17

Small Island States

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CONTENTS

EXECUTIVE SUMMARY

The small island states considered in this chapter are located mainly in the tropics and the subtropics. These island states span the ocean regions of the Pacific, Indian, and Atlantic, as well as the Caribbean and Mediterranean Seas. Because of the very nature of these states, the ocean exerts a major influence on their physical, natural, and socioeconomic infrastructure and activities.

Although small island states are not a homogeneous group, they share many common features that serve to increase their vulnerability to projected impacts of climate change. These characteristics include their small physical size and the fact that they are surrounded by large expanses of ocean; limited natural resources; proneness to natural disasters and extreme events; relative isolation; extreme openness of their economies, which are highly sensitive to external shocks; large populations with high growth rates and densities; poorly developed infrastructure; and limited funds, human resources, and skills. These characteristics limit the capacity of small island states to mitigate and adapt to future climate and sea-level change.

The most significant and immediate consequences for small island states are likely to be related to changes in sea levels, rainfall regimes, soil moisture budgets, and prevailing winds (speed and direction) and short-term variations in regional and local patterns of wave action. Owing to their coastal location, the majority of socioeconomic activities and infrastructure and the population are likely to be highly vulnerable to the impacts of climate change and sea-level rise.

Review of past and present trends of climate and climate variability indicates that temperatures have been increasing by as much as 0.1°C per decade, and sea level has risen by 2 mm yr^{-1} in regions in which small island states are located. Analysis of observational data for these regions suggests that increases in surface air temperatures have been greater than global rates of warming (e.g., in the Pacific Ocean and the Caribbean Sea regions). Observational evidence also suggests that much of the variability in the rainfall record of Caribbean and Pacific islands appears to be closely related to the onset of El Niño-Southern Oscillation (ENSO). However, part of the variability in these areas also may be attributable to the influence of the Inter-Tropical Convergence Zone (ITCZ) and the South Pacific Convergence Zone (SPCZ). It is acknowledged however, that for some small islands it is difficult to establish clear trends of sea-level change because of limitations of observational records, especially geodetic-controlled tide gauge records.

The use of the state-of-the-art coupled atmosphere-ocean general circulation models (AOGCMs) to estimate future response of climate to anthropogenic radiative forcing suggests an enhanced climate change in the future. Several AOGCMs have been analyzed for the Atlantic, Pacific, and Indian Ocean regions and the Caribbean and Mediterranean Seas. The outputs from these models indicate general increases in surface air temperature for the 2050s and 2080s and an increase in rainfall of about 0.3% for the 2050s and 0.7% for the 2080s for the Pacific region. However, a marginal decline in rainfall is projected for the other regions, with a possible reduction of water availability. The diurnal temperature range is projected to decrease marginally for the regions of the small island states for both time horizons.

With respect to extreme events, AOGCM (CSIRO and ECHAM) transient experiments project that by the 2050s and 2080s, there will be increased thermal stress during summer, as well as more frequent droughts and floods in all four tropical ocean regions in which small island states are located.This projection implies that in the future these regions are likely to experience floods during wet seasons and droughts during dry seasons. Furthermore, warming in some regions (e.g., the Pacific Ocean) is likened to an El Niño pattern, suggesting that climate variability associated with the ENSO phenomenon will continue on a seasonal and decadal time scale. It is probable that such an association may dominate over any effects attributable to global warming. Given their high vulnerability and low adaptive capacity to climate change, communities in the small island states have legitimate concerns about their future on the basis of the past observational record and climate model projections. In this Third Assessment Report, analysis of the scientific-technical literature identifies the following key issues among the priority concerns of small island states.

Development, sustainability, and equity issues. The small island states account for less than 1% of global greenhouse gas (GHG) emissions but are among the most vulnerable of all locations to the potential adverse effects of climate change and sea-level rise. Economic development and alleviation of poverty constitute the single most critical concern of many small island states. Thus, with limited resources and low adaptive capacity, these islands face the considerable challenge of meeting the social and economic needs of their populations in a manner that is sustainable. At the same time, they are forced to implement appropriate strategies to adapt to increasing threats resulting from greenhouse gas forcing of the climate system, to which they contribute little.

Sea-level rise. Although there will be regional variation in the signal, it is projected that sea level will rise by as much as 5 mm yr^{-1} over the next 100 years as a result of GHG-induced global warming. This change in sea level will have serious consequences for the social and economic development of many small island states. For some islands, the most serious consideration will be whether they will have adequate potential to adapt to sea-level rise within their own national boundaries.

Beach and coastal changes. Most coastal changes currently experienced in the small island states are attributable to human activity. With the projected increase in sea level over the next 50–100 years superimposed on further shoreline development, however, the coastal assets of these states will be further stressed. This added stress, in turn, will increase the vulnerability of coastal environments by reducing natural resilience, while increasing the economic and social "costs" of adaptation.

Biological systems. Coral reefs, mangroves, and seagrass beds, which provide the economic foundation for many small islands, often rely on "stable" coastal environments to sustain themselves. Although it is acknowledged that human-induced stresses are contributing to their degradation, these systems will be adversely affected by rising air temperature and sea levels. In most small islands, coral reefs already are undergoing great stress from episodic warming of the sea surface, causing widespread bleaching. Mangroves—which are common on low-energy, nutrient/sediment-rich coasts and embayments in the tropics—have been altered by human activities. Changes in sea levels are likely to affect landward and longshore migration of remnants of mangrove forests, which provide some protection for the coasts and backshore infrastructure. It is projected that changes in the availability of sediment supply, coupled with increases in temperature and water depth as a consequence of sea-level rise, will adversely impact the productivity and physiological functions of seagrasses. Consequently, this would have a negative downstream effect on fish populations that feed on these communities.

Biodiversity. It is estimated that 33% of known threatened plants are island endemics, and 23% of bird species found on islands also are threatened. Although there is still some uncertainty about precisely how and to what extent biodiversity and wildlife in small islands will be affected, available projections suggest that climate change and sea-level rise will cause unfavorable shifts in biotic composition and adversely affect competition among some species.

Water resources, agriculture, and fisheries. The availability of water resources and food remain critical concerns in island communities. In many countries, water already is in short supply because islands (many of which are drought-prone) rely heavily on rainwater from small catchments or limited freshwater lenses. Arable land for crop agriculture often is in short supply; thus, the likely prospect of land loss and soil salinization as a consequence of climate change and sea-level rise will threaten the sustainability of both subsistence and commercial agriculture in these islands. Because water resources and agriculture are so climate sensitive, it is expected that these sectors also will be adversely affected by future climate and sea-level change. Although climate change is not expected to have a significant impact on world fisheries output, it is projected to have a severe impact on the abundance and distribution of reef fish population on the islands.

Human health, settlement and infrastructure, and tourism. Several human systems are likely to be affected by projected changes in climate and sea levels in many small island states. Human health is a major concern in many tropical islands, which currently are experiencing a high incidence of vector- and water-borne diseases. This is attributable partly to changes in temperature and rainfall, which may be linked to the ENSO phenomenon, and partly to changes in the patterns of droughts and floods. Climate extremes also place a huge burden on human welfare; this burden is likely to increase in the future. Almost all settlements, socioeconomic infrastructure, and activities such as tourism in many island states are located at or near coastal areas. Their location alone renders them highly vulnerable to future climate change and sea-level rise. Tourism is a major revenue earner and generates significant employment in many small islands. Changes in temperature and rainfall regimes, as well as loss of beaches, could be devastating for the economies that rely on this sector. Because climate change and sea-level rise are inevitable in the future, it is vital that beach and coastal assets in the small island states are managed wisely. Integrated coastal management has been identified and proposed as an effective framework for accomplishing this goal.

Sociocultural and traditional assets. Other island assets, such as know-how and traditional skills (technologies), are under threat from climate change and sea-level rise. In some societies, community structures and assets such as important traditional sites of worship, ritual, and ceremony—particularly those at or near the coasts—could be adversely affected by future climate change and sea-level rise.

It is significant to note that although many vulnerability assessment methodologies have been applied to different regions of the world with varying degrees of success, global assessments have consistently identified the small island states as one of the most high-risk areas, irrespective of methodology employed. This evidently robust finding must be of considerable concern to these states. It is further established that climate change is inevitable as a result of past GHG emissions and that small islands are likely to suffer disproportionately from the enhanced effects of climate change and sea-level rise. Hence, identification and implementation of effective adaptation measures and avoidance of maladaptation (i.e., measures that increase exposure rather than decrease vulnerability) are critical for small islands, even if there is swift implementation of any global agreement to reduce future emissions.

For most small islands, the reality of climate change is just one of many serious challenges with which they are confronted. Such pressing socioeconomic concerns as poverty alleviation; high unemployment; and the improvement of housing, education, and health care facilities all compete for the slender resources available to these countries. In these circumstances, progress in adaptation to climate change almost certainly will require integration of appropriate risk reduction strategies with other sectoral policy initiatives in areas such as sustainable development planning, disaster prevention and management, integrated coastal management, and health care planning.

17.1. Regional Characteristics

17.1.1. Review of Previous Work

Almost without exception, small island states have been shown to be at great risk from projected impacts of climate change, particularly sea-level rise. The projected global rate of rise of 5 mm yr^{-1} (±2–9 mm yr^{-1}) is two to four times greater than the rate experienced in the previous 100 years (IPCC, 1998). Many of these islands rarely exceed 3–4 m above present mean sea level; even on the higher islands, most of the settlements, economic activity, infrastructure, and services are located at or near the coast.

Reliable instrumental records indicate that on average, Caribbean islands have experienced an increase in temperature exceeding 0.5°C since 1900. During the same period, there has been a significant increase in rainfall variability, with mean annual total rainfall declining by approximately 250 mm. For Pacific islands, the post-1900 temperature increase has been slightly lower than in the Caribbean: less than 0.5°C. In the case of rainfall, no clear trend emerges from the record, which shows decadal fluctuations of ±200 mm and 50–100 mm for mean annual and mean seasonal totals, respectively (IPCC, 1998).

Given the strong influence of the ocean on the climate of islands, and based on projected warming of the oceans (1–2°C for the Caribbean Sea and Atlantic, Pacific, and Indian Oceans) with a doubling of carbon dioxide (CO_2), small islands in these regions are expected to continue to experience moderate warming in the future. Under a similar scenario, mean rainfall intensity also is projected to increase by 20–30% over the tropical oceans, where most small island states are located. However, a decrease in mean summer precipitation over the Mediterranean Sea, where the small islands of Malta and Cyprus are located, is projected (IPCC, 1998).

Based on these projections, certain marine and coastal ecosystems are most likely to be adversely affected. Corals—many species of which currently exist near the upper limits of their tolerance to temperature—are projected to experience more frequent bleaching episodes as a result of elevated sea surface temperatures (SSTs). Bleaching therefore will pose a distinct threat to the productivity and survival of these valuable ecosystems (Wilkinson, 1996; Brown, 1997a,b; CARICOMP, 1997; Woodley *et al.*, 1997). On some islands, mangroves also are expected to be threatened by the impacts of climate change. Where the rate of sedimentation is slower than the projected rate of sea-level rise and where mangroves cannot naturally adapt and migrate landward, the vulnerability of these ecosystems will increase (IPCC, 1996, 1998). In some cases, the natural resilience of these ecosystems already has been impaired by anthropogenic stresses; thus, their capacity to cope with an additional stressor such as climate change will be further compromised.

Sea-level rise poses by far the greatest threat to small island states relative to other countries. Although the severity of the threat will vary from island to island, it is projected that beach erosion and coastal land loss, inundation, flooding, and salinization of coastal aquifers and soils will be widespread. Moreover, protection costs for settlement, critical infrastructure, and economic activities that are at risk from sea-level rise will be burdensome for many small island states. Similarly, tourism—the leading revenue earner in many states—is projected to suffer severe disruption as a consequence of adverse impacts expected to accompany sea-level rise (Teh, 1997; IPCC, 1998).

17.1.2. Special Circumstances of Small Islands

Small island states are by no means a homogeneous group of countries. They vary by geography; physical, climatic, social, political, cultural, and ethnic character; and stage of economic development. Yet they tend to share several common characteristics that not only identify them as a distinct group but underscore their overall vulnerability in the context of sustainable development (Maul, 1996; Leatherman, 1997). These common characterists include the following:

- Limited physical size, which effectively reduces some adaptation options to climate change and sea-level rise (e.g., retreat; in some cases entire islands could be eliminated, so abandonment would be the only option)
- Generally limited natural resources, many of which already are heavily stressed from unsustainable human activities
- High susceptibility to natural hazards such as tropical cyclones (hurricanes) and associated storm surge, droughts, tsunamis, and volcanic eruptions
- Relatively thin water lenses that are highly sensitive to sea-level changes
- In some cases, relative isolation and great distance to major markets
- Extreme openness of small economies and high sensitivity to external market shocks, over which they exert little or no control (low economic resilience)
- Generally high population densities and in some cases high population growth rates
- Frequently poorly developed infrastructure (except for major foreign exchange-earning sectors such as tourism)
- Limited funds and human resource skills, which may severely limit the capacity of small islands to mitigate and adapt to the effects of climate change.

17.1.3. Past and Present Trends

The Intergovernmental Panel on Climate Change (IPCC) in its Second Assessment Report (SAR) projected a global average temperature increase of 1.0–3.5°C, and a consequential rise in global mean sea level of 15–95 cm by the year 2100. Results from observational data show that temperatures have been increasing by as much as 0.1°C per decade and sea levels by approximately 2 mm yr^{-1} in the regions where most of the small island states are located—namely, the Pacific, Indian, and Atlantic Oceans and the Caribbean Sea (see Figure 17-1). There also is evidence that the ENSO phenomenon will continue

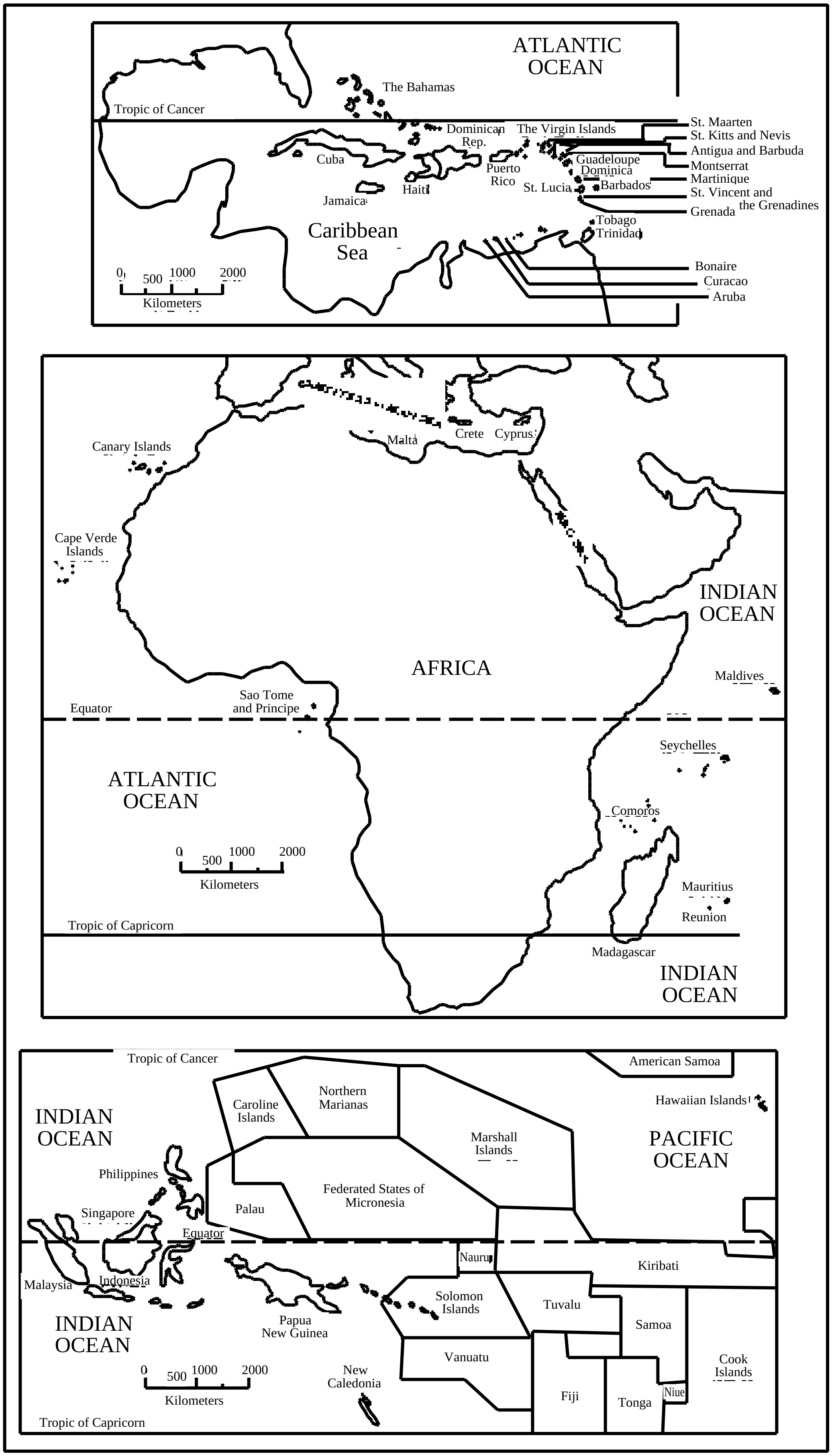

Figure 17-1: Main regions of the world in which small island states are located.

to have a major influence on climate variability in these regions.

