16

Small islands

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Executive summary

Small islands, whether located in the tropics or higher latitudes, have characteristics which make them especially vulnerable to the effects of climate change, sea-level rise, and extreme events (very high confidence).
This assessment confirms and strengthens previous observations reported in the IPCC Third Assessment Report (TAR) which show that characteristics such as limited size, proneness to natural hazards, and external shocks enhance the vulnerability of islands to climate change. In most cases they have low adaptive capacity, and adaptation costs are high relative to gross domestic product (GDP). [16.1, 16.5]

Sea-level rise is expected to exacerbate inundation, storm surge, erosion and other coastal hazards, thus threatening vital infrastructure, settlements and facilities that support the livelihood of island communities (very high confidence).
Some studies suggest that sea-level rise could lead to a reduction in island size, particularly in the Pacific, whilst others show that a few islands are morphologically resilient and are expected to persist. Island infrastructure tends to predominate in coastal locations. In the Caribbean and Pacific islands, more than 50% of the population live within 1.5 km of the shore. Almost without exception, international airports, roads and capital cities in the small islands of the Indian and Pacific Oceans and the Caribbean are sited along the coast, or on tiny coral islands. Sea-level rise will exacerbate inundation, erosion and other coastal hazards, threaten vital infrastructure, settlements and facilities, and thus compromise the socio-economic well-being of island communities and states. [16.4.2, 16.4.5, 16.4.7]

There is strong evidence that under most climate change scenarios, water resources in small islands are likely to be seriously compromised (very high confidence).
Most small islands have a limited water supply, and water resources in these islands are especially vulnerable to future changes and distribution of rainfall. Many islands in the Caribbean are likely to experience increased water stress as a result of climate change. Under all Special Report on Emissions Scenarios (SRES) scenarios, reduced rainfall in summer is projected for this region, so that it is unlikely that demand would be met during low rainfall periods. Increased rainfall in winter is unlikely to compensate, due to lack of storage and high runoff during storms. In the Pacific, a 10% reduction in average rainfall (by 2050) would lead to a 20% reduction in the size of the freshwater lens on Tarawa Atoll, Kiribati. Reduced rainfall coupled with sea-level rise would compound this threat. Many small islands have begun to invest in the implementation of adaptation strategies, including desalination, to offset current and projected water shortages. [16.4.1]

Climate change is likely to heavily impact coral reefs, fisheries and other marine-based resources (high confidence).
Fisheries make an important contribution to the GDP of many island states. Changes in the occurrence and intensity of El Niño-Southern Oscillation (ENSO) events are likely to have severe impacts on commercial and artisanal fisheries. Increasing sea surface temperature and rising sea level, increased turbidity, nutrient loading and chemical pollution, damage from tropical cyclones, and decreases in growth rates due to the effects of higher carbon dioxide concentrations on ocean chemistry, are very likely to affect the health of coral reefs and other marine ecosystems which sustain island fisheries. Such impacts will exacerbate non-climate-change stresses on coastal systems. [16.4.3]

On some islands, especially those at higher latitudes, warming has already led to the replacement of some local species (high confidence).
Mid- and high-latitude islands are virtually certain to be colonised by non-indigenous invasive species, previously limited by unfavourable temperature conditions. Increases in extreme events are virtually certain to affect the adaptation responses of forests on tropical islands, where regeneration is often slow, in the short term. In view of their small area, forests on many islands can easily be decimated by violent cyclones or storms. However, it is possible that forest cover will increase on some high-latitude islands. [16.4.4, 5.4.2.4]

It is very likely that subsistence and commercial agriculture on small islands will be adversely affected by climate change (high confidence).
Sea-level rise, inundation, seawater intrusion into freshwater lenses, soil salinisation, and decline in water supply are very likely to adversely impact coastal agriculture. Away from the coast, changes in extremes (e.g., flooding and drought) are likely to have a negative effect on agricultural production. Appropriate adaptation measures may help to reduce these impacts. In some high-latitude islands, new opportunities may arise for increased agricultural production. [16.4.3, 15.4.2.4]

