cultural, and Development Studies at Moi University, Eldoret, Kenya. CRS aims to promote teaching, research, and outreach activities in the area of forced migration, to understand its root causes, and to instruct the current generation in the principles and practices of social justice, peace, and democracy in the management of public affairs. CRS became operative in 1992, launching a one-week course on "Refugee Rights and Law" for relevant officers of the Kenyan government and NGOs. This marked the beginning of collaborative activities with the Refugee Studies Programme, University of Oxford, the United Nations High Commissioner for Refugees Nairobi office, the US Agency for International Development, the British Council, and the Ford Foundation.

Middle East

The American University in Cairo, Center for Migration and Refugee Studies (CMRS). The Center for Migration and Refugee Studies, previously known as the Forced Migration and Refugee Studies (FMRS) program, at The American University in Cairo was established in 2000 as a program of education, research, and outreach on refugee issues. In 2008 it developed into a regional center that encompasses all forms of international mobility, whether voluntary or forced, economic or political, individual or collective, temporary or permanent. CMRS works along three building blocks—research, education and outreach—aiming to form strong synergies among them. CMRS's research program includes a systematic and comparative inventory of the situation regarding migration and refugee movements across the Middle East and Africa, as well as in-depth studies of emerging issues in the region. It gathers in-house faculty and fellows as well as a network of scholars established in other countries covering the region, with a focus on producing policy-oriented research. CMRS's outreach includes disseminating knowledge on migration and refugee issues beyond the university's gates, as well as providing a range of educational services to refugee communities.

Gulf Research Center (GRC). Based in Dubai, United Arab Emirates, the Gulf Research Center is a privately funded, nonpartisan think tank, education provider, and consultancy specializing in the Gulf region (the six Gulf Cooperation Council countries, and Iran, Iraq, and Yemen). Established in 2000, the Center conducts research on political, social, economic, security, and environmental issues from a Gulf perspective, redressing the current imbalance in Gulf area studies, where regional opinions and interests are underrepresented. With "Knowledge for All" as its motto, the GRC strives to promote different aspects of development and facilitate reforms in the region in order to secure a better future for its citizens.

American University of Beirut, Issam Fares Institute for Public Policy and International Affairs (IFI). The Issam Fares Institute for Public Policy and International Affairs at the American University of Beirut (AUB) was inaugurated in 2006 to harness the policy-related research of AUB's internationally respected faculty and other scholars in order to contribute positively to Arab policymaking and international relations. In the established tradition of AUB, IFI is a neutral, dynamic, civil, and open space where people representing all viewpoints in society can gather and discuss significant issues of the day, anchored in a long-standing commitment to mutual understanding and high-quality research. The main goals of IFI are to raise the quality of public policy–related debate and decision making in the Arab world and abroad; to enhance the Arab world's input in international affairs; and to enrich the quality of interaction among scholars, officials, and civil society actors in the Middle East and abroad. It operates research-to-policy programs in the areas of climate change and environment, Palestinian refugee camps, youth-related issues, and think tanks and public policymaking in the Arab world.

The Arab Center for the Development of the Rule of Law and Integrity (ACRLI). The Arab Center for the Development of the Rule of Law and Integrity is a regional, nongovernmental, nonprofit organization, founded in 2003 by a group of judges, specialists, lawyers, and academics from Lebanon and other Arab countries. ACRLI was established to develop and reinforce the rule of law in the Arab world and promote integrity and good governance based on respect for civil and human rights and sound democratic practices.

South Asia

All India Disaster Mitigation Institute (AIDMI). The All India Disaster Mitigation Institute is an NGO based in Gujarat, India, that works toward bridging the gap between policy, practice, and research related to disaster risk mitigation and reduction. Established after the 1987–89 Gujarat droughts, AIDMI evolved from a project in 1989 to an autonomous organization in 1995. As an operational as well as learning organization, it is able to link local communities with national and international policies of relief and long-term recovery. AIDMI has expanded work over the years to now cover 11 types of disasters in six areas of India and seven countries in Asia. AIDMI has shown that disasters are not only about relief but about prevention on the one hand and development on the other.