Analyses conducted by the New Zealand Meteorological Services reveal that, since 1920, temperature has risen by 0.6–0.7°C in Noumea (New Caledonia) and Rarotonga (Cook Islands), which is greater than the mean global increase. Based on data from 34 stations in the Pacific from about 160°E and mostly south of the equator, surface air temperatures have increased by 0.3–0.8°C during the 20th century, with the greatest increase in the zone southwest of the SPCZ. This is well in excess of global rates of warming. Further recent work undertaken by the New Zealand Institute of Water and Atmospheric Research (NIWA) shows a noticeable change in aspects of the South Pacific climate since the mid-1970s. For instance, western Kiribati, the northern Cook Islands, Tokelau, and northern French Polynesia have become wetter, whereas New Caledonia, Fiji, and Tonga have become drier. Meanwhile, Samoa, eastern Kiribati, Tokelau, and northeast French Polynesia have become cloudier, with warmer nighttime temperatures; New Caledonia, Fiji, Tonga, the southern Cook islands, and southwest French Polynesia and Tuvalu have become warmer and sunnier (Salinger *et al.*, 1995). It also might be noted that in the Pacific generally, observed changes in temperature and cloudiness appear to be closely influenced by the pattern of ENSO events (Salinger, 1999).

The records also indicate that rainfall has increased in the northeast Pacific but has decreased in the southwest Pacific region. Interannual variations in temperature and rainfall are strongly associated with ENSO, resulting in water shortages and drought in Papua New Guinea, the Marshall Islands, the Federated States of Micronesia, American Samoa, Samoa, and Fiji. Although a causal link has yet to be established, all of the foregoing changes have coincided with an eastward shift of the SPCZ since 1970. Research now suggests that some of the foregoing changes (including the shift in the SPCZ) may be closely correlated with interdecadal patterns of variability—for example, the Pacific Decadal Oscillation (PDO) (Salinger and Mullen, 1999). It should be noted, nevertheless, that the changes observed in the 20th century are considered to be consistent with patterns related to anthropogenic GHG-induced climate change (Salinger *et al*., 1995; Hay, 2000).

The most significant and more immediate consequences for small island states are likely to be related to changes in sea levels, rainfall regimes, soil moisture budgets, and prevailing winds (speed and direction), as well as short-term variations in regional and local sea levels and patterns of wave action (Sem *et al*., 1996). The short-term (including interannual) variations are likely to be strengthened by the ENSO phenomenon. Vulnerability assessment studies undertaken in some small islands suggest that climate change will impose diverse and significant impacts on small island states (Leatherman, 1997). In most small islands (including the high islands), the majority of the population, socioeconomic activities, and infrastructure are located within a few hundred meters of the coast; therefore, they are highly vulnerable to the impacts of climate change and sea-level rise (Hay *et al*., 1995; Bijlsma, 1996; Nurse *et al*., 1998; Burns, 2000). In this regard, an increase in the frequency and magnitude of tropical cyclones would be a major concern for small island states. This would increase the risk of flooding, accelerate existing rates of beach erosion, and cause displacement of settlements and infrastructure.

The key questions, therefore, arehow will the impacts manifest themselves, and what are the most appropriate responses for avoiding, minimizing, or adapting to these impacts? Because small island states traditionally experience some of the greatest interannual variations in climatic and oceanic conditions, many of their natural systems are well adapted to the stresses that result. Thus, many strategies that small island states might employ to adapt to climate change usually are the same as those that constitute sound environmental management, wise use of resources, and appropriate responses to present-day climate variability.

Although the full extent of climate change impacts in the small island states is far from certain, mostly adverse consequences are projected for several systems. The combined effect of GHG-induced climate change and sea-level rise can contribute to coastal erosion and land loss, flooding, soil salinization, and intrusion of saltwater into groundwater aquifers. The quantity and quality of available water supplies can affect agricultural production and human health. Similarly, changes in SST, ocean circulation, and upwelling could affect marine organisms such as corals, seagrasses, and fish stocks. Tourism—which is a very important economic activity in many island states—could be affected through beach erosion, loss of land, and degraded reef ecosystems, as well as changes in seasonal patterns of rainfall.

17.1.4. Scenarios of Future Climate Change and Variability

17.1.4.1. The Models Used

Projections of future climate change discussed in this chapter essentially are based on data sets available at IPCC Data Distribution Centers (DDCs) at Hamburg and Norwich and currently available numerical experiments with state-of-the-art global climate models that consider a near-identical GHG

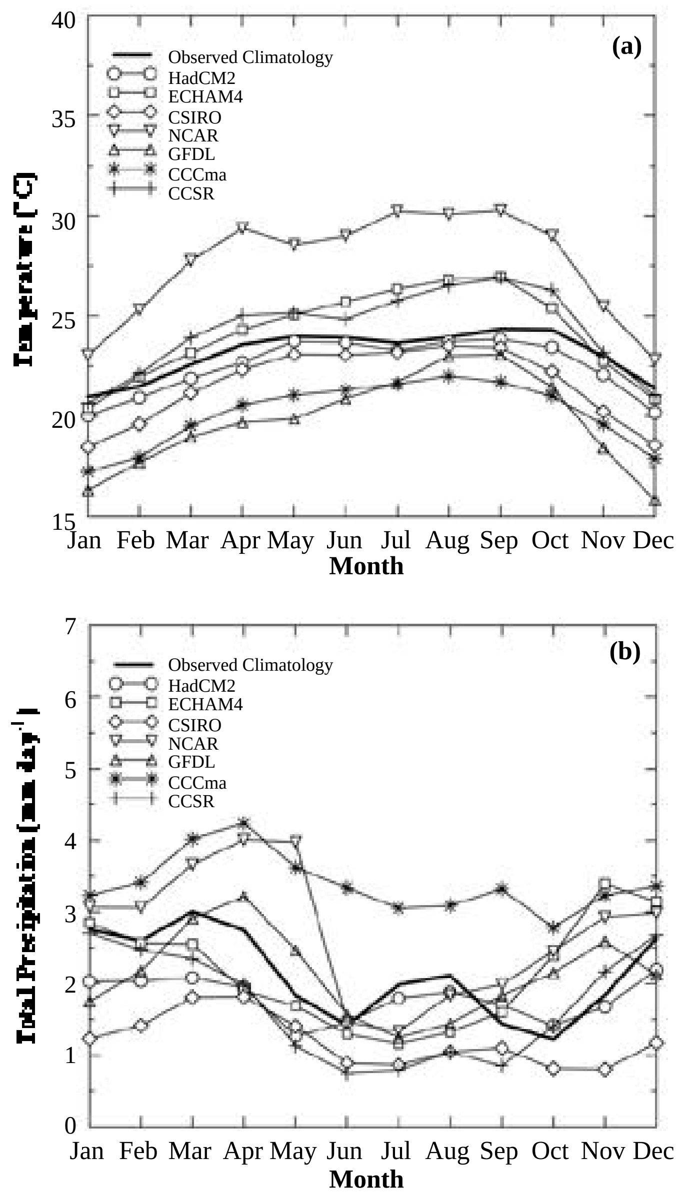

Figure 17-2: Validation of seven AOGCM-simulated and observed climatology [(a) temperature and (b) rainfall] for Meditarranean Sea islands.

forcing: 1% yr-1 growth in GHG concentrations (IS92a) after 1990. Coupled AOGCMs offer the most credible tools for estimating the future response of climate to anthropogenic radiative forcings. The DDCs have compiled outputs generated in transient experiments with a set of seven recent AOGCMs that reflect the state-of-the-art of model experiments and provide a representative range of results from different AOGCMs.

17.1.4.2. Region-Specific Model Validation

A model validation exercise was undertaken for the four main regions (the Atlantic Ocean and Caribbean Sea, the Pacific Ocean, the Indian Ocean, and the Mediterranean Sea region) in which the majority of small island states are located. The results indicate that five of the seven AOGCMs [HadCM2 (UK), ECHAM4 (Germany), CSIRO (Australia), CCSR/NIES (Japan), and CCCma (Canada)] have reasonable capability in simulating the broad features of present-day climate and its variability over these regions. Comparison of the monthly mean observed and model-simulated climatology of surface air temperature and rainfall over the Mediterranean Sea and Indian Ocean regions is shown in Figures 17-2 and 17-3. The time period of 30 years (1961–1990) in baseline climatology has been used for the purpose of these model validation exercises and to generate climate change scenarios for these island regions. Two future time periods centered around the 2050s (2040–2069) and the 2080s (2070–2099) have been considered here in developing scenarios of changes in surface air temperature and precipitation.

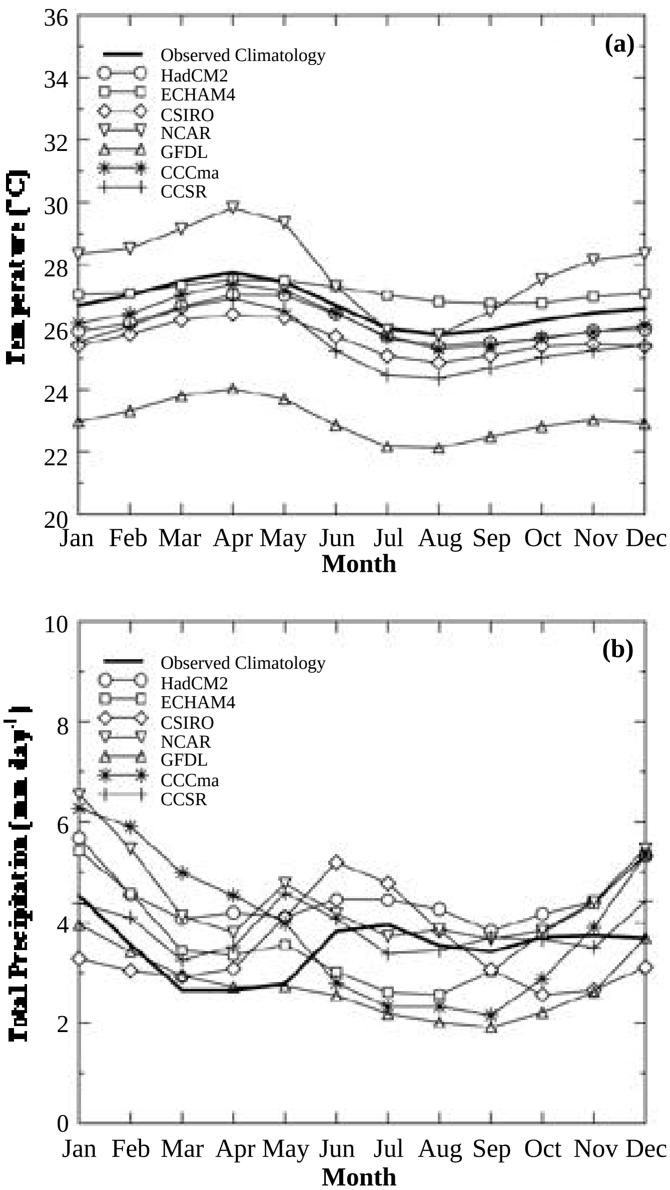

Figure 17-3: Validation of seven AOGCM-simulated and observed climatology [(a) temperature and (b) rainfall] for Indian Ocean islands.

For the four regions identified above, the HadCM2, ECHAM4, CSIRO, CCSR/NIES, and CCCma models have demonstrated good capability in simulating the present-day area-averaged monthly mean climatology in terms of surface temperature, diurnal temperature range, and rainfall (Lal *et al*., 2001). The model projections discussed here are the scenarios arising from GHG-induced positive radiative forcings and those that take into account the negative radiative forcing of sulfate aerosols (direct effects).

17.1.4.3. Climate Change Projections for Small Island States

17.1.4.3.1. Surface air temperature

Tables 17-1, 17-2, and 17-3 provide an ensemble of climate change scenario results inferred from the five AOGCMs referred to above for four regions. These tables summarize projected seasonal mean changes in surface air temperature and precipitation during the 2050s and 2080s. The projected area-averaged annual mean warming as a consequence of increases in atmospheric concentrations of GHGs over the Atlantic Ocean and Caribbean Sea, the Pacific Ocean , the Indian Ocean, and the Mediterranean Sea is approximately 2.0, 2.0, 2.1, and 2.8°C, respectively, for the 2050s, and approximately 3.1, 3.0, 3.2, and 4.3°C, respectively, for the 2080s (see Table 17-1). Projected warming over the Mediterranean Sea area is marginally higher during Northern Hemisphere (NH) summer than during NH winter for both time periods. The increase in surface air temperature is more or less uniform in both seasons in the other three regions (Tables 17-2 and 17-3). The scatter of projected annual mean surface temperature increase over each of the regions, as simulated by each of the five GCMs, is depicted in Figures 17-4 to 17-7. The area-averaged annual increase in mean surface temperature resulting from increases in GHGs is projected to be smallest over the Pacific Ocean region and highest over the Mediterranean Sea. It is evident that even though aerosol forcing marginally reduces surface warming, the magnitude of projected warming is still considerable and could substantially impact the small island states.