New studies confirm previous findings that the effects of climate change on tourism are likely to be direct and indirect, and largely negative (high confidence).
Tourism is the major contributor to GDP and employment in many small islands. Sea-level rise and increased sea water temperature will cause accelerated beach erosion, degradation of coral reefs, and bleaching. In addition, a loss of cultural heritage from inundation and flooding reduces the amenity value for coastal users. Whereas a warmer climate could reduce the number of people visiting small islands in low latitudes, it could have the reverse effect in mid- and high-latitude islands. However, water shortages and increased incidence of vector-borne diseases may also deter tourists. [16.4.6]

There is growing concern that global climate change is likely to impact human health, mostly in adverse ways (medium confidence).
Many small islands are located in tropical or sub-tropical zones whose weather and climate are already conducive to the transmission of diseases such as malaria, dengue, filariasis, schistosomiasis, and food- and water-borne diseases. Other climate-sensitive diseases of concern to small islands include diarrhoeal diseases, heat stress, skin diseases, acute respiratory infections and asthma. The observed increasing incidence of many of these diseases in small islands is attributable to a

combination of factors, including poor public health practices, inadequate infrastructure, poor waste management practices, increasing global travel, and changing climatic conditions. [16.4.5]

16.1 Introduction

While acknowledging their diversity, the IPCC Third Assessment Report (TAR) also noted that small island states share many similarities (e.g., physical size, proneness to natural disasters and climate extremes, extreme openness of their economies, low adaptive capacity) that enhance their vulnerability and reduce their resilience to climate variability and change.

Analysis of observational data showed a global mean temperature increase of around 0.6°C during the 20th century, while mean sea level rose by about 2 mm/yr, although sea-level trends are complicated by local tectonics and El Niño-Southern Oscillation (ENSO) events. The rate of increase in air temperature in the Pacific and Caribbean during the 20th century exceeded the global average. The TAR also found much of the rainfall variability appeared to be closely related to ENSO events, combined with seasonal and decadal changes in the convergence zones.

Owing to their high vulnerability and low adaptive capacity, small islands have legitimate concerns about their future, based on observational records, experience with current patterns and consequences of climate variability, and climate model projections. Although emitting less than 1% of global greenhouse gases, many small islands have already perceived a need to reallocate scarce resources away from economic development and poverty alleviation, and towards the implementation of strategies to adapt to the growing threats posed by global warming (e.g., Nurse and Moore, 2005).

While some spatial variation within and among regions is expected, the TAR reported that sea level is projected to rise at an average rate of about 5.0 mm/yr over the 21st century, and concluded that sea-level change of this magnitude would pose great challenges and high risk, especially to low-lying islands that might not be able to adapt (Nurse et al., 2001). Given the sea level and temperature projections for the next 50 to 100 years, coupled with other anthropogenic stresses, the coastal assets of small islands (e.g., corals, mangroves, sea grasses and reef fish), would be at great risk. As the natural resilience of coastal areas may be reduced, the 'costs' of adaptation could be expected to increase. Moreover, anticipated land loss, soil salinisation and low water availability would be likely to threaten the sustainability of island agriculture and food security.

In addition to natural and managed system impacts, the TAR also drew attention to projected human costs. These included an increase in the incidence of vector- and water-borne diseases in many tropical and sub-tropical islands, which was attributed partly to temperature and rainfall changes, some linked to ENSO. The TAR also noted that most settlements and infrastructure of small islands are located in coastal areas, which are highly vulnerable not only to sea-level rise (SLR) but also to high-energy waves and storm surge. In addition, temperature and rainfall changes and loss of coastal amenities could adversely affect the vital tourism industry. Traditional knowledge and other cultural assets (e.g., sites of worship and ritual), especially those near the coasts, were also considered to be vulnerable to climate change and sea-level rise. Integrated coastal management was proposed as an effective management framework in small islands for ensuring the sustainability of coastal resources. Such a framework has been adopted in several island states. More recently, the Organisation of Eastern Caribbean States (OECS, 2000) has adopted a framework called 'island systems management', which is both an integrated and holistic (rather than sectoral) approach to whole-island management including terrestrial, aquatic and atmospheric environments.

The TAR concluded that small islands could focus their efforts on enhancing their resilience and implement appropriate adaptation measures as urgent priorities. Thus, integration of risk reduction strategies into key sectoral activities (e.g., disaster management, integrated coastal management and health care planning) should be pursued as part of the adaptation planning process for climate change.