Asia Foundation, Sri Lanka. Recognizing that a sustainable peace is tied to overcoming deeper problems of a weakened democracy, lack of justice, and human rights violations, the Asia Foundation's program in Sri Lanka seeks to identify and support organizations and institutions that promote democratic governance and the rule of law as essential for lasting peace and prosperity. The Asia Foundation programs in Sri Lanka date back to 1954. The Foundation has been a pioneer in strengthening community-based legal services and mediation for the poor in Sri Lanka. It supported a definitive study on the relationship between aid, conflict, and peace building in Sri Lanka, and a follow-up study on the US involvement in the country's peace process. The Foundation distributes some 80,000 new English-language publications a year to libraries throughout Sri Lanka.

The Bangladesh Centre for Advanced Studies (BCAS). The Bangladesh Centre for Advanced Studies, based in Dhaka, is an independent, nonprofit, nongovernmental policy, research, and implementation institute working on sustainable development at the local, national, regional, and global levels. BCAS addresses sustainable development through five interactive themes: environment-development integration; good governance and popular participation; poverty alleviation and sustainable livelihoods; economic growth, public-private partnerships, and sustainable markets; and corporate social responsibility.

Institute for Peace Studies and Conflict Resolution (IPSCR). The Institute for Peace Studies and Conflict Resolution was established in January 2007 under the aegis of the Centre for Study of Society and Secularism, Mumbai. The overarching goal of the Institute is to create enabling conditions for peace and security by creating awareness in the society of factors affecting peace; addressing myths attributed to religious teachings; research and study into communal and sectarian conflicts; capacity building and peace advocacy, especially among youth; and supporting women's empowerment. IPSCR collaborates with other institutions, including the Tata Institute of Social Science Research, and the Department of Civics and Politics and the Department of Sociology, University of Mumbai.

Institute of Policy Studies (IPS). The Institute of Policy Studies, based in Islamabad and founded in 1979, is an autonomous, nonprofit, civil society organization, dedicated to promoting policy-oriented research on Pakistan affairs, international relations, and religion and faith. IPS provides a forum for informed discussion and dialogue on national and international issues; formulates viable plans; and presents key initiatives and policy measures to policymakers, analysts, political leaders, legislators, researchers, academia, civil society organizations, media, and other stakeholders. Periodicals and publications, interaction, dialogue, thematic research, and capacity-building programs are instrumental in its research endeavors. IPS garners collaboration as well as extends its active cooperation to other organizations in one or more areas of research.

Pakistan Institute of Legislative Development and Transparency (PILDAT). The Pakistan Institute of Legislative Development and Transparency is an indigenous, independent, and nonpartisan research and training institution committed to strengthening democracy and democratic institutions. PILDAT works to increase the legislative capabilities of elected officials, carries out in-depth analysis of the democratic developments of the country, provides performance reviews of the Parliament and provincial assemblies, and encourages the culture and value of democracy in youth through the first-ever Youth Parliament of Pakistan. The Institute also facilitates the formulation of issue-based caucuses across party lines, including the Young Parliamentarians' Forum, the Parliamentary Consultative Group on Women's Issues, and the Parliamentary Group on Inter-Faith Relations. PILDAT also facilitates non-Parliamentary groups of leading intellectuals and thinkers for discourse on issues such as free and fair elections, the electoral process, youth and politics, and dialogue between Muslims and the West.

Quaid-i-Azam University, Department of Defence & Strategic Studies. Quaid-i-Azam University, founded in 1967, is rated as one of the top public institutions of higher education in Pakistan and has established research collaborations with selected universities/research organizations in the United States, Europe, and South Asia. Since its establishment in 1980, the Department of Defence & Strategic Studies has awarded MSc degrees to 111 officers of the armed forces and 514 civilians. Thereby, it has made a significant contribution to the development of national expertise in the fields of defense and security studies. The academic training imparted by the Department is geared toward the development of requisite academic knowledge and analytical ability for evaluation of national, regional, and international strategic environment and policies. Since 1980, 69 MSc theses and 556 seminar papers have been written on wide-ranging subjects in the field of defense and strategic and security studies. The Department's faculty, in addition to its regular teaching, contributes research articles to various professional journals and delivers lectures at the National Defense College, Foreign Services Academy, Joint Services Staff College Islamabad, and Staff College Quetta.