With respect to diurnal changes, GCM simulations with increasing concentrations of GHGs in the atmosphere suggest relatively more

***Table 17-1**: Ensemble of annual mean climate change scenarios for small islands for the 2050s and 2080s as inferred from AOGCMs (numbers in brackets show standard deviation between model projections).*

	Annual Mean Temperature Change (°C)				**Annual Mean Precipitation Change (%)**			
	2050s		*2080s*		*2050s*		*2080s*	
Regions	GHG	GHG+A	GHG	GHG+A	GHG	GHG+A	GHG	GHG+A
Atlantic Ocean and Caribbean	2.03 (±0.43)	1.71 (±0.25)	3.06 (±0.84)	2.64 (±0.61)	-5.2 (±11.9)	-1.3 (±7.8)	-6.8 (±15.8)	-0.7 (±12.3)
Pacific Ocean	1.98 (±0.41)	1.63 (±0.23)	2.99 (±0.87)	2.54 (±0.63)	5.5 (±2.5)	4.9 (±0.8)	7.6 (±3.3)	7.0 (±1.9)
Indian Ocean	2.10 (±0.43)	1.64 (±0.23)	3.16 (±0.89)	2.61 (±0.65)	3.1 (±4.5)	1.6 (±3.9)	5.1 (±4.3)	4.3 (±4.9)
Mediterranean	2.83 (±0.62)	2.31 (±0.29)	4.27 (±1.26)	3.57 (±0.83)	1.0 (±11.0)	-2.4 (±8.6)	4.3 (±14.9)	-0.1 (±12.9)

***Table 17-2**: Ensemble of seasonal mean climate change scenarios for small islands for the 2050s as inferred from AOGCMs (numbers in brackets show standard deviation between model projections).*

	Temperature Change (°C)				**Precipitation Change (%)**			
	December–February		*June–August*		*December–February*		*June–August*	
Regions	GHG	GHG+A	GHG	GHG+A	GHG	GHG+A	GHG	GHG+A
Atlantic Ocean and Caribbean	2.00 (±0.46)	1.68 (±0.32)	2.01 (±0.44)	1.71 (±0.21)	3.4 (±14.3)	5.9 (±7.4)	-14.4 (±12.2)	-6.9 (±11.5)
Pacific Ocean	1.98 (±0.39)	1.65 (±0.20)	1.98 (±0.43)	1.61 (±0.27)	4.3 (±1.9)	3.7 (±1.2)	7.2 (±4.8)	6.8 (±3.3)
Indian Ocean	2.11 (±0.43)	1.67 (±0.15)	2.09 (±0.44)	1.63 (±0.30)	3.5 (±6.0)	2.0 (±7.5)	-1.8 (±10.0)	-4.7 (±4.5)
Mediterranean	2.64 (±0.72)	2.27 (±0.44)	2.93 (±0.53)	2.27 (±0.17)	8.1 (±14.7)	2.6 (±15.7)	-4.8 (±10.3)	-8.9 (±6.0)

***Table 17-3**: Ensemble of seasonal mean climate change scenarios for small islands for the 2080s as inferred from AOGCMs (numbers in brackets show standard deviation between model projections).*

	Temperature Change (°C)				**Precipitation Change (%)**			
	December–February		*June–August*		*December–February*		*June–August*	
Regions	GHG	GHG+A	GHG	GHG+A	GHG	GHG+A	GHG	GHG+A
Atlantic Ocean and Caribbean	3.01 (±0.87)	2.61 (±0.66)	3.07 (±0.86)	2.64 (±0.61)	4.8 (±14.6)	8.5 (±12.9)	-19.2 (±18.8)	-8.2 (±17.1)
Pacific Ocean	2.97 (±0.82)	2.56 (±0.57)	2.98 (±0.91)	2.52 (±0.67)	6.0 (±1.5)	5.6 (±1.6)	10.2 (±5.9)	8.9 (±4.9)
Indian Ocean	3.18 (±0.88)	2.61 (±0.60)	3.16 (±0.91)	2.62 (±0.69)	5.9 (±10.3)	6.2 (±10.5)	-2.6 (±12.6)	-5.9 (±7.4)
Mediterranean	3.94 (±1.34)	3.31 (±1.01)	4.52 (±1.16)	3.70 (±0.72)	16.1 (±21.1)	9.9 (±21.6)	-7.4 (±16.2)	-11.6 (±10.7)

pronounced increases in minimum temperature than in maximum temperature over the regions where the small island states are located, on an annual mean basis as well as during winter, for both the 2050s and the 2080s. Hence, a marginal decrease in diurnal temperature range (between 0.3 and 0.7°C) is projected.

17.1.4.3.2. Precipitation

In general, all AOGCMs simulate only a marginal increase or decrease in annual rainfall. An area-averaged annual mean increase in precipitation of approximately 0.3% for the 2050s and 0.7% for the 2080s over the Pacific Ocean area is projected, either as a consequence of increases in atmospheric concentrations of GHGs or because of the combined influence of GHGs and sulfate aerosols. The projected increase in precipitation is at a maximum during NH summer (June-July-August) for both time periods. A marginal decline in precipitation is projected for the other three regions, particularly during NH summer—suggesting the possibility of reduced water availability (Lal *et al*., 2001).

17.1.4.3.3. Extreme high temperature and precipitation events

An analysis of model-simulated daily temperature and precipitation data (from CSIRO and ECHAM model experiments) for the present-day atmosphere and for the two future time slices (2050s and 2080s) projects that the frequency of extreme temperatures during the summer is likely to be higher in all four regions. This implies an increased likelihood of thermal stress conditions during the 2050s and more so during the 2080s. Similarly, although the models project a lesser number of annual rainy days, an increase in the daily intensity of precipitation also is projected (Lal *et al*., 2001). This suggests an increase in the probability of occurrence of more frequent droughts, as well as floods, in the Atlantic Ocean and Caribbean Sea, the Mediterranean Sea, and the Indian and Pacific Oceans.

17.1.4.3.4. ENSO and precipitation variability

Although it is difficult to obtain reliable regional projections of climate change from GCMs, some consistent patterns are beginning to emerge for the Pacific with regard to ENSO and precipitation variability. Although ocean temperatures over most of the western and southern Pacific warm more slowly than the global average, the eastern central Pacific warms faster than the global average in outputs from several AOGCMs (Meehl and Washington, 1996; Timmerman *et al*., 1997; Knutson and Manabe, 1998; Jones *et al*., 1999). These results have been broadly interpreted as an El Niño-like pattern (e.g., Cai and Whetton, 2000) because some simulations appear

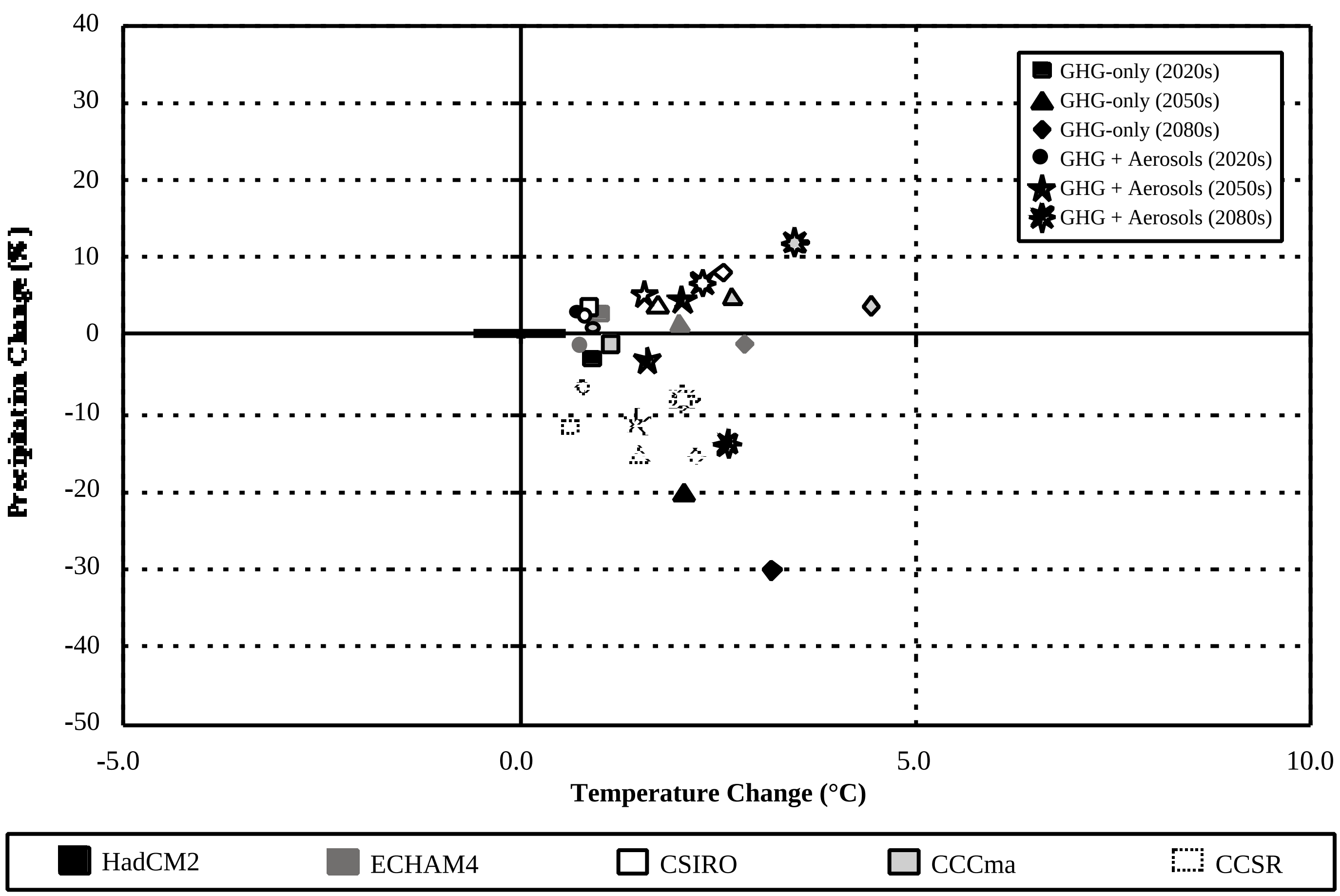

Figure 17-4: Climate change scenarios for Atlantic Ocean and Caribbean Sea islands as simulated by five AOGCMs for the 2020s, 2050s, and 2080s.

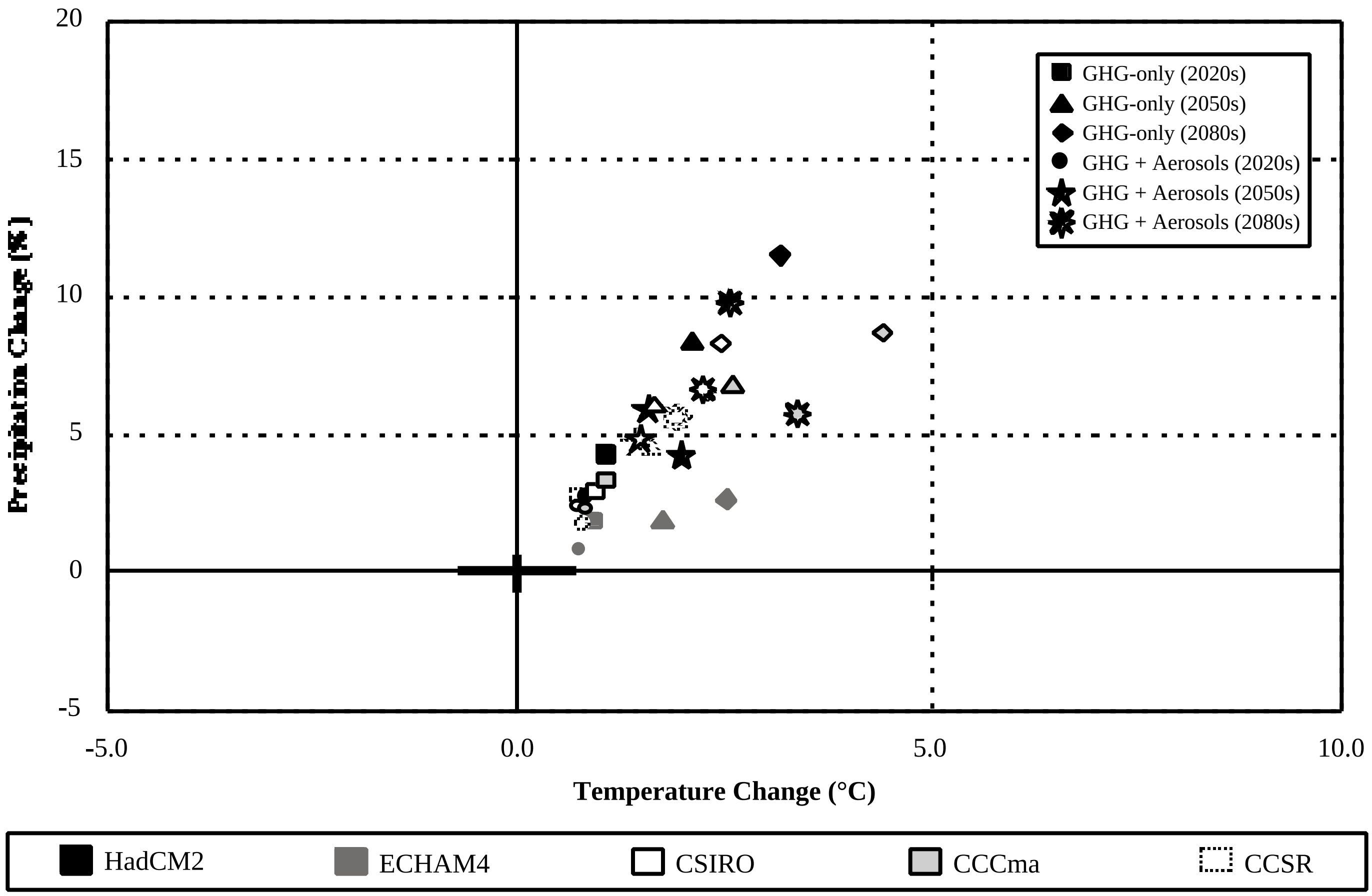

Figure 17-5: Climate change scenarios for Pacific Ocean islands as simulated by five AOGCMs for the 2020s, 2050s, and 2080s.

to project more frequent ENSO-like patterns (Timmerman *et al*., 1997). In the Pacific, climate variability associated with the ENSO phenomenon manifests itself on a seasonal to decadal time scale. This, in turn, affects factors such as temperature, rainfall, wind speed and direction, sea level, and tropical cyclone climatology that are directly associated with numerous climate-related impacts in the region.

Jones *et al*. (1999) have produced projected ranges of change in average temperature and rainfall for the western Pacific, based on scaled patterns from three independent AOGCMs and a suite of two AOGCMs and a regional circulation model (RCM). These scaled patterns were produced by the regression method described in Hennessy *et al.* (1998) and Giorgi and Mearns (1999), in which the influences of decadal variability are significantly reduced. Jones *et al.* (1999) showed that warming in the Pacific region is projected to increase by less than the global average in most cases. Projections of rainfall are constrained by the models' ability to simulate the SPCZ and ITCZ. All models were able to produce aspects of both features, although the eastern part of the ITCZ was not well captured by any of the models; the higher resolution models were the most realistic. The models also did not produce consistent changes to these features, execept for a large increase in rainfall over the central and east-central Pacific. Most of the projected changes across the western Pacific were increases, with significant increases along the equatorial belt from North Polynesia to further east. Possible decreases were noted in some models for Melanesia and South Polynesia in both halves of the year (April–October and November–March).

Climate variability in the Pacific is a combination of seasonal, multi-annual variability associated with the ENSO phenomenon and decadal variability, the latter influencing the ENSO phenomenon itself. The major concern for impacts in the region is not with the mean climate changes described above but with the extremes that are superimposed on those mean changes. Numerous studies describe the likely intensification of rainfall when the mean change ranges from a slight decrease to an increase. For instance, mean decreases of 3.5% over South Polynesia from the mixed-layer GCM (UKHI) produced little change in intensity, whereas an increase of 7.5% over Micronesia halved the return periods of heavy rainfall events (Jones *et al*., 1999).