Building upon the TAR, this chapter assesses recent scientific information on vulnerability to climate change and sea-level rise, adaptation to their effects, and implications of climate-related policies, including adaptation, for the sustainable development of small islands. Assessment results are presented in a quantitative manner wherever possible, with near, middle, and far time-frames in this century, although much of the literature concerning small islands is not precise about the time-scales involved in impact, vulnerability and adaptation studies. Indeed, independent scientific studies on climate change and small islands since the TAR have been quite limited, though there are a number of synthetic publications, regional resource books, guidelines, and policy documents including: *Surviving in Small Islands: A Guide Book* (Tompkins et al., 2005); *Climate Variability and Change and Sea-level rise in the Pacific Islands Region: A Resource Book for Policy and Decision Makers, Educators and Other Stakeholders* (Hay et al., 2003); *Climate Change: Small Island Developing States* (UNFCCC, 2005); and *Not If, But When: Adapting to Natural Hazards in the Pacific Island Region: A Policy Note* (Bettencourt et al., 2006).

These publications rely heavily on the TAR, and on studies undertaken by global and regional agencies and contracted reports. It is our qualitative view that the volume of literature in refereed international journals relating to small islands and climate change since publication of the TAR is rather less than that between the Second Assessment Report in 1995 and the TAR in 2001. There is also another difference in that the present chapter deals not only with independent small island states but also with non-autonomous small islands in the continental and large archipelagic countries, including those in high latitudes. Nevertheless the focus is still mainly on the autonomous small islands predominantly located in the tropical and sub-tropical regions; a focus that reflects the emphasis in the literature.

16.2 Current sensitivity and vulnerability

16.2.1 Special characteristics of small islands

Many small islands are highly vulnerable to the impacts of climate change and sea-level rise. They comprise small land masses surrounded by ocean, and are frequently located in regions prone to natural disasters, often of a hydrometeorological and/or geological nature. In tropical areas they host relatively large populations for the area they occupy, with high growth rates and densities. Many small islands have poorly developed infrastructure and limited natural, human and economic resources, and often small island populations are dependent on marine resources to meet their protein needs. Most of their economies are reliant on a limited resource base and are subject to external forces, such as changing terms of trade, economic liberalisation, and migration flows. Adaptive capacity to climate change is generally low, though traditionally there has been some resilience in the face of environmental change.

16.2.2 Climate and weather

16.2.2.1 General features

The climate regimes of small islands are quite variable, generally characterised by large seasonal variability in precipitation and by small seasonal temperature differences in low-latitude islands and large seasonal temperature differences in high-latitude islands. In the tropics, cyclones and other extreme climate and weather events cause considerable losses to life and property.

The climates of small islands in the central Pacific are influenced by several contributing factors such as trade wind regimes, the paired Hadley cells and Walker circulation, seasonally varying convergence zones such as the South Pacific Convergence Zone (SPCZ), semi-permanent sub-tropical high-pressure belts, and zonal westerlies to the south, with ENSO as the dominant mode of year-to-year variability (Fitzharris, 2001; Folland et al., 2002; Griffiths et al., 2003). The Madden-Julian Oscillation (MJO) is a major mode of variability of the tropical atmosphere-ocean system of the Pacific on time-scales of 30 to 70 days (Revell, 2004), while the leading mode of variability with decadal time-scale is the Interdecadal Pacific Oscillation (IPO) (Salinger et al., 2001). A number of studies suggest that the influence of global warming could be a major factor in accentuating the current climate regimes and the changes from the normal that come with ENSO events (Folland et al., 2003; Hay et al., 2003).

The climate of the Caribbean islands is broadly characterised by distinct dry and wet seasons with orography and elevation being significant modifiers on the sub-regional scale. The dominant influences are the North Atlantic Sub-tropical High (NAH) and ENSO. During the Northern Hemisphere winter, the NAH lies further south, with strong easterly trades on its equatorial flank modulating the climate and weather of the region. Coupled with a strong inversion, a cool ocean, and reduced atmospheric humidity, the region is generally at its driest during the Northern Hemisphere winter. With the onset of the Northern Hemisphere spring, the NAH moves northwards, the trade wind intensity decreases, and the region then comes under the influence of the equatorial trough.

In the Indian Ocean, the climate regimes of small islands in tropical regions are predominantly influenced by the Asian monsoon; the seasonal alternation of atmospheric flow patterns which results in two distinct climatic regimes: the south-west or summer monsoon and the north-east or winter monsoon, with a clear association with ENSO events.