Regional Centre for Strategic Studies (RCSS). Based in Colombo, the Regional Centre for Strategic Studies is an independent, nonprofit NGO that fosters collaborative research, networking, and interaction on strategic and international issues pertaining to South Asia. RCSS coordinates research on strategic and security-related issues; promotes interaction among scholars and other professionals in and outside the region who are engaged in South Asian strategic and international studies; and fosters relationships and collaboration among institutions studying issues related to conflict, conflict resolution, cooperation, stability, and security in South Asia.

South Asia Center for Policy Studies (SACEPS). The South Asia Center for Policy Studies is an independent, nonprofit NGO engaged in regional cooperation in South Asia. SACEPS was established in mid-1999 and housed at the Centre for Policy Research, New Delhi, and then at the Centre for Policy Dialogue, Dhaka. SACEPS moved to Kathmandu

after establishing its permanent secretariat in 2005. The Centre's main aim is promoting policy dialogues, research, and interaction among policymakers, the business community, and civil society. SACEPS uses its institutional base to network with well-established national institutions in the region and bolster regional cooperation.

Sustainable Development Policy Institute (SDPI). The Sustainable Development Policy Institute, based in Islamabad, was founded in 1992 as an independent, nonprofit organization which would serve as a source of expertise on socioeconomic development and environmental issues in Pakistan. The Institute works to conduct policy-oriented research and advocacy from a broad multidisciplinary approach; promote the implementation of policies, programs, laws, and regulations of sustainable development; strengthen civil society through collaboration with other organizations; disseminate research findings through media, conferences, lectures, publications, and curricula development; and contribute to building up national research capacity and infrastructure. The Institute acts as both a generator of original research on sustainable development issues and as an information resource for concerned individuals and institutions. SDPI's function is thus twofold: an advisory role fulfilled through research, policy advice, and advocacy; and an enabling role realized through providing other individuals and organizations with resource materials and training.

The Energy and Resources Institute (TERI). The Energy and Resources Institute was formally established in 1974 in New Delhi with the purpose of tackling the acute problems that mankind is likely to face in the years ahead resulting from the depletion of the Earth's energy resources and the pollution their unsustainable use causes. The Institute works to provide environment-friendly solutions to rural energy problems, tackle global climate change issues across continents, advance solutions to the growing urban transport congestion and air pollution, and promote energy efficiency in the Indian industry. TERI is the largest developing country institution devoted to finding innovative solutions toward a sustainable future. TERI has established affiliate institutes abroad: TERI-NA (North America) in Washington, DC; TERI-Europe in London, UK; and has a presence in Japan and Malaysia.

Southeast Asia

Center for Migrant Advocacy Philippines (CMA). The Center for Migrant Advocacy–Philippines is a nonprofit, nongovernmental advocacy group that promotes the rights of overseas Filipinos, land- and sea-based migrant workers and immigrants, and their families. It works to help improve the economic, social, and political conditions of migrant Filipino families everywhere through policy advocacy, information dissemination, direct assistance, networking, and capacity building. CMA is also a resource center that gathers information, conducts studies, and analyzes urgent issues on overseas migration and related concerns and disseminates information to its partners, networks, and constituents.

CMA is a member of the Philippine Migrant Rights Watch, Migrant Forum in Asia, and the Philippine Alliance of Human Rights Advocates.

Centre for Strategic and International Studies, Jakarta (CSIS). The Centre for Strategic and International Studies, based in Jakarta and established in 1971, is an independent nonprofit organization focusing on policy-oriented studies on domestic and international issues. Its mission is to contribute to improved policymaking through research, dialogue, and public debate. CSIS believes that long-term planning and vision for Indonesia and the region must be based on an in-depth understanding of economic, political, and social issues, including regional and international developments. In the area of foreign policy, the Centre's research is complemented and strengthened by its relations with an extensive network of research, academic, and other organizations worldwide. CSIS's research is used by government, universities, research institutions, civil society organizations, media, and businesses.