GCMs currently project an increase in SSTs of approximately 1°C by the 2050s and increased rainfall intensity in the central equatorial Pacific, which would impact many small island states in that region. Recent variations over the tropical Pacific Ocean and surrounding land areas are related to the fact that since the mid-1970s, warm episodes (El Niño) have been relatively more frequent or persistent than the opposite phase (La Niña). There are indications that the ENSO phenomenon may be the primary mode of climate variability on the 2- to 5-year

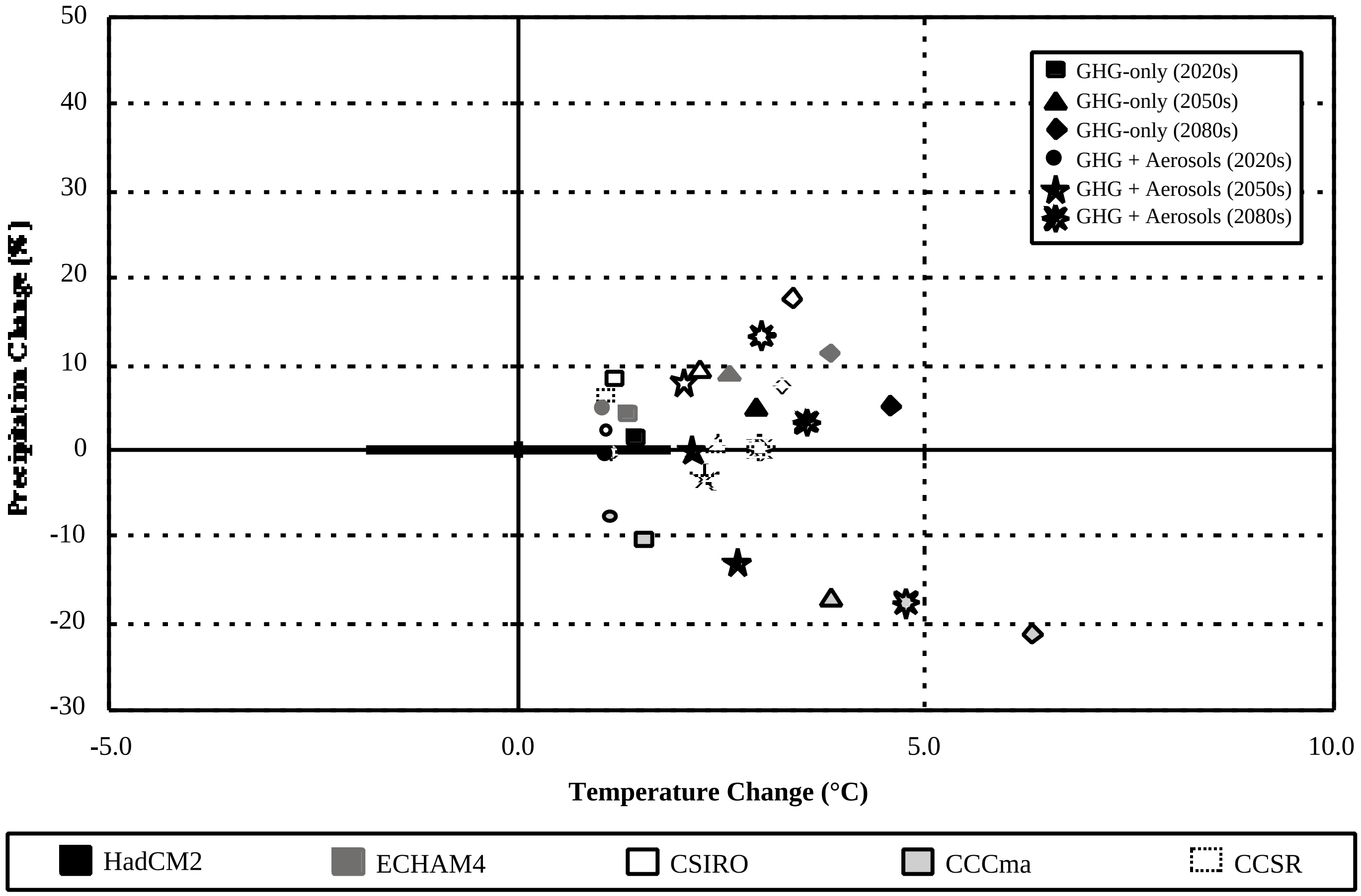

Figure 17-6: Climate change scenarios for Mediterranean Sea islands as simulated by five AOGCMs for the 2020s, 2050s, and 2080s.

time scale and that the current large interannual variability in the rainfall associated with ENSO is likely to dominate over any mean effects attributable to global warming (Jones *et al.*, 1999).

Comparisons between observations and model simulations for the Pacific region further indicate that regional warming would be mostly less than the global average because of the large expanse of ocean. However, there has been a strong indication from several model simulations that the least warming would occur in the southern ocean; the greatest warming could be expected in the far west, central, and eastern equatorial Pacific. In the case of rainfall, increases are likely to be greater where warming over the ocean is greatest, although one GCM output showed no increase in rainfall variability between 1960 and 2100. Model variability is likely to be much lower than historical variability because of the great influence of ENSO, particularly in the Pacific (Jones *et al.*, 1999).

17.1.4.3.5. Tropical cyclones

There is no consensus regarding the conclusions of studies related to the behavior of tropical cyclones in a warmer world. Working Group I concludes that current information is insufficient to assess recent trends, and confidence in understanding and models is inadequate to make firm projections (see TAR WGI). Royer *et al*. (1998), using a downscaled AOGCM coupled with Gray's method for hurricane forecasting, found no significant change in hurricane frequency or geographical extent for the north Atlantic Ocean, the Pacific Ocean, or the Indian Ocean.

Notwithstanding the foregoing conclusions, individual studies have reported the likelihood of a possible increase of approximately 10–20% in *intensity* of tropical cyclones under enhanced CO_2 conditions (Holland, 1997; Tonkin *et al*. 1997). This finding is supported by Jones *et al*. (1999), who conducted an analysis of tropical cyclones from a 140-year simulation of an RCM nested in a coupled AOGCM for the Pacific region (see Box 17-1). Although the preliminary analysis implies that there might be a small decrease in cyclone formation, an increase in system intensity is projected. The pattern of cyclones during phases of ENSO was unchanged, suggesting that the relationship between cyclone distribution and ENSO may continue. The study by Jones *et al.* (1999) considers that increases in cyclone intensity (10–20%) estimated by Tonkin *et al*. (1997) and Holland (1997) are highly likely.

17.2. Key Regional Concerns

17.2.1. Development, Sustainability, and Equity Issues

The small island states account for less than 1% of global GHG emissions but are among the most vulnerable of all areas to the

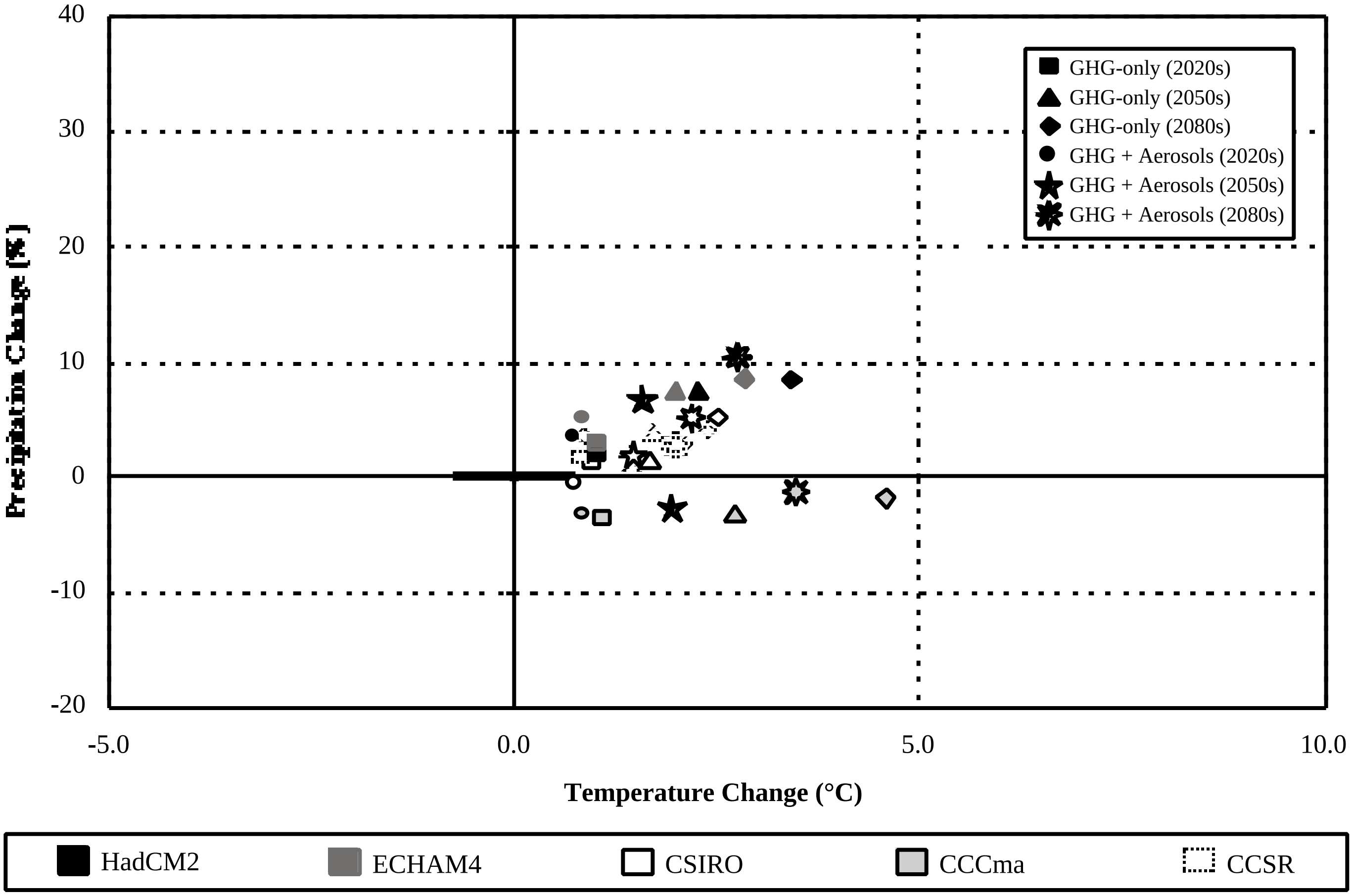

Figure 17-7: Climate change scenarios for Indian Ocean islands as simulated by five AOGCMs for the 2020s, 2050s, and 2080s.

potential adverse effects of climate change and sea-level rise (Jones, 1998; Nurse *et al.,* 1998). It has been established that there already is a global commitment to climate change and sea-level rise as a result of greenhouse forcing arising from historic emissions (Warwick *et al.*, 1996; Jones, 1998; Nicholls *et al*., 1999; Parry *et al*., 1999). Moreover, analysis has shown that even with a fully implemented Kyoto Protocol, by 2050 warming would be only about 1/20th of a degree less than what is projected by the IPCC (Parry *et al.*, 1999). Therefore, climate change impacts are inevitable.

Thus, owing to their high vulnerability and low adaptive capacity to climate change, communities in small island states have legitimate concerns about their future on the basis of the past observational record and present climate model projections. Economic development, quality of life, and alleviation of poverty presently constitute the most pressing concerns of many small island states. Thus, with limited resources and low adaptive capacity, these islands face the considerable challenge of charting development paths that are sustainable and controlling GHG emissions, without jeopardizing prospects for economic development and improvements in human welfare (Munasinghe, 2000; Toth, 2000). At the same time, given the inevitability of climate change and sea-level rise, they are forced to find resources to implement strategies to adapt to increasing threats resulting from GHG forcing of the climate system, to which they contribute little (Hay and Sem, 1999; Sachs, 2000). Consequently, the already meager resources of these island states will be placed under further pressure.

17.2.2 Water-Level Changes

17.2.2.1. Sea-Level Rise

Although the severity of the threat will vary regionally, sea-level rise of the magnitude currently projected (i.e., 5 mm yr^{-1}, with a range of 2–9 mm yr^{-1}), is expected to have disproportionately great effects on the economic and social development of many small island states (Granger, 1997; IPCC, 1998). Coastal land loss already is projected to have widespread adverse consequences. Indeed, it is argued that land loss from sea-level rise, especially on atolls (e.g., those in the Pacific and Indian Oceans) and low limestone islands (e.g., those in the Caribbean), is likely to be of a magnitude that would disrupt virtually all economic and social sectors in these countries (Leatherman, 1997). Recent estimates indicate that with a 1-m rise in sea level, 10.3 km^2 of land in Tongatapu island, Tonga, would be lost (Mimura and Pelesikoti, 1997). This figure would increase to 37.3 km^2 (14%) with storm surge superimposed on a 1-m sea-level rise scenario. For some main Yap Island (Federated States of Micronesia) sites, a retreat of 9 to 96 m is projected with a 1-m rise in sea level (Richmond *et al.*, 1997). On Majuro Atoll, Marshall Islands, land loss from one area based on the Bruun rule is estimated

Box 17-1. Climate Change Scenarios for the South Pacific Region

As part of the Pacific Islands Climate Change Assistance Programme, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) has prepared regional climate change scenarios for the four South Pacific regions of Micronesia, Melanesia, and north and south Polynesia (Jones *et al.,* 1999). Six coupled atmosphere-ocean climate simulations were included in the analysis of regional climate change scenarios: CSIRO Mark 2 GCM with and without sulfates, CSIRO DARLAM 125 km, DKRZ ECHAM4/OPYC3 GCM, Hadley Centre HADCM2, and the Canadian CGCM1. The regional scenarios derived can be considered as projections that represent a range of possible future climates.

Generally, the models project a temperature increase that is less than the global mean. Results show the least warming in the South Pacific; regional maximum warming is projected in the far west, central, and eastern equatorial Pacific. Four of the models show an increase in rainfall over the central and eastern Pacific over both half-years (i.e., May to October and November to April). Movements of both the ITCZ and the SPCZ were not consistent between models, but rainfall consistently increased. Increases in daily rainfall intensity are expected in regions where rainfall increases, remains the same, or decreases slightly, as derived from several models and studies. Thus, high confidence is attached to this result.

Historical sea-level rise over the Pacific from tide gauge records adjusted for postglacial rebound is consistent with global estimates of 1–2 mm yr^{-1}. ENSO is the dominant influence on climate variability in the Pacific, and model outputs show that the ENSO phenomenon is likely to continue to 2100. The results also suggest that under climate change, there is likely to be a more El Niño-like mean state over the Pacific. There is no evidence that tropical cyclone numbers may change, but a general increase in *tropical cyclone intensity*, expressed as possible increases in wind speed and central pressure of 10–20% with $2xCO_2$ equivalent, now appears likely. Moderate confidence is attached to this result. No significant change in regions of formation was noted in the DARLAM 125 km resolution simulation, although this may alter in response to long-term changes to ENSO. Although there appears to be no major change in regions of origin, tropical cyclones showed a tendency to track further poleward. Low confidence is attached to this result.

to be nearly 65 ha of dry land from a 1-m rise in sea level (Holthus *et al*., 1992).

One of the most serious considerations for some small islands is whether they will have adequate potential to adapt to sea-level rise within their own national boundaries (Nurse, 1992; IPCC, 1998). In tiny islands where physical space already is very scarce, adaptation measures such as retreat to higher ground and use of building set-backs appear to have little practical utility. In extreme circumstances, sea-level rise and its associated consequences could trigger abandonment and significant "off-island migration," at great economic and social costs (Leatherman, 1997; Nicholls and Mimura, 1998).

17.2.2.2. Storm Surge and Flood Risks

Changes in the highest sea levels at a given locality will result from the change in mean sea level at that location and changes in storm-surge heights. If mean sea level rises, present extreme levels will be attained more frequently, all else being equal. The increase in maximum heights will be equal to the change in the mean, which implies a significant increase in the area threatened with inundation. This will be especially true in areas with a small surge envelope, which is typical in most small islands. Under such circumstances, even incrementally small elevations in sea level would have severely negative effects on atolls and low islands (Forbes and Solomon, 1997; Nicholls *et al*., 1999).

Changes in storm-surge heights also would result from alterations in the occurrence of strong winds and low pressures, as would occur during the passage of tropical storms and cyclones. It is already known that tropical cyclones are the major cause of storm surges that impact small islands in the Atlantic, Pacific, and Indian Oceans. Changes in the frequency and intensity of tropical cyclones could result from alterations to SST, large-scale atmospheric circulation, and the characteristics of ENSO (Pittock *et al*., 1996). Although there is no consensus yet with regard to whether there will be changes in the behavior of these systems (Royer *et al*., 1998; Jones *et al*., 1999), the prospect of extreme sea levels (related to storm surges and higher wave amplitudes) is a concern that small island states cannot easily ignore.