The climates of small islands in the Mediterranean are dominated by influences from bordering lands. Commonly the islands receive most of their rainfall during the Northern Hemisphere winter months and experience a prolonged summer drought of 4 to 5 months. Temperatures are generally moderate with a comparatively small range of temperature between the winter low and summer high.

16.2.2.2 Observed trends

Temperature

New observations and reanalyses of temperatures averaged over land and ocean surfaces since the TAR show consistent warming trends in all small-island regions over the 1901 to 2004 period (Trenberth et al., 2007). However, the trends are not linear. Recent studies show that annual and seasonal ocean surface and island air temperatures have increased by 0.6 to 1.0°C since 1910 throughout a large part of the South Pacific, south-west of the SPCZ. Decadal increases of 0.3 to 0.5°C in annual temperatures have been widely seen only since the 1970s, preceded by some cooling after the 1940s, which is the beginning of the record, to the north-east of the SPCZ (Salinger, 2001; Folland et al., 2003).

For the Caribbean, Indian Ocean and Mediterranean regions, analyses shows warming ranged from 0 to 0.5°C per decade for the 1971 to 2004 period (Trenberth et al., 2007). Some high-latitude regions, including the western Canadian Arctic Archipelago, have experienced warming more rapid than the global mean (McBean et al., 2005).

Trends in extreme temperature across the South Pacific for the period 1961 to 2003 show increases in the annual number of hot days and warm nights, with decreases in the annual number of cool days and cold nights, particularly in the years after the onset of El Niño (Manton et al., 2001; Griffiths et al., 2003). In the Caribbean, the percentage of days having very warm maximum or minimum temperatures has increased considerably since the 1950s, while the percentage of days with cold temperatures has decreased (Peterson et al., 2002).

Precipitation

Analyses of trends in extreme daily rainfall across the South Pacific for the period 1961 to 2003 show extreme rainfall trends which are generally less spatially coherent than those of extreme temperatures (Manton et al., 2001; Griffiths et al., 2003). In the Caribbean, the maximum number of consecutive dry days is decreasing and the number of heavy rainfall events is increasing. These changes were found to be similar to the changes reported from global analysis (Trenberth et al., 2007).

Tropical and extra-tropical cyclones

Variations in tropical and extra-tropical cyclones, hurricanes and typhoons in many small-island regions are dominated by ENSO and decadal variability which result in a redistribution of tropical storms and their tracks, so that increases in one basin are often compensated by decreases in other basins. For example, during an El Niño event, the incidence of tropical storms typically decreases in the Atlantic and far-western Pacific and the Australian regions, but increases in the central and eastern Pacific, and *vice versa*. Clear evidence exists that the number of storms reaching categories 4 and 5 globally have increased since 1970, along with increases in the Power Dissipation Index (Emanuel, 2005) due to increases in their intensity and duration (Trenberth et al., 2007). The total number of cyclones and cyclone days decreased slightly in most basins. The largest increase was in the North Pacific, Indian and South-West Pacific oceans. The global view of tropical storm activity highlights the important role of ENSO in all basins. The most active year was 1997, when a very strong El Niño began, suggesting that the observed record sea surface temperatures (SSTs) played a key role (Trenberth et al., 2007). For extra-tropical cyclones, positive trends in storm frequency and intensity dominate during recent decades in most regional studies performed. Longer records for the North Atlantic suggest that the recent extreme period may be similar in level to that of the late 19th century (Trenberth et al., 2007).

In the tropical South Pacific, small islands to the east of the dateline are highly likely to receive a higher number of tropical storms during an El Niño event compared with a La Niña event and *vice versa* (Brazdil et al., 2002). Observed tropical cyclone activity in the South Pacific east of 160°E indicates an increase in level of activity, with the most active years associated with El Niño events, especially during the strong 1982/1983 and 1997/1998 events (Levinson, 2005). Webster et al. (2005) found more than a doubling in the number of category 4 and 5 storms in the South-West Pacific from the period 1975–1989 to the period 1990–2004. In the 2005/2006 season, La Niña influences shifted tropical storm activity away from the South Pacific region to the Australian region and, in March and April 2006, four category 5 typhoons occurred (Trenberth et al., 2007).