People and Nature Reconciliation (PanNature). People and Nature Reconciliation is a nonprofit organization based in Hanoi, Vietnam, and was established in 2006 by a diverse group of dedicated Vietnamese environmental professionals. Its mission is to protect and conserve diversity of life and to improve human well-being in Vietnam by seeking, promoting, and implementing feasible, nature-friendly solutions to important environmental problems and sustainable development issues. PanNature implements activities and programs with the following tools: research and environmental education, training and capacity building, communication and publications, field conservation initiatives, policy analysis and advocacy, and networking and partnership development.

S. Rajaratnam School of International Studies (RSIS). Based in Singapore, the S. Rajaratnam School of International Studies was established in January 2007 as an autonomous school within the Nanyang Technological University. RSIS is a leading research and graduate teaching institution in strategic international affairs in the Asia-Pacific region. Its name honors the contributions of Mr. S. Rajaratnam, who was one of Singapore's founding fathers and a well-respected visionary diplomat and strategic thinker. RSIS includes the International Centre for Political Violence and Terrorism Research, the Centre of Excellence for National Security, the Centre for Non-Traditional Security Studies, and the Consortium of Non-Traditional Security Studies in Asia. The focus of research is on issues relating to the security and stability of the Asia-Pacific region and their implications for Singapore and other countries in the region.

Singapore Institute of International Affairs (SIIA). The Singapore Institute of International Affairs is a nonprofit NGO dedicated to the research, analysis, and discussion of regional and international issues. Founded in 1961 and registered as a membership-based society, it is Singapore's oldest think tank. Its mission is to make Singapore a more cosmopolitan society that better understands the international affairs of its region and the world.

Stimson Board of Directors

Stimson's *Regional Voices: Transnational Challenges* project is devoted to enhancing the information and analysis available to policymakers about emerging transnational security challenges in the Middle East, South Asia, Southeast Asia, and East Africa. It seeks the direct input of experts and practitioners in the regions, especially those who constitute new voices in the conversation with the US policy community.

Impacts of Climate Change on Coastal Ecosystems in the Indian Ocean Region

"Once some critical threshold is passed, even relatively small stresses may trigger rapid ecosystem degradation and loss of integrity. Climate change may very likely be the factor pushing some ecosystems over the limit."

—**Nirmalie Pallewatta,** *University of Colombo, Sri Lanka*

Climate Change and Sea Level Rise: Issues and Challenges for Coastal Communities in the Indian Ocean Region

"The key to ICZM [Integrated Coastal Zone Management] is to empower timely decision making at the appropriate levels, providing the flexibility to respond to evolving circumstances and cope with persistent uncertainties... The major challenge to ICZM is to realize these potentials while mitigating or adapting to vulnerabilities through a process that enhances the livelihoods of the inhabitants and provides communities with avenues for input to, and support from, external institutions."

—**Nazria Islam, Golam Rabbani, A. Atiq Rahman,** *Bangladesh Centre for Advanced Studies*

Impacts and Implications of Climate Change for the Coastal Zones of Egypt

"The coastal zone of Egypt is highly exposed to the potential impacts of climate change. In particular, the Nile Delta region is acutely vulnerable to sea level rise and saltwater intrusion. The potential effects include significant socioeconomic implications, which may involve mass population displacement from the delta."

—**Mohamed El Raey,** *University of Alexandria, Egypt*

Small Island Developing States: Incubators of Innovative Adaptation and Sustainable Technologies?

"SIDS can become effective incubators of sustainable technology. Despite the opportunities, technology development and transfer are often hampered by several key challenges. These constraints are not international or external in nature, but include a number of internal impediments that need urgent attention if SIDS are to adapt effectively to climate change."

—**Alain De Comarmond,** *Ministry of Environment, Natural Resources and Transport* and **Rolph Payet,** *Special Advisor to the President, Republic of Seychelles*

Adaptation Policies in the Coastal Zones of the Indian Ocean Region: Challenges, Opportunities, and Strategies

"Although many Indian Ocean and Southeast Asian countries face common and interrelated challenges, they lack a regional policy framework for climate adaptation... Reducing such environmental and climate change risks requires information and early warning systems from a regional or international network."

—**Poh Poh Wong,** *National University of Singapore*

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