Based on global sea-level rise scenarios produced by the Hadley Centre (HADCM2 and HADCM3), Nicholls *et al.* (1999) estimate that global sea levels are expected to rise by about 38 cm between 1990 and the 2080s. They project that many coastal areas are likely to experience annual or more frequent flooding, with the islands of the Caribbean and the Indian and Pacific Oceans facing the largest relative increase in flood risk. Projected out to the 2080s, the number of people facing high flood risk from sea-level rise in these regions would be 200 times higher than in the case of no climate change (Nicholls *et al*., 1999). Recent studies for Cuba (based on HADCM2 and IS92a scenarios) also project that 98 coastal settlements with a combined population exceeding 50,000 persons would be inundated by a 1-m rise in sea level (Perez *et al.,* 1999).

17.2.3. Beach and Coastal Changes

The morphology, characteristics, and classification of beaches are influenced by a variety of factors, including island origin, geologic structure and composition (e.g., volcanic, coral atoll, raised atoll, reef island, or emergent limestone), age, elevation, and size (Gillie, 1997; Solomon and Forbes, 1999). Thus, given their varied origins, a wide range of beach types and characteristics is represented in the small island states of the Caribbean and Mediterranean Seas and the Atlantic, Pacific, and Indian Oceans.

Coastal erosion—partly the result of anthropogenic factors such as sand mining (Gillie, 1997; Ragoonaden, 1997)—already is a problem on many islands and evidently may be exacerbated by sea-level rise (Mimura and Nunn, 1998). On many atolls (as in the Pacific) and low reef islands (as in the Caribbean), carbonate beaches are maintained by sand produced from productive reefs whose degradation already is causing accelerated beach erosion. Similarly, in the Mediterranean Sea, where the islands are periodically susceptible to flooding and scour from storm surges, an increase in storminess would further stress natural and human systems located at the coast (Nicholls and Hoozemans, 1996). The impact of the equivalent of a 1-m rise in sea level for a cumulative few hours on the coast was observed in Singapore on 7-14 February 1974. The event indicates clearly the vulnerability of the island's low-lying area to flooding and coastal erosion if sea-level rise takes place (Wong, 1992).

Beach erosion rates of approximately 2–4 m yr^{-1}, on average, have been reported for several beaches in Trinidad and Tobago, where mean relative sea-level rise of 8–10 mm yr^{-1} has been recorded by two gauges during the past 15 years. Although beach erosion results from multiple forces, sea-level rise is considered a contributory factor (Singh, 1997a,b). Ragoonaden (1997) measured shoreline retreat of 2.7 m yr^{-1} at Flic-en-Flac (Mauritius), and Nunn and Mimura (1997) report that the coasts of some islands in Fiji have retreated by more than 30 m in the past 70 years. In the specific case of Viti Levu and Taveuni, Fiji, beach erosion has been attributed to a combination of human-induced causes (including loss of the mangrove fringe and other natural protection) and elevated sea level, which has been rising at a rate of approximately 1–1.5 mm yr^{-1} since 1960 (Forbes and Solomon, 1997; Nunn and Mimura, 1997).

17.2.3.1. Response, Adaptation, and Management

It is now widely accepted that strategies for adaptation to sea-level rise tend to fall into three main categories: retreat, accommodate, and protect (Bijlsma, 1996; IPCC, 1996, 1998). Hard engineering—involving the construction of groynes, seawalls, breakwaters, and bulkheads—has long been the traditional response to coastal erosion and flooding in many small island states. Unfortunately, this approach has not always been efficiently implemented and has even helped to increase coastal vulnerability in some cases (Mimura and Nunn, 1998; Solomon and Forbes, 1999). In these specific circumstances, the term "maladaptation" (which refers to a response that does not succeed in reducing vulnerability but increases it instead; see Chapter 18) may be applied. Realistically, however, for some islands the application of hard solutions may be the only practical option along well-developed coasts, where vital infrastructure is at immediate risk.

There are other potential options available to small island states, including enhancement and preservation of natural protection (e.g., replanting of mangroves and protection of coral reefs), use of softer options such as artificial nourishment, and raising the height of the ground of coastal villages (Nunn and Mimura, 1997). Raising the height of the ground requires additional aggregate such as sand and stone and a lot of pumping, in which many small islands are seriously deficient. Removal of materials from "unimportant" islands to build up important islands via sand transfer by pipes and barges has been suggested by the IPCC (1990). Some island states may be faced with few practical options. Thus, it might be necessary for them to lose some islands so that the entire nation is not completely inundated (Nicholls and Mimura, 1998).

Similarly, beach nourishment may not be a practical or economical option for many island nations because sand often is a scarce resource (Leatherman, 1997; IPCC, 1998). Moreover, beach nourishment requires maintenance in the form of periodic sand replenishment, sometimes every 5–10 years or less (Amadore *et al*., 1996). Such a requirement could prove to be unsustainable in small economies. In contrast, on some islands such as Singapore, where the technology and resources are more readily available, beach fill projects (used in combination with offshore breakwaters to form artificial headlands) is a feasible option (Wong, 1985). As a general strategy to respond to sea-level rise, it is likely that Singapore will focus on three main types of responses: coastal protection for developed or heavily populated areas and reclaimed land, anti-salt-intrusion measures for coastal reservoirs, and flood prevention measures (such as tidal gates) for major canals (Wong 1992).

In some islands, such as those in the Caribbean, more emphasis is being placed on the application of "precautionary" approaches, such as enforcement of building set-backs, land-use regulations, building codes, and insurance coverage. In addition, application of traditional, appropriate responses (e.g., building on stilts and use of expendable, readily available indigenous building materials), which have proven to be effective responses in many islands in the past, ought to be more widely considered (Forbes and Solomon, 1997; Mimura and Nunn, 1998).

Given the vulnerability of many small island states to various aspects of global change, integrated coastal management (ICM) is rapidly becoming an attractive paradigm for planning adaptation (Bijlsma, 1996; Cicin-Sain, 1998; Nicholls and Mimura, 1998). Furthermore, ICM can be regarded as both an anticipatory and a predictive tool, with the capability to plan for and respond to medium- and long-term concerns such as sea-level rise as well as short-term, present-day needs (Nurse, 1999; Solomon and Forbes, 1999). In addition, ICM can provide an effective framework for resolving potential conflict among competing stakeholder interests, in a manner that is equitable to all groups. In this context, it is noteworthy that all of the small island states that recently participated in the U.S. Country Studies Program (i.e., Federated States of Micronesia, Samoa, Fiji, Kiribati, Marshall Islands, Sri Lanka, and Mauritius) concluded that ICM was the most appropriate adaptation strategy and should form an essential part of their climate change national action plans (Huang, 1997).

Enhancing the resilience of coastal systems has been suggested (e.g., Bijlsma, 1996) as an appropriate proactive adaptive response to reduce vulnerability. Klein and Nicholls (1998) agree that this could be a more cost-effective way to prepare for uncertain changes such as sea-level rise, rather than relying entirely on building traditional, more costly coastal defenses. Helmer *et al.* (1996) strongly support the notion of enhancement of coastal resilience whereby dynamic systems (e.g., dunes, lagoons, and estuaries) should be allowed to utilize their natural capacity to grow in response to rising sea levels. This philosophy could be applied through pilot studies in small islands. One of the ways in which a dynamic and resilient coast can be created is by managed retreat, based on an enforced building set-back that allows the coastline to recede to a new line of defense, thus restoring natural coastal processes and systems. An orderly plan to retreat could be a feasible option on larger islands that cannot commit the resources necessary to prevent coastal land loss in the face of rising sea levels (Leatherman, 1997).

One recommended approach to planning adaptation to sea-level rise and coastal change involves an estimation of the costs of protecting or abandoning developed properties. For developed coasts, West and Dowlatabadi (1999) propose that the real economic evaluation of sea-level rise should be regarded as the difference in utility (not just damages) with and without a sea-level rise scenario, in which it is assumed that physical conditions (e.g., erosion and storms) and human behavior remain constant. This is an improvement on past approaches, which provided the estimated costs of sea-level rise on the basis of market value of inundated land and property or the cost of structural protection.

17.2.4. Coral Reefs, Mangroves, and Seagrasses

17.2.4.1. Coral Reefs

Coral reefs represent one of the most important natural resources of many tropical islands. They are a source of food, beach sand, and building materials and function as natural breakwaters along the coasts of many tropical islands. They also provide habitats for many marine animals and reef fish and generate significant revenues for many small island economies through avenues such as tourism (e.g., snorkeling and scuba diving). On many islands, coral reefs are facing severe threats from climate- and non-climate-related stressors. The total areal extent of living coral reefs has been estimated at about 255,000–1,500,000 km^2 (Spalding and Grenfell, 1997), of which 58% are considered at risk from human activities, according to a global assessment (Bryant *et al*., 1997).

Owing to their narrow temperature tolerances, some species of corals currently live at or near their thermal limits (Goreau, 1992; IPCC, 1998). SSTprojections (based on three variants of the Max Planck Institute ECHAM and CSIRO GCMs) suggest that the thermal tolerance of reef-building corals will be exceeded within the next few decades. Moreover, the incidence of bleaching will rise rapidly, with the rate of increase highest in the Caribbean and slowest in the central Pacific region (Hoegh-Guldberg, 1999).

There is now substantial evidence that indicates that “episodic” warming of the ocean surface, as occurs in El Niño years, leads to significant coral bleaching (Brown and Ogden, 1993; Glynn, 1993; Goreau and Hayes, 1994; Wilkinson and Buddemeier, 1994; Brown, 1997a,b; CARICOMP, 1997; Goreau *et al*., 1997). The major coral bleaching episodes in the past 20 years were found to be associated with periods when ocean temperature were about 1°C higher than the summer maximum. It also has been suggested that bleaching events could occur annually in most tropical oceans in the next 30–50 years (Hoegh-Guldberg, 1999). Bleaching was particularly severe and widespread during the period of the most recent El Niño episode of 1997–1998, which was considered to be the most intense such event on record. On some islands, more than 90% of all live reefs have been affected (Goreau and Hayes, 1994), with branching species generally most severely impacted (Wilkinson 1998, 1999). An assessment of the literature on coral bleaching is provided in Chapter 6.

The impact of increasing CO_2 concentrations in the oceans on coral reefs is now the focus of an emerging though as yet unresolved debate. Since publication of the SAR and the *Special Report on Regional Impacts of Climate Change* (IPCC, 1998), it has been suggested that the ability of reef plants and animals to make the limestone skeletons that build the reefs is being reduced by rising atmospheric CO_2 concentrations. Indeed, some authors suggest that based on projected CO_2 concentration in the atmosphere, the calcification rate of corals would decline by approximately 14–30% by 2050 (Gattuso *et al.*, 1999; Kleypas *et al*., 1999). Again, see Chapter 6 for a full evaluation of the main issues in this debate.

Chapter 6 points out that earlier IPCC assessments have concluded that the threat of sea-level rise to reefs (as opposed to reef islands) is negligible. This conclusion was based on projected rates of global sea-level rise from Warrick *et al*. (1996) on the order of 2–9 mm yr^{-1} over the next 100 years. It has been suggested that healthy reef flats will be able to keep pace with projected sea-level rise, given an approximate upper limit of vertical reef growth during the Holocene of 10 mm yr^{-1} (Schlager, 1999). However, the prognosis is far less positive in many small island states (e.g., in the Caribbean Sea and the Indian Ocean), where reef structures have been weakened by a variety of anthropogenic stresses. This concern also is applicable to many island countries, where reefs in close proximity to major settlements have been severely stressed. The ability of reefs to keep pace with sea-level rise also will be adversely affected by more frequent coral bleaching episodes and by reduced calcification rates resulting from higher CO_2 concentrations.

17.2.4.2. Mangroves

Mangroves provide important functions as protection against storms, tides, cyclones, and storm surges and are used as "filters" against the introduction of pests and exotic insects (Menendez and Priego, 1994; Suman, 1994). Mangroves have important ecological and socioeconomic functions as well, particularly in relation to animal and plant productivity, as nutrient sinks, for substrate stabilization, and as a source of wood products. These functions sometimes may be in conflict and differ in importance between riverine, basin, and coastal fringe mangroves; the latter are important primarily for shoreline protection.

Many mangrove forests are under stress from excessive exploitation, reducing resilience in the face of sea-level rise. The importance of sediment flux in determining mangrove response to rising sea levels is well established in the literature. Ellison and Stoddart (1991), Ellison (1993), and Parkinson and Delaune (1994) have suggested that mangrove accretion in low- and high-island settings with low sediment supply may not be able to keep up with future rates of sea-level rise, but Snedaker and Meeder (1994) have suggested that low-island mangroves may be able to accommodate much higher rates. These observations may not necessarily represent conflicting views because the resilience of mangroves to sea-level rise also is conditioned by the composition and status of the stands and other factors such as tidal range and sediment supply (Woodroffe, 1995; Ewel *et al*., 1998; Farnsworth, 1998). In some protected coastal settings, inundation of low-lying coastal land actually may promote progressive expansion of mangrove forest with rising sea level (Richmond *et al*., 1997), provided vertical accretion keeps pace.

Notwithstanding the foregoing, studies have shown that mangrove forests in some small islands will be lost as a result of elevated sea levels. For example, it is projected that with a 1-m sea-level rise in Cuba, more than 300 ha of mangroves, representing approximately 3% of that country's forests, would be at risk (Perez *et al.*, 1999). Under similar conditions, Alleng (1998) projects a complete collapse of the Port Royal mangrove wetland in Jamaica, which has shown little capacity to migrate in the past 300 years; Suman (1994) envisages that accelerated sea-level rise would adversely affect mangroves in Puerto Rico, where 62% already has been eliminated by direct human activity.

17.2.4.3. Seagrasses

Seagrass communities provide useful habitat for many marine fish, particularly in the shallow, intertidal environments of many islands. It is postulated that an increase in SST will adversely affect seagrass communities because these ecosystems already are sensitive to land-based pollution and runoff in coastal environments (Edwards, 1995). It is argued further that the distribution of seagrasses will shift as a result of temperature stress, which in turn can cause changes in sexual reproduction patterns (Short and Neckles, 1999). In addition, an increase in temperature will alter seagrasses' growth rates and other physiological functions. Sea-level rise would mean increasing water depth and reduction of the amount of light reaching the seagrass beds, which would reduce plant productivity.

The effect of increased CO_2 in the water column will vary according to species and environmental circumstances but will likely alter the competition between species, as well as between seagrasses and algal populations (Beer and Koch, 1996). Laboratory experiments suggest that some seagrasses, such as *Zostera marina,* are able to respond positively to increased CO_2 levels by increasing their rate of photosynthesis (Zimmerman *et al*., 1997), although earlier research on field-collected samples of *Thallassia testudinum* suggests that maximum photosynthesis is lower with elevated CO_2 (Durako, 1993).

As with other submerged aquatic plants, seagrasses are sensitive to ultraviolet-B (UV-B) radiation because such radiation can penetrate depths of up to 10 m (Larkum and Wood, 1993). Laboratory experiments have demonstrated that the response can vary from strong photosynthetic tolerance, in the case of *Halophila wrightii*; to moderate tolerance, as with *Syringodium filiforme*; to little photosynthetic tolerance, as exhibited by *Halophila engelmanni* (Hader, 1993; Short and Neckles, 1999).

17.2.5. Biodiversity of Islands

Small islands are highly variable with respect to their biological diversity. Some states, such as the low reef islands, have low biodiversity and low endemism. Coral reefs exhibit the highest known diversity among marine ecosystems, with 91,000 described species of reef taxa. Table 17-4 gives the diversity of mammals, birds, plants, and endemism for some select small island states. In general, small islands in absolute figures tend to have high terrestrial diversity and endemism. In Cuba, for instance, 50% of the flora and 41% of the fauna are endemic (Vales *et al*., 1998). In the Canary Islands, 45% of all bird species are endemic. In the Hawaiian islands—the most isolated of all floristic regions—more than 90% of plant species are endemic (Biagini, 1999). When relative biodiversity and endemism are calculated in relation to area, the figures for many small island states tend to be higher than those for most other regions of the world.