In the Caribbean, hurricane activity was greater from the 1930s to the 1960s, in comparison with the 1970s and 1980s and the first half of the 1990s. Beginning with 1995, all but two Atlantic hurricane seasons have been above normal (relative to the 1981-2000 baseline). The exceptions are the two El Niño years of 1997 and 2002. El Niño acts to reduce activity and La Niña acts to increase activity in the North Atlantic. The increase contrasts sharply with the generally below-normal seasons observed during the previous 25-year period, 1975 to 1994. These multi-decadal fluctuations in hurricane activity result almost entirely from differences in the number of hurricanes and major hurricanes forming from tropical storms first named in the tropical Atlantic and Caribbean Sea.

In the Indian Ocean, tropical storm activity (May to December) in the northern Indian Ocean has been near normal in recent years. For the southern Indian Ocean, the tropical cyclone season is normally active from December to April. A lack of historical record-keeping severely hinders trend analysis (Trenberth et al., 2007).

Sea level

Analyses of the longest available sea-level records, which have at least 25 years of hourly data from 27 stations installed around the Pacific basin, show the overall average mean relative sea-level rise around the whole region is +0.77 mm/yr (Mitchell et al., 2001). Rates of relative sea level have also been calculated for the SEAFRAME stations in the Pacific. Using these results and focusing only on the island stations with more than 50 years of data (only four locations), the average rate of sea-level rise (relative to the Earth's crust) is 1.6 mm/yr (Bindoff et al., 2007). Church et al. (2004) used TOPEX/Poseidon altimeter data, combined with historical tide gauge data, to estimate monthly distributions of large-scale sea-level variability and change over the period 1950 to 2000. Church et al. (2004) observed the maximum rate of rise in the central and eastern Pacific, spreading north and south around the sub-tropical gyres of the Pacific Ocean near 90°E, mostly between 2 and 2.5 mm/yr but peaking at over 3 mm/yr. This maximum was split by a minimum rate of rise, less than 1.5 mm/yr, along the equator in the eastern Pacific, linking to the western Pacific just west of 180° (Christensen et al., 2007).

The Caribbean region experienced, on average, a mean relative sea-level rise of 1 mm/yr during the 20th century. Considerable regional variations in sea level were observed in the records; these were due to large-scale oceanographic phenomena such as El Niño coupled with volcanic and tectonic crustal motions of the Caribbean Basin rim, which affect the land levels on which the tide gauges are located. Similarly, recent variations in sea level on the west Trinidad coast indicate that sea level in the north is rising at a rate of about 1 mm/yr, while in the south the rate is about 4 mm/yr; the difference being a response to tectonic movements (Miller, 2005).

In the Indian Ocean, reconstructed sea levels based on tide gauge data and TOPEX/Poseidon altimeter records for the 1950 to 2001 period give rates of relative sea-level rise of 1.5, 1.3 and 1.5 mm/yr (with error estimates of about 0.5 mm/yr) at Port Louis, Rodrigues, and Cocos Islands, respectively (Church et al., 2006). In the equatorial band, both the Male and Gan sea-level sites in the Maldives show trends of about 4 mm/yr (Khan et al., 2002), with the range from three tidal stations over the 1990s being from 3.2 to 6.5 mm/yr (Woodworth et al., 2002). Church et al. (2006) note that the Maldives has short records and that there is high variability between sites, and their 52-year reconstruction suggests a common rate of rise of 1.0 to 1.2 mm/yr.

Some high-latitude islands are in regions of continuing postglacial isostatic uplift, including parts of the Baltic, Hudson Bay, and the Canadian Arctic Archipelago (CAA). Others along the Siberian coast and the eastern and western margins of the CAA are subsiding. Although few long tide-gauge records exist in the region, relative sea-level trends are known to range from negative (falling relative sea level) in the central CAA and Hudson Bay to rates as high as 3 mm/yr or more in the Beaufort Sea (Manson et al., 2005). Available data from the Siberian sector of the Arctic Ocean indicate that late 20th century sea-level rise was comparable to the global mean (Proshutinsky et al., 2004).

16.2.3 Other stresses

Climate change and sea-level rise are not unique contributors to the extreme vulnerability of small islands. Other factors include socio-economic conditions, natural resource and space limitations, and the impacts of natural hazards such as tsunami and storms. In the Pacific, vulnerability is also a function of internal and external political and economic processes which affect forms of social and economic organisation that are different from those practiced traditionally, as well as attempts to impose models of adaptation that have been developed for Western economies, without sufficient thought as to their applicability in traditional island settings (Cocklin, 1999).