Although there generally is high diversity associated with the ecosystems (marine and terrestrial) of islands, their long-term survival is threatened by anthropogenic stresses including pollution, overexploitation, and generally poor management. As in other regions, it is expected that climate change will affect the biodiversity of small islands directly and indirectly. Rising atmospheric CO_2 concentrations are projected to increase the productivity of some communities and alter competition

***Table 17-4**: Biodiversity status for selected small island states, 1990 (extracted from IPCC, 1998).*

Country	Known Mammal Species	Known Endemic Mammal Species	Known Bird Species	Known Endemic Bird Species	Known Plant Species	Known Endemic Plant Species
Cuba	31	12	342	22	6,004	3,229
Dominican Republic	20	—	254	0	5,000	1,800
Fiji	4	1	109	26	1,307	760
Haiti	3	0	220	0	4,685	1,623
Jamaica	24	3	262	25	2,746	923
Mauritius	4	2	81	9	700	325
Palau	214	57	708	80	10,000	—
Solomon Islands	53	19	223	44	2,780	30
Trinidad and Tobago	100	1	433	1	1,982	236

among others by eliminating some species and introducing new species to take their place (McIver, 1998). In marine ecosystems such as coral reefs, incremental increases in atmospheric CO_2 would be expected to threaten the diversity of these systems by the process described in Section 17.2.4.1 (Hatcher, 1997).

The impacts of climate change and sea-level rise on biota in island states are much greater than the impacts on continental areas. For example, sea-level rise could impact the habitats of the endangered Tuamotu sandpiper (*Prosobonia cancellata*) and bristle-thighed curlew (*Numenius tahitiensis*), as well as the seabird colony of 18 species on Laysan Island (Hawaii). Other potentially vulnerable areas (not inclusive) for breeding seabirds include the Kerguelen and Crozet Islands (seabirds), the Galapagos Islands (Galapagos penguin, *Spheniscus mendiculus*), and the nesting habitat for the Bermuda petrel (*Pterodroma cahow*) (Sattersfield *et al.*, 1998). Based on outputs from HADCM2 and scenarios IS92a and Kyoto 1, Suarez *et al.* (1999) also have found that in the eastern region of Cuba, certain endemic species of flora would face extinction.

Inundation and flooding of low-lying forested islets with species such as the Manus fantail (*Rhipidura semirubra*) also might be lost. The majority of threatened bird species on islands are found in forested habitats (Sattersfield *et al.*, 1998). Impacts of climate change on these species likely would be from physiological stress and changes and loss in habitat, especially from fires and cyclones. For example, 30% of the forested area on the Santa Cruz islands was lost in one cyclone in 1993. Some vulnerable species and areas include the endangered New Caledonian lorikeet (*Charmosyna diadema*) and critically endangered New Caledonian rail *(Gallirallus lafresnayanus)* on New Caledonia, the Samoan white-eye (*Zosterops samoensis*) and critically endangered Samoan moorhen (*Gallinula pacifica*) on Savai'i (Samoa), and the Santo Mountain starling (*Aplonis santovestris*) on Espiritu Santo (Sattersfield *et al.*, 1998). In Samoa, most species of flowering plants are pollinated by a few species of animals; nearly 100% of seed dispersal in the dry season is mediated by flying foxes (*Pteropus spp.*) (Cox *et al*., 1991). Likewise, flying foxes are the key pollinators and seed dispersers on many islands in the South Pacific. If their habitat is threatened by climate change, the result would be the loss of many dependent plant species.

Generally on islands, one of every three known threatened plants is endemic. Among birds, approximately 23% of the species found on islands are threatened, compared with only 11% of the global bird population (McNeely *et al*., 1993). Establishment of terrestrial, marine, or coastal reserves such as the Morne Trois Pitons Park and Forestry Reserve (Dominica, 1986), Bonaire Marine Park (Netherlands Antilles, 1979), Tobago Cays Marine Park (St. Vincent and the Grenadines), Soufriere Marine Management Area (St. Lucia, 1997), and other similar management units ("biosphere reserves") established elsewhere is a useful management option. It has been demonstrated that the creation of such reserves helps to preserve endangered habitats and ecosystems of small islands and will contribute to maintenance of biological diversity, while increasing the resilience of these systems to cope with climate change.

17.2.6. Water Resources

Availability of water resources is a limiting factor for economic and social development in small island states. Many such countries rely almost entirely on a single source of supply, such as groundwater (Barbados, Antigua, The Bahamas, Kiribati), rainwater (Tuvalu, northern atolls of Cook Islands, and the Maldives), surface reservoirs and imports (Singapore), or rivers and other surface flows (Seychelles, Dominica).

Water supply is most vulnerable in the atoll states of the Pacific, where water supply is sensitive to precipitation patterns and changes in storm tracks (Salinger *et al*., 1995). Captured rainwater is stored in cisterns; the only backup reserve for these islands is a thin wedge of fresh groundwater that sits on top of the saltwater lens. A reduction in precipitation coupled with sea-level rise would not only cause a diminution of the volume of potable water but would reduce the size of the narrow freshwater lens (Amadore *et al*., 1996).

The situation is equally critical in the low limestone islands of the eastern Caribbean, where seasonality of rainfall (a marked dry and wet season regime) is pronounced. On islands such as Anguilla, Antigua and Barbuda, Grenada, and Barbados, more than 65% of total annual rainfall may be recorded in the wet season, which spans the 6-month period of June to December. Moreover, most of the rainfall is strongly associated with the genesis and passage of easterly waves, tropical depressions, and storms (Gray, 1993; Nurse *et al.,* 1998). Thus, changes in the occurrence of these heavy rainfall events will certainly impact the water supply of many Caribbean islands. The situation is further exacerbated in Barbados, where recent research has shown that groundwater recharge is restricted to the three wettest months of the year, and only 15–30 % of annual rainfall reaches the aquifer (Jones *et al.,* 1998).

Reduced availability of adequate water supply in a changing climate also poses a potential threat to the Mediterranean islands of Cyprus and Malta. Because these two countries already experience water shortages (Nicholls and Hoozemans, 1996), and given a projected decrease in mean summer precipitation over the Mediterranean Sea region (IPCC, 1998), the water resources of these states could be placed under considerable pressure in the future (Tables 17-2 and 17-3). The threat is equally strong in some parts of the eastern Caribbean. Within the past few decades in Dominica, for instance, an apparent tendency toward more extended periods of drought is well correlated with reduced flows in the Castle Comfort, Roseau, Layou, and Geneva Rivers (Government of Commonwealth of Dominica, 2000). Because rivers are the main source of potable and irrigation water on the island and are also harnessed for power generation, declining flows have become a matter of serious national concern.

Climate change can present additional water management and related challenges. Such challenges may arise from a variety of sources, including increased flood risks and impeded drainage and the presence of elevated water tables—which may pose special engineering problems. It is projected that on Andros island, the Bahamas, where the water table presently is only 30 cm below the surface, high evaporation rates and increasing brackishness will eventuate with continued sea-level rise (Martin and Bruce, 1999). Similar projections also have been made for Cuba, where underground water supplies already are stressed (Planos and Barros, 1999). For many small island states, the prospect of salinity intrusion into the freshwater lens would be a matter of great concern. In many of these islands where salinization from overpumping of aquifers is already occurring (e.g., The Bahamas and Barbados), sea-level rise would compound the risk. In some cases, higher salinity would be experienced not only in coastal aquifers but also inland at freshwater pumping plants as the salty groundwater rises. Singh (1997a,b) has reported a recent increase in salinity levels for several coastal aquifers in Trinidad and Tobago in the southern Caribbean, attributable mainly to rapid drawdown exacerbated by sea-level rise.

There now is substantial evidence to support the view that precipitation variability in various parts of the world is linked to ENSO events. During the 1982–1983 ENSO event, rainfall in many parts of the western Pacific was a mere 10–30% of the long-term mean average (Falkland, 1992). More specifically, it is well established that ENSO has a strong influence on rainfall patterns in the tropics and low-latitude regions of the Southern Hemisphere (Shea, 1994; Whetton *et al*., 1996). In the Caribbean islands, droughts appear to be more frequent in El Niño years, whereas conditions tend to be wetter in La Niña years. The devastating drought in the region in 1998 coincided with what is believed to be the strongest El Niño signal on record. ENSO-related droughts also are known to occur in the low-lying atolls of the tropical Pacific. Thus, in countries such as the Federated States of Micronesia and the Marshall Islands where rainwater is the main source of supply, more frequent and intense ENSO events will impose further stress on already meager water resources (Meehl and Washington, 1996); other islands in the central and eastern tropical Pacific will experience heavy rains (Jones *et al.,* 1999).

Realistically, the options available to many small islands for reducing the adverse effects of climate change on water availability are limited. This implies that greater urgency and emphasis will have to be placed on improving water resource management efforts, including inventorying of resources and rational and equitable allocation. Implementation of more efficient rainwater harvesting methods, efficient leak detection and repair, use of water-saving devices, and aggressive recycling efforts are strategies worth considering. Desalination also is becoming an increasingly attractive option, especially where the necessary technical and financial capacity is available and in cases in which more traditional strategies are inadequate or not feasible (e.g., in Singapore, Malta, Cyprus, Barbados, Antigua and Barbuda, St. Kitts and Nevis, and Grenada). As part of their long-term adaptation strategy, these water-scarce islands might wish to include "no-regrets" measures, which will promote sustainability with or without climate change. Some countries may even wish to consider application of market-based systems to allocate water supplies, which could result in less wasteful practices under current conditions and thus enable water users to more efficiently adapt to climate change (Amadore *et al*., 1996).

17.2.7 Tourism

Tourism is a major economic sector in many small island states. Table 17-5, which expresses tourist arrivals in terms of the populations of small island states for which data were available, shows that in most small island states, the numbers of visitors substantially exceed the number of inhabitants. Table 17-5 also expresses tourism receipts in terms of gross national product (GNP) and in terms of foreign exchange inflows from exports of goods and services. Again, the ratios tend to be relatively high in most small island states; the Maldives, Antigua and Barbuda, and the Bahamas exhibit the highest ratios. In many countries, tourism also makes a significant contribution to employment. For example, the

***Table 17-5**: Tourist inflows and receipts, various years, for select small island states (Waters, 1998).*

Country	Number of Tourists (000s)[a]	Tourists as % of Population[a]	Tourist Receipts[b] as % of GNP	as % of Exports
Antigua and Barbuda	232	364.2	63.4	73.5
Bahamas	1618	586.4	42.0	75.6
Barbados	472	182.4	39.2	56.2
Cape Verde	45	11.4	11.5	37.3
Comoros	26	4.9	10.6	47.8
Cuba	1153	10.5	8.8	n/a
Cyprus	2088	280.7	24.0	49.1
Dominica	65	97.6	15.9	32.5
Dominican Republic	2211	28.1	13.6	30.2
Fiji	359	45.3	19.2	29.1
Grenada	111	116.2	27.0	60.6
Haiti	149	2.2	3.9	50.5
Jamaica	1192	45.6	31.6	39.8
Maldives	366	130.7	95.0	68.4
Malta	1111	294.7	22.9	28.7
Mauritius	536	46.4	15.7	26.8
Papua New Guinea	66	1.5	2.1	3.0
St. Kitts and Nevis	88	210.5	30.6	63.6
St. Lucia	248	164.7	41.1	66.6
St. Vincent	65	54.6	23.8	45.9
Samoa	68	31.1	19.6	48.8
Seychelles	130	166.7	34.6	52.2
Singapore	7198	209.2	6.2	4.1
Solomon Islands	16	3.7	2.8	4.2
Trinidad and Tobago	324	28.7	4.2	8.3
Vanuatu	49	27.1	19.3	40.9

[a] Data on tourist inflows and ratio to population pertain to 1997.
[b] Data for tourist receipts pertain to 1997 for the Bahamas, Cape Verde, Jamaica, the Maldives, Malta, Mauritius, Samoa, Seychelles, Singapore, and Solomon Islands; to 1996 for Antigua and Barbuda, Cuba, Dominica, Dominican Republic, Fiji, Grenada, Haiti, Papua New Guinea, St. Lucia, and St. Vincent; to 1995 for Barbados, Comoros, Cyprus, Trinidad and Tobago, and Vanuatu; and to 1994 for St. Kitts and Nevis.

industry provides jobs for 70% of the labor force in the Bahamas, 40% in Malta, and 20% in Seychelles (Waters, 1998).

It is widely acknowledged that the effects of climate change on tourism will be both direct and indirect. For instance, sea-level rise would disrupt the sector through loss of beaches, inundation, degradation of coastal ecosystems, saline intrusion, and damage to critical infrastructure (Nicholls and Hoozemans, 1996; Teh, 1997; Perez *et al.*, 1999). Because many small islands are so heavily dependent on the tourism sector for their economic survival, adverse impacts on the industry, from climate change or other causes, would be of great concern in these countries. In many small islands, the industry also would be sensitive to other climate-related impacts, such as loss of attractiveness of coral reefs as a result of bleaching.

Ahigh proportion of tourism in small island states is motivated by the desire of visitors from developed countries of the north (their largest market) to escape cold winters. Small island states are becoming increasingly concerned that projected milder winters in these markets could reduce the appeal of these islands as tourist destinations (Martin and Bruce, 1999). It is projected that tourism could be further harmed by increased airline fares if GHG mitigation measures (e.g., levies and emission charges) were to result in higher costs to airlines servicing routes between the main markets and small island states (Wall, 1996).

To ensure the sustainability of the tourist industry in Cyprus, it has been recommended that a strategy of protection of infrastructure combined with planned retreat would be effective and appropriate to local circumstances. The overall goal would be to maintain the limited beach area to sustain the vital tourist industry, specifically by erecting hard structures, enforcing building set-backs, and use of artificial nourishment, although the latter measure may require external sources of sand (Nicholls and Hoozemans, 1996). Although not all these strategies may be applicable to the atoll states, many other island nations—such as Barbados, Jamaica, Grenada, St. Lucia, and Singapore—already have begun to implement similar approaches as part of the ICM process.

17.2.8. Food Security

17.2.8.1. Crop Agriculture

Subsistence agricultural production is vital to the economies, nutritional status, and social well-being of small islands—particularly the small, low-lying, atoll states where food security is a major concern. The main subsistence crops include taro, sweet potato, yam, breadfruit, bananas, coconut, and a variety of vegetables. Production of cash crops such as sugarcane, copra, coffee, cocoa, rubber, and tea (grown at higher elevations on high islands) also is important because export of these products earns valuable foreign exchange. Climate change could precipitate heat stress, changes in soil moisture and temperature, evapotranspiration, and rainfall that might affect the growth of some subsistence root crops and vegetables. The consequences of such changes for agriculture are likely to be more severe in areas that already are under stress—for example, water-scarce islands. Crop agriculture also can be affected by tropical cyclones and other extreme events, such as floods and droughts. To the extent that many small islands are susceptible to these phenomena, it is highly likely that crop production in these states would be impacted by alterations in the patterns of these events as a consequence of climate change.

On low islands and atolls in the Pacific, practically all crop agriculture is concentrated at or near the coast. Thus, changes in the height of the water table and salinization as a result of sea-level rise would be stressful for most varieties of taro and other crops, which have low tolerance for salt. It has been suggested that in general, C_3 crops, which include many tropical crops, will benefit more from the effect of CO_2 fertilization than C_4 plants. However, recent findings indicate that the impact on sugarcane and maize yields would be adverse (Jones *et al*., 1999).

Singh and El Maayar (1998), using GCM (CCC 11) outputs and high, medium, and low CO_2 emission scenarios coupled with a crop model (FAO) to simulate crop yields, found that sugarcane yields may decrease by 20–40% under a $2xCO_2$ climate change scenario in Trinidad and Tobago in the southern Caribbean. The decrease in yields is attributed to increased moisture stress caused by the warmer climate. These reductions in sugarcane yields deriving from climate change are similar to those found for maize—another C_4 crop—in nearby Venezuela (Maytin *et al*., 1995). These results are supported by similar findings in Mauritius, which are derived from the Agricultural Production Systems Simulator Model (APSIM-Sugarcane) developed by the Agricultural Production Systems Research Unit, Australia. The study projects a decline in sucrose yield by more than 50% with a doubling of CO_2 (Cheeroo-Nayamuth and Nayamuth, 1999).

17.2.8.2. Fisheries

Although fishing is largely artisanal or small-scale commercial, it is an important activity on most small islands and makes a significant contribution to the protein intake of island inhabitants (Blommestein *et al*., 1996; Mahon, 1996). The impacts of climate change on fisheries are complex and in some cases are indirect. As with other renewable resources, an assessment of climate change impacts on fisheries is complicated by the presence of anthropogenic and other non-climate-related stresses, such as habitat loss and overexploitation (Challenger, 1997).

Many breeding grounds for commercially important fish and shellfish are located in shallow waters near coasts. These areas include mangroves, coral reefs, seagrass beds, and salt ponds—all of which are likely to be affected by climate change. Generally, fisheries in the small island states are not expected to be adversely affected by sea-level rise *per se*. Higher sea level would be a critical factor for fisheries only if the rate of rise were far more rapid than the current succession of coastal ecosystems (e.g., mangroves, seagrasses, corals) on which some fish species depend (Everett, 1996). In tropical islands, these ecosystems function as nurseries and forage sites for a variety of important commercial and subsistence species. In this context, the unfavorable effects of higher CO_2 concentrations on coral reef development, coupled with widespread coral bleaching, must be considered a significant threat in many small island states (see Section 17.2.4.1). Fish production obviously would suffer if these habitats were endangered or lost (Costa *et al*., 1994).

On a global scale, it is not expected that climate change and climate variability will lead to any significant reduction in fisheries production. However, important changes in the abundance and distribution of local stocks (which may be of direct concern to some small islands) are likely to occur (IPCC, 1996). For example, Lehodey *et al*. (1997) have shown that spatial shifts in the abundance of skipjack tuna in the Pacific are linked to the ENSO cycle. They note that catches are highest in the western equatorial Pacific warm pool, which can be displaced by as much as 50° of longitude eastward during El Niño episodes and westward in La Niña years (Lehodey *et al.*, 1997). This must be a concern to Pacific islanders whose access to the skipjack stocks now appears to be largely controlled by the periodicity of ENSO events.

Several management strategies for minimizing the adverse effects of climate change on fish stocks have been proposed. These measures—many of which already are being implemented in some island states—include conservation, restoration, and enhancement of vital habitats such as mangroves, coral reefs, and seagrass beds; establishment and management of marine reserves and protected areas for identified critical species; and implementation of bilateral and multilateral agreements and protocols for exploitation and management of shared fisheries (migratory and straddling stocks) (IPCC, 1998; Berkes *et al*., 2001). Aquaculture also may be considered by island states as another means of reducing stress on wild stocks. However, great precaution must be taken to ensure that this measure does not exacerbate existing problems of habitat loss and competition for nutrients (Carvalho and Clarke, 1998; see also Section 6.6.4).

17.2.9. Human Welfare

17.2.9.1. Settlement and Infrastructure

In most small island states (including high islands such as Seychelles, Reunion, and Fiji), narrow coastal plains provide attractive locations for settlement and a variety of infrastructure to support economic and social needs. Most of the population, settlements, and economic activities are concentrated in areas where competition for space is acute and where fragile ecosystems, aquatic and terrestrial, coexist. In most Caribbean islands, for example, more than 50% of the population live within 2 km of the coast. On atolls, most of the important infrastructure and population clusters often are less than 100 m from the shoreline. As the shortage of coastal space becomes increasingly acute in many small islands, land reclamation often is practiced as a solution to this need. Ironically, this practice exposes these islands to greater risk by attracting more settlement and infrastructure to already highly vulnerable locations.

As elsewhere, coastal development in most small islands has been undertaken in the past without taking climate change and sea-level projections into consideration. With currently projected rates of sea-level rise and flooding, coupled with the possibility of more intense and frequent extreme events such as cyclones (hurricanes) and associated storm surge, critical infrastructure such as social services, airports, port facilities, roads, coastal protection structures, tourism facilities, and vital utilities will be at severe risk. Furthermore, the capacity of most small island states to respond effectively to these threats is limited by their low adaptive capacity, which results from a combination of factors—including physical size (little opportunity to retreat), limited access to capital and technology, and a shortage of human resource skills.

In some countries, particularly the low islands and micro-atolls, resettlement within national boundaries may have to be considered as the only viable option. However, implementation of this strategy could become extremely complicated, especially for densely populated coastal lowlands such as in the Federated States of Micronesia (950 persons km^{-2}), Majuro, Marshall Islands (2,188 persons km^{-2}) and Male, Republic of Maldives (35,000 persons km^{-2}). In extreme circumstances, it may even become necessary to abandon some atolls altogether (Nurse *et al.,* 1998). Such an option would be socially and culturally disruptive and would require access to substantial resources—which most of these countries may be unable to afford.

17.2.9.2. Human Health

Increased instability of weather patterns and large interannual variability in climate enhanced by ENSO forcing and GHG-induced climate change have catalyzed a new focus on possible health consequences in a changing climate (Epstein, 1997; Epstein *et al.*, 1997; Hales *et al.*, 1997; Woodward *et al.*, 1998). Many tropical islands are now experiencing high incidences of vector- and water-borne diseases that are attributed to changes in temperature and rainfall regimes, which may be linked to events such as ENSO, droughts, and floods. In the Pacific, there is growing evidence that outbreaks of dengue are becoming more frequent and appear to be strongly correlated with the ENSO phenomenon (Hales *et al*., 1997, 1999a). Many of the small island states lie in the tropical zone, where the climate is suitable for the transmission of tropical diseases such as malaria, dengue, filariasis, and schistosomiasis.

Some of the small island states, such as the Bahamas, Kiribati, the Marshall Islands, and the Maldives, are a mere 3–4 m above mean sea level, which predisposes them to inundation with seawater and, as a consequence, salinization of freshwater supplies and flooding from sea-level rise. Furthermore, low-lying islands are particularly vulnerable to storms and cyclones; these also can adversely affect public water supplies. Vector-borne diseases such as malaria and dengue are particularly sensitive to warming and flooding. Filariasis and schistosomiasis are less sensitive to short-term seasonal climatic changes, but the epidemiology of these diseases could change with long-term effects of climate change. Water-borne diseases such as shigella, cryptosporidium, giardia, and amoebiasis could increase as a result of disruption of sewage and water systems by flooding (see Chapter 9).

It is also projected that, with temperature and rainfall changes, some vectors could extend their range, so there is likely to be wider transmission of some diseases (McMichael, 1996). For example, malaria—which previously tended to be confined largely to the western and central Pacific region—now appears to be extending east as far as Fiji. It also is worth noting that the interior uplands of many islands, which now are virtually free of vectors (e.g., *Aedes aegypti* mosquito) that transmit malaria, dengue, and other tropical illnesses—could become favorable breeding sites in a changing climate (disease-specific details appear in Chapter 9).

In some regions—for example, the Pacific—it has been noted that extreme weather events appear to be occurring at a higher frequency than elsewhere (Timmerman *et al*., 1997). As a consequence, physical injuries arising from these events can be expected to increase.

It is well-established that vulnerability to such health risks will vary according to factors such as availability of quality health care, the present health status of the population, and availability of technical and other resources (McMichael, 1993; WHO, 1996). Unfortunately, health care facilities and related infrastructure in many small island states and other developing countries often are inadequate. Hence, the resilience of such states and their capacity to respond effectively to (or mitigate) increasing health threats posed by climate change is likely to be low.

A range of adaptation strategies for reducing the severity of possible climate change-related health threats has been proposed, and many of these measures may be successfully pursued in the small island states. Such measures include, *inter alia,* implementation of effective health education programs, preventive maintenance and improvement of health care facilities, cost-effective sewerage and solid waste management practices, and disaster preparedness plans (McMichael, 1996).

Adoption of efficient early warning systems also would be beneficial in vulnerable small islands (Stern and Easterling, 1999). This process would involve monitoring of health-risk indicators by improving the forecasting of conditions that are favorable to the outbreak of climate-sensitive diseases such as dengue, cholera, and malaria (Patz *et al.*, 1996; IPCC, 1998; Epstein, 1999). Where large populations exist, as in urban areas, simple, low-cost measures could be implemented to control the vectors of dengue and other diseases, where a risk of transmission exists. At the individual level, insecticide-treated bed nets could provide protection against vectors of malaria and filariasis. Simple technology, such as the use of sari cloth to filter drinking water, reduces the risk of cholera transmission at the household level. Although some measures for adapting to climate change can be deferred, early implementation of preventive strategies could reduce current and future health "costs."

17.2.10. Other Economic and Sociocultural Impacts

Climate change could have direct and indirect impacts on other economic and social sectors in some small islands. The insurance industry is one sector that is highly sensitive to the magnitude and frequency of various hazards, including climate-related phenomena such as tropical storms and floods. Because insurance premiums are based on assessment of risk of occurrence of a particular event, any indication of an increase in the frequency or intensity of phenomena such as tropical cyclones and floods is likely to trigger an increase in the cost of insurance. Within the past decade, insurance costs in the Caribbean have increased significantly, following the passage of a series of severe hurricanes that caused widespread socioeconomic dislocation, injury, and loss of life. Claims were so high that some reinsurance companies withdrew from the market; others imposed higher deductibles, separate conditions for windstorms, and a premium structure to minimize the risk of underinsurance (Murray, 1993; Saunders, 1993). Even in cases in which these systems did not make landfall in the insular Caribbean itself—as with Hurricane Andrew, which devastated southern Florida in the United States—an increase in insurance premiums in the islands subsequently occurred.

Certain traditional island assets (goods and services) also will be at risk from climate change and sea-level rise. These assets include subsistence and traditional technologies (skills and knowledge), community structure, and coastal villages and settlements. Sea-level rise and climate changes, coupled with environmental changes, have destroyed some very important and unique cultural and spiritual sites, coastal protected areas, and traditional heritage sites in the Federated States of Micronesia, Tuvalu, the Marshall Islands, Niue, and Kiribati and continue to threaten others (Kaluwin and Smith, 1997). Although some of these assets fall into the category of nonmarket goods and services, they are still considered to be of vital importance in small island states. In Tuvalu, for instance (as in other Pacific atoll states), strong traditional ties to land and sea constitute a vital component of local cosmology (Sem *et al.*, 1996). Some of these values and traditions are compatible with modern conservation and environmental practices; therefore, priority action is needed in the following areas: research into traditional knowledge and practices of conservation and environment control—which have sustained these societies for generations, even in the face of hazards, risk, and uncertainty; inventorying of traditional, heritage, and other cultural sites; encouragement of practices that marry use of modern science and technology with traditional wisdom; and more effective transmission of traditional knowledge to younger generations.

17.3. Vulnerability and Adaptation Potential

17.3.1. Setting the Context

The potential impacts of climate change on small island states discussed in Section 17.2 have given rise to considerable concern. Relevant chapters in the First Assessment Report (FAR; Tsyban *et al.*, 1990) and SAR (Bijlsma, 1996) and in the *Special Report on Regional Impacts of Climate Change* (Nurse *et al.*, 1998) already concluded that low-lying small islands are among the most vulnerable countries in the world. A similar conclusion is reached in this Third Assessment Report (see Section 19.3.7). Their overall vulnerability is shown to be a function of the *degree of exposure* of these states to climate change and their *limited capacity to adapt* to projected impacts.

This section assesses the relevant literature on the vulnerability of small island states that has become available since the SAR, including an overview of available country studies. In addition, this section pays particular attention to adaptation. Whereas Bijlsma (1996) and Nurse *et al.* (1998) focuse on available adaptation options, this section takes a process-oriented approach to adaptation and recognizes adaptive capacity as an important determinant of vulnerability.

17.3.2. Generic Issues

Many definitions of vulnerability and adaptation exist in the literature (see Chapter 18). However, this report defines vulnerability to climate change as "the degree to which a system is sensitive to and unable to cope with adverse impacts of climatic stimuli. Vulnerability is a function of a system's exposure and its adaptive capacity." Adaptation is the "adjustment in natural or human systems in response to actual or expected climatic stimuli, or their effects" (see Chapter 2). Vulnerability therefore is a function of potential impacts and adaptive capacity, and adaptation refers to both natural and human system responses. Whereas the previous section focused on impacts and responses of natural systems, this section discusses the relevance of adaptation for human systems in a small islands context.

17.3.3. Vulnerability

Despite their heterogeneity, small island states share some common characteristics that help to define their high vulnerability and low adaptation potential to climate change effects (Nurse *et al.*, 1998; see also Section 17.1.2). Vulnerability assessment typically seeks to achieve three main goals: to identify the degree of future risks induced by climate change and sea-level rise; to identify the key vulnerable sectors and areas within a country; and to provide a sound basis for designing adaptation strategies and their implementation.

The IPCC Common Methodology was the first method to be widely applied to assess the vulnerability of countries to sea-level rise (IPCC, 1992). However, the methodology lacks the flexibility to consider factors of critical significance for small islands (e.g., so-called nonmarket goods and services) and requires certain quantitative data that often are not easily available in many small island states. An index-based method was developed for use in the south Pacific (Yamada *et al.*, 1995, based on Kay and Hay, 1993). In addition, alternative assessment methodologies were developed in conjunction with the various country study programs (e.g., Leatherman, 1996; Klein and Nicholls, 1998). What is significant, however, is that all available assessments confirm the high vulnerability of small island states to climate change, independent of the methodology applied. As already noted, global assessments come to the same conclusions (Nicholls *et al*., 1999). This is therefore a robust finding, which must be of considerable concern to these countries.

Climate change is expected to be one factor among many that affect ecological systems and economic development. Other factors that interact with climate change include overexploitation of resources, pollution, increasing nutrient fluxes, decreasing freshwater availability, sediment starvation, and urbanization (Goldberg, 1994; Viles and Spencer, 1995). Particularly relevant for small island states are rapid population growth, intra- and inter-island migration, rapid changes in social structure, and effects of economic globalization. These nonclimate stresses can decrease the resilience of natural and human systems, increasing their vulnerability to climate variability and anticipated climate change (Nicholls and Branson, 1998; Klein and Nicholls, 1999).

Most vulnerability indices developed to date have focused on economic and social systems, although studies by Ehrlich and Ehrlich (1991) and Atkins *et al.* (1998) focus on environmental vulnerability. The economic vulnerability indices include those developed by Briguglio (1995, 1997), the Commonwealth Secretariat (Wells, 1996, 1997; Atkins *et al.*, 1998), Pantin (1997), and the Caribbean Development Bank (Crowards, 1999). Another index, the Environmental Vulnerability Index, has been developed recently for small island states, particularly countries for which data availability is limited. It incorporates climate, nonclimate, and human stresses on the environment and seeks to reflect relative vulnerability as a function of these combined factors (Kaly e*t al*., 1999). All vulnerability indices consistently identify small states—sometimes more specifically small island states—as being more economically vulnerable than larger states.

Box 17-2. Tools for Vulnerability Assessment and Adaptation Policy Development

The numerous and well-developed interactions between the natural and human systems of island countries underscore the relevance of integrated assessment as a meaningful analytical tool for designing adaptation strategies. One such tool that has proven particularly beneficial is VANDACLIM, an integrated assessment model developed by the International Global Change Institute (University of Waikato, New Zealand), in collaboration with the South Pacific Regional Environment Programme (SPREP) and United Nations Institute for Training and Research (UNITAR) (Warrick *et al*., 1999). Enhanced and country-specific versions of VANDACLIM currently are being developed.

Development of VANDACLIM involved linking a regional scenario generator with selected impact models for four key sectors: agriculture, coastal zones, human health, and water resources. The user has considerable flexibility in generating scenarios; the user can choose among a large range of projections from GHG emission scenarios; the low, mid, or high cases from each projection (which encompasses the range of uncertainty in model parameter values); several GCM patterns; and the year of interest (in 5-year increments from 1990 to 2100).