Socio-economic stresses

Socio-economic contributors to island vulnerability include external pressures such as terms of trade, impacts of globalisation (both positive and negative), financial crises, international conflicts, rising external debt, and internal local conditions such as rapid population growth, rising incidence of poverty, political instability, unemployment, reduced social cohesion, and a widening gap between poor and rich, together with the interactions between them (ADB, 2004).

Most settlements in small islands, with the exception of some of the larger Melanesian and Caribbean islands, are located in coastal locations, with the prime city or town also hosting the main port, international airport and centre of government activities. Heavy dependence on coastal resources for subsistence is also a major feature of many small islands.

Rapid and unplanned movements of rural and outer-island residents to the major centres is occurring throughout small islands, resulting in deteriorating urban conditions, with pressure on access to urban services required to meet basic needs. High concentrations of people in urban areas create various social, economic and political stresses, and make people more vulnerable to short-term physical and biological hazards such as tropical cyclones and diseases. It also increases their vulnerability to the impacts of climate change and sea-level rise (Connell, 1999, 2003).

Globalisation is also a major stress, though it has been argued that it is nothing new for many small islands, since most have had a long history of colonialism and, more latterly, experience of some of the rounds of transformation of global capitalism (Pelling and Uitto, 2001). Nevertheless, in the last few years, the rate of change and growth of internationalisation have increased, and small islands have had to contend with new forms of extra-territorial economic, political and social forces such as multinational corporations, transnational social movements, international regulatory agencies, and global communication networks. In the present context, these factors take on a new relevance, as they may influence the vulnerability of small islands and their adaptive capacity (Pelling and Uitto, 2001; Adger et al., 2003a).

Pressure on island resources

Most small islands have limited sources of freshwater. Atoll countries and limestone islands have no surface water or streams and are fully reliant on rainfall and groundwater harvesting. Many small islands are experiencing water stress at the current levels of rainfall input, and extraction of groundwater is often outstripping supply. Moreover, pollution of groundwater is often a major problem, especially on low-lying islands. Poor water quality affects human health and carries water-borne diseases. Water quality is just one of several health issues linked to climate variability and change and their potential effects on the well-being of the inhabitants of small islands (Ebi et al., 2006).

It is also almost inevitable that the ecological systems of small islands, and the functions they perform, will be sensitive to the rate and magnitude of climate change and sea-level rise, especially where exacerbated by human activities (e.g., ADB, 2004, in the case of the small islands in the Pacific). Both terrestrial ecosystems on the larger islands and coastal ecosystems on most islands have been subjected to increasing degradation and destruction in recent decades. For instance, analysis of coral reef surveys over three decades has revealed that coral cover across reefs in the Caribbean has declined by 80% in just 30 years, largely as a result of continued pollution, sedimentation, marine diseases, and over-fishing (Gardner et al., 2003).

Interactions between human and physical stresses

External pressures that contribute to the vulnerability of small islands to climate change include energy costs, population movements, financial and currency crises, international conflicts, and increasing debt. Internal processes that create vulnerability include rapid population growth, attempts to increase economic growth through exploitation of natural resources such as forests, fisheries and beaches, weak infrastructure, increasing income inequality, unemployment, rapid urbanisation, political instability, a growing gap between demand for and provision of health care and education services, weakening social capital, and economic stagnation. These external and internal processes are related and interact in complex ways to heighten the vulnerability of island social and ecological systems to climate change.

Natural hazards of hydrometeorological origin remain an important stressor and cause impacts on the economies of small islands that are disproportionally large (Bettencourt et al., 2006). The devastation of Grenada following the passage of Hurricane Ivan on 7 September 2004 is a powerful illustration of the reality of small-island vulnerability (Nurse and Moore, 2005). In less than 8 hours, the country's vital socio-economic infrastructure, including housing, utilities, tourism-related facilities and subsistence and commercial agricultural production, suffered incalculable damage. The island's two principal foreign-exchange earners – tourism and nutmeg production – suffered heavily. More than 90% of hotel guest rooms were either completely destroyed or damaged, while more than 80% of the island's nutmeg trees were lost. One of the major challenges with regard to hydrometeorological hazards is the time it takes to recover from them. In the past it was common for socio-ecological systems to recover from hazards, as these were sufficiently infrequent and/or less damaging. In the future, climate change may create a situation where more intense and/or more frequent extreme events may mean there is less time in which to recover. Sequential extreme events may mean that recovery is never complete, resulting in long-term deteriorations in affected systems, e.g., declines in agricultural output because soils never recover from salinisation; urban water systems and housing infrastructure deteriorating because damage cannot be repaired before the next extreme event.