VANDACLIM integrates a variant of the “Bruun rule” with a simple inundation model that is suitable for flat, low-lying deltaic coastal plains. Health impacts projections are derived from a biophysical index that estimates potential incidence of malaria and a simple threshold index for estimating change in the risk of cholera outbreaks related to extreme flooding events. For water resources, three models are included: an atmospheric water balance model for assessing the overall water resource situation for the country; a water balance-river discharge model for estimating monthly mean discharge for estimating wet and dry season river flow; and a discharge-flood area model for defining the areal extent of flooding. For agriculture, various crop models and indices are integrated, including degree-day models, rainfall (soil moisture), a land suitability index, and temperature for a variety of tropical crops.

Most existing studies have fulfilled the first two of the three aforementioned goals of vulnerability assessment, although information on socioeconomic impacts of climate change often is limited. The third goal—to provide a basis to guide possible adaptation—usually is met only in general terms. Effective planning and design of adaptation strategies requires more detailed information on crucial vulnerable sectors and areas. Such information may be partly derived from analysis at an integrated level (see Box 17-2)—as suggested, for instance, by Klein and Nicholls (1999).

17.3.4. Adaptation and Adaptive Capacity

As Campbell (1996) notes, a key misconception is that adaptation is a task carried out by governments. Insofar as governments have property and are responsible for carrying out a variety of activities, they will be required to take adaptive action. Most adaptation, however, will be carried out by individual stakeholders and communities, urban or rural, that inhabit island countries. Therefore, the government's primary role is to facilitate and steer this process—ideally in a manner that benefits the wider community.

Small island states often are susceptible to the impacts of a wide range of natural hazards, including climatic extremes. In the south Pacific region alone, island states suffered a total of 79 tropical cyclones, 95 storm surges, 12 floods, 31 droughts, four earthquakes, five landslides, two tsunamis, and four volcanic eruptions during the 1990s (Burns, 2000; Gillespie and Burns, 2000; Hay, 2000). The World Conference on Natural Disaster Reduction and the Global Conference on Sustainable Development of Small Island States noted several issues that influence adaptation to such impacts. These issues include the limited capacity of developing small island states to respond to and recover from natural and environmental disasters, owing to their narrow resource base and small size. Another issue is the decline in traditional coping mechanisms employed by island states, such as food preservation and storage techniques and disaster-resistant housing designs.

Given their high vulnerability, it is generally accepted that a proactive approach to adaptation planning would be especially beneficial to small islands, to minimize the adverse effects of climate change and sea-level rise (Campbell and de Wet, 2000). One essential prerequisite for implementing adaptive measures is support from policymakers and the general public. Thus, raising public awareness and understanding about the threats of climate change and sea-level rise and the need for appropriate adaptation require urgent and consistent attention. Because strong social and kinship ties exist in many small island states—for example, in the Pacific—a community-based approach to adaptation could be vital if adaptation policies and options are to be successfully pursued.

It also should be noted that small island states have faced many hazards in the past; as a consequence, their inhabitants have developed some capacity to cope by resorting to a combination of strategies, including application of traditional knowledge, locally appropriate technology (e.g., construction on stilts in flood-prone areas), use of indigenous materials, and other customary practices. Thus, for these states, it would be mandatory for any climate change adaptation policy and implementation plan to incorporate these traditional coping skills.

One of the obstacles to implementation of adaptation strategies stems from the uncertainties associated with the projection of future climate change and its impacts, at scales appropriate to small islands. Therefore, better guidance is needed for policy development in the face of uncertainties, together with more reliable climate projections at a scale that is relevant to the small island states (Edwards, 2000).

Many island states confront a range of pressing socioeconomic concerns (e.g., poverty alleviation, unemployment, health, and education), and climate change tends to be assigned a low priority on most national agendas. Thus, given the long lead time for implementing and assesing adaptation (as much as 50–100 years), progress in realizing its goals almost certainly will require integration of adaptation strategies with other sectoral and national policies, such as economic development, disaster prevention and management, integrated coastal management, and sustainable development frameworks.

17.3.5. Regional and External Factors

Small island states account for a small percentage of world energy consumption and extremely low levels of global GHG emissions and on balance are likely to be severely impacted by the effects of climate change (Yu *et al*., 1997; see Box 17-3). In most states, the bulk of the energy requirements are met

Box 17-3. Greenhouse Gas Emissions from Small Island States in the Pacific

Based on application of the *IPCC Guidelines for National Greenhouse Gas Inventories*, Pacific island countries are responsible for a per capita equivalent emission of approximately 0.96 t of CO_2 yr^{-1}. Hence, the total Pacific island population of 7.1 million in 22 countries produces 6.816 Mt of CO_2 yr^{-1}. In contrast, based on International Energy Agency data for 1996, global CO_2 emissions arising from fossil fuel combustion alone are 22,620.46 Mt of CO_2 yr^{-1}, or 4.02 t of CO_2 yr^{-1} per capita. Thus, on average, Pacific islanders produce approximately one-quarter of the CO_2 emissions attributable to the average person worldwide. Expressed another way, the Pacific islands region as a whole accounts for 0.03% of the global emissions of CO_2 from fuel combustion despite having approximately 0.12% of the world's population.

Source: Hay and Sem, 1999.

Box 17-4. Renewable Energy Use in Small Island States: A "Win-Win" Strategy

Most small islands are heavily dependent on imported fossil fuels for the majority of their energy requirements, particularly transport and electricity production. This is clearly demonstrated in the case of the Caribbean and Pacific islands, where petroleum imports are responsible for more than 75 and 88%, respectively, of primary energy demand. The cost of fossil fuel imports also places a considerable economic burden on small island states, accounting on average for almost 15% of all imports in these countries. In addition, the cost of electricity production (US$0.10–0.15 and 0.20 kWh^{-1} for the Caribbean and the Pacific, respectively) can be as much as three to four times higher than in developed countries.

In many islands, the high unit cost of conventional power production versus the increasingly competitive cost of renewable energy technologies (especially solar and wind), make the latter economically viable and environmentally friendly options. For these reasons, several small island states are making a significant contribution to global utilization of renewable energy resources. These include, *inter alia*, the following countries:

- Barbados, where approximately 33% of all households use solar water heaters
- La Desirade, Guadeloupe, where more than 75% of all electricity is generated from wind power
- Fiji and Dominica, where hydropower accounts for more than 30% of electricity production
- Tuvalu, where photovoltaics supply 45% of the electricity
- Reunion, where almost 20% of the electricity is biomass-generated (from bagasse, a by-product of sugarcane); bagasse also is becoming increasingly important as an energy source in Jamaica and Fiji.

Sources: Jensen, 1999; Ellis and Fifita, 1999.

from imported fossil fuels, which places a heavy burden on island economies (Yu *et al*., 1997). Adaptation and mitigation strategies in these countries, as elsewhere, will necessitate more economic and efficient energy use and greater emphasis on development of renewable energy sources (see Box 17-4).

To implement these strategies, many small islands, will require external technical, financial, and other assistance (Rijsberman, 1996). Given these states'size and limited individual capacities, pooling of resources through regional cooperation has been proposed as an effective means of designing and implementing some adaptation measures (Nicholls and Mimura, 1998). Some island groupings already have begun to implement regional projects aimed at building capacity to respond to climate change. Two projects—Caribbean Planning for Adaptation to Climate Change (CPACC), which is being implemented by 12 Caribbean states, and Pacific Islands Climate Change Assistance Program (PICCAP), which is being executed by SPREPfor 10 Pacific island countries—are outstanding models of regional cooperation.

17.4. Synthesis

17.4.1. Feedbacks, Interactions, and Resilience: The Relevance of these Concepts to Small Islands

Feedback mechanisms in changing systems are poorly understood. These mechanisms could produce a series of *downstream effects* as conditions within a system deviate from "normal" and can include mechanisms that bring conditions back toward "normal" (correcting) or push conditions further away from "normal" (compounding). Feedback of interactions between humans and the environment in the face of climate change are likely to be negative and are expected to increase. As humans have to take adaptive actions to preserve their systems in the face of climate change and sea-level rise, there is a risk that impacts on the environment will increase, despite better awareness of the issues. The short-term needs of humans are likely to take precedence over longer-term needs, which are intimately tied up with the environment. This could mean greater-than-expected and unpredictable indirect impacts resulting from climate change and sea-level rise.

Small island states urgently need sensible predictive information and tools for minimizing the likely outcomes of climate change and sea-level rise because it is now generally accepted that small islands are intrinsically more vulnerable than larger countries (Briguglio, 1992, 1993, 1995, 1997; Wells, 1996, 1997; Atkins *et al*., 1998; UNDP, 1998). The vulnerability of natural systems is still under investigation, although work is underway (Yamada *et al*., 1995; Sem *et al*., 1996; Kaly *et al*., 1999). This makes the requirement for information and tools for generating such information a top priority. The outcome of climate change on human and natural systems in small island states will depend on changes induced by climate itself, feedback mechanisms, human adaptive capacity, and the resilience of biophysical and human systems.

Indicators of high resilience might include the presence of healthy, intact ecosystems; the ability of species to acclimatize to new temperature regimes; the presence of land higher than the maximum predicted transgression plus storm surges; high productivity; reproduction and recruitment of species; and high rates of natural recovery (Kaly *et al*., 1999).

Resilience refers to the innate ability of biophysical and human systems to maintain their integrity when subjected to disturbance (Holling, 1973; Ludwig *et al*., 1997). For most natural systems, knowledge of resilience to climate change and sea-level rise is inadequate. For example, there are insufficient data to describe the ability of a reef to withstand sea-level rise of 20–40 cm over the next 50 years (but see Hoegh-Guldberg, 1999). Predicting which ecological variables (e.g., species, processes) might be affected and what effect this would have on ecosystem diversity, function, and future resilience may be difficult or impossible (Lubchenco *et al*., 1993). Proxy estimates have been made, most notably using recent El Niño events in the eastern Pacific; these estimates have many of the expected effects of climate change (Castilla *et al*., 1993; Burns, 2000). For oceans, these and other proxy estimates predict the extinction of species, mass mortality and bleaching of corals, changes in the geographic range of species, increases in disease, unexpected predation, decreases in productivity, and increases in harmful algal blooms (Glynn, 1984, 1988, 1991; Bak *et al*., 1984; Hallegraeff, 1993; Lessios, 1998; Hoegh-Guldberg, 1999).

Although earlier work suggested that systems exposed to perturbations tend to have greater capacity to recover from shock (e.g., Holling, 1973), research in a small island context challenges this conventional wisdom. Kaly *et al*. (1999) demonstrate that for many systems, the greater the number and intensity of hazards (human-induced as well as natural) that have impacted them in the past, the greater is their level of vulnerability to future stresses. Furthermore, because neither the natural resilience nor the altered resilience of any ecosystem is known—let alone the resilience that might arise as a result of summed or interactive effects—it is impossible to directly estimate overall resilience. This finding is very disturbing for most small island states, where ecosystems already are severely stressed from natural and anthropogenic forces.

17.4.2. Uncertainties and Risks

17.4.2.1. Inconsistencies and Limitations in Projected Changes

Present ability to accurately assess the effects of climate change in small island states, as in other regions, is further impeded by conflicting predictions of how natural systems may respond. For example, some studies cite the responses of ecosystems to El Niño events in the 1980s and 1990s as indicative of the likely effects of climate change, with conflicting outcomes (Salinger, 1999; Gillespie and Burns, 2000; Hay, 2000). On one hand, it is expected that primary productivity in oceans will *decrease* as a result of global warming when upwelled waters become shoaled (Roemmich and McGowan, 1995; Barber *et al*., 1996). On the other hand, it has been predicted that harmful algal blooms will *increase* with increasing temperatures (Colwell, 1996; Nurse *et al.*, 1998; see also Hales *et al*., 1999b). Clearly, forecasting of likely outcomes will be more complex than may have been expected initially. Thus, planning of appropriate responses in regions of low adaptive capacity, such as small island states, presents an even greater challenge.

17.4.2.2. Ecosystem Collapse

One of the likely outcomes of climate change and sea-level rise in natural systems is their collapse. Although ecosystem collapse is not presently well-defined or understood, it is a concern of island countries, which depend heavily on resources provided by these systems to sustain their economic and social well-being (Burns, 2000; Gillespie and Burns, 2000). If mangrove systems are to migrate inland, for example, what is involved is the collapse of the original mangrove system on the existing shore and its eventual replacement with another ecosystem. It is unclear whether the old mangrove area would be replaced by a viable alternative marine ecosystem or whether the new mangroves produced inland would be a viable ecosystem, with all of the same functional characteristics of the original. These and similar questions are central to understanding the ability of human and natural systems to adapt to climate change and sea-level rise.

17.5. Future Requirements, Information, and Research Needs

Although good progress has been made in understanding the vulnerability and adaptation potential of small island states to climate change, the foregoing discussion highlights critical information gaps and uncertainties that still exist. It has been established that small island states constitute a very high-risk group of countries as a consequence of their high vulnerability and low adaptive capacity. Climate change is inevitable, even if any global agreement to limit GHG emissions were swiftly implemented. Thus, the need to focus on adaptation options and requirements already is critical for small islands, given that these countries are projected to suffer disproportionately from the effects of climate change (Bijlsma, 1996; Nurse *et al*., 1998; Nicholls *et al*., 1999; Gillespie and Burns, 2000). The agenda set out below therefore is designed not only to fill existing knowledge gaps but also to help identify opportunities for minimizing the adverse effects of climate change (including avoidance of maladaptation), as an important component of adaptation planning in these islands:

- For most small islands, the lack of geographical detail is a critical shortcoming. Outputs from GCMs currently used to assess climate change impacts in small islands are coarse and do not provide adequate information for countries at the scale of small islands. Hence, there is an urgent need for downscaling the outputs of the GCMs to better define and understand island-scale processes and impacts.
- Research into the sensitivity of small islands to climate change, employing an integrated approach, should continue. Studies on the vulnerability of human and biophysical systems to climate change and their interaction with and response to natural and human stresses (including extreme events) need to be integrated because the more common "reductionist" approaches tend to be deficient in their treatment of interactive effects.

- Some small island states have initiated efforts to reduce the impact of natural disasters and to use seasonal to interannual climate analysis and climate forecasts to reduce the impacts of natural hazards. Because long-term climate change may result in a more El Niño-like state, with more frequent and severe extreme climate events, support to build on these past efforts could help to reduce the vulnerability of these islands to climate change.
- Although small islands have many characteristics in common, the heterogeneity factor should not be overlooked. Local conditions on widely varying island types (e.g., tectonic changes, shorelines with large sediment availability versus those with sediment deficits, highly fragmented versus single-island states) may increase or decrease climate change impacts, so the outcomes could be dramatically different in each small island setting. Climate change assessments under such varying circumstances would improve present understanding of vulnerability and adaptation requirements in small islands.
- Given their wide geographical dispersion, there is a need for a coordinated monitoring program for small islands that evaluates the long-term response of ecosystems to climate variability and change. The focus of such an effort should be on the complex interactions that may occur within human and natural systems to modify the frequency and magnitude of impacts expected and to identify ecosystems that may be in danger of collapsing, so that timely adaptive action might be taken. Such work would help to improve our understanding of the concepts of homeostasis, resilience, and feedback mechanisms, which—though frequently alluded to in the literature—are poorly understood and are critical for adaptation planning at the local and regional scale.
- Although the susceptibility of small islands to climate change impacts is high and adaptive capacity is low, the overall level of vulnerability varies within and among states. Thus, vulnerability indices being developed and refined specifically for small islands [Crowards, 1999 (Caribbean Development Bank); Kaly *et al*., 1999 (SOPAC)] have the potential to make a significant contribution to adaptation planning and implementation in this constituency. Countries therefore might wish to consider continuation of this work among their research priorities.

Finally, there is some uneasiness in the small island states about perceived overreliance on the use of outputs from climate models as a basis for planning risk reduction and adaptation to climate change. There is a perception that insufficient resources are being allocated to relevant empirical research and observation in small islands. Climate models are simplifications of very complex natural systems; they are severely limited in their ability to project changes at small spatial scales, although they are becoming increasingly reliable for identifying general trends. In the face of these concerns, therefore, it would seem that the needs of small island states can best be accommodated by a balanced approach that combines the outputs of downscaled models with analyses from empirical research and observation undertaken in these countries.

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