16.2.4 Current adaptation

Past studies of adaptation options for small islands have largely focused on adjustments to sea-level rise and storm surges associated with tropical cyclones. There was an early emphasis on protecting land through ‘hard’ shore-protection measures rather than on other measures such as accommodating sea-level rise or retreating from it, although the latter has become increasingly important on continental coasts. Vulnerability studies conducted for selected small islands (Nurse et al., 2001) show that the costs of overall infrastructure and settlement protection are a significant proportion of GDP, and well beyond the financial means of most small island states; a problem not always shared by the islands of metropolitan countries (i.e., with high-density, predominantly urban populations). More recent studies since the TAR have identified major areas of adaptation, including water resources and watershed management, reef conservation, agricultural and forest management, conservation of biodiversity, energy security, increased development of renewable energy, and optimised energy consumption. Some of these are detailed in Section 16.5. Proposed adaptation strategies have also focused on reducing vulnerability and increasing resilience of systems and sectors to climate variability and extremes through mainstreaming adaptation (Shea et al., 2001; Hay et al., 2003; ADB, 2004; UNDP, 2005).

16.3 Assumptions about future trends

16.3.1 Climate and sea-level change

16.3.1.1 Temperature and precipitation

Since the TAR, future climate change projections have been updated (Ruosteenoja et al., 2003). These analyses reaffirm previous IPCC projections that suggest a gradual warming of SSTs and a general warming trend in surface air temperature in all small-island regions and seasons (Lal et al., 2002). However, it must be cautioned that, because of scaling problems, these projections for the most part apply to open ocean surfaces and not to land surfaces. Consequently the temperature changes may well be higher than current projections.

Projected changes in seasonal surface air temperature (Table 16.1) and precipitation (Table 16.2) for the three 30-year periods (2010 to 2039, 2040 to 2069 and 2070 to 2099) relative to the baseline period 1961 to 1990, have been prepared by Ruosteenoja et al. (2003) for all the sub-continental scale regions of the world, including small islands. They used seven coupled atmosphere-ocean general circulation models (AOGCMs), the greenhouse gas and aerosol forcing being inferred from the IPCC Special Report on Emissions Scenarios (SRES; Nakićenović and Swart, 2000) A1FI, A2, B1 and B2 emissions scenarios.

All seven models project increased surface air temperature for all regions of the small islands. The Ruosteenoja et al. (2003) projected increases all lie within previous IPCC surface air temperature projections, except for the Mediterranean Sea. The increases in surface air temperature are projected to be more or less uniform in both seasons, but for the Mediterranean Sea, warming is projected to be greater during the summer than the winter. For the South Pacific, Lal (2004) has indicated that the surface air temperature by 2100 is estimated to be at least 2.5°C more than the 1990 level. Seasonal variations of projected warming are minimal. No significant change in diurnal temperature range is likely with a rise in surface temperatures. An increase in mean temperature would be accompanied by an increase in the frequency of extreme temperatures. High-latitude regions are likely to experience greater warming, resulting in decreased sea ice extent and increased thawing of permafrost (Meehl et al., 2007).

Regarding precipitation, the range of projections is still large, and even the direction of change is not clear. The models simulate only a marginal increase or decrease (10%) in annual rainfall over most of the small islands in the South Pacific. During summer, more rainfall is projected, while an increase in daily rainfall intensity, causing more frequent heavier rainfall events, is also likely (Lal, 2004).

Table 16.1. *Projected increase in air temperature (°C) by region, relative to the 1961–1990 period.*

Region	2010–2039	2040–2069	2070–2099
Mediterranean	0.60 to 2.19	0.81 to 3.85	1.20 to 7.07
Caribbean	0.48 to 1.06	0.79 to 2.45	0.94 to 4.18
Indian Ocean	0.51 to 0.98	0.84 to 2.10	1.05 to 3.77
Northern Pacific	0.49 to 1.13	0.81 to 2.48	1.00 to 4.17
Southern Pacific	0.45 to 0.82	0.80 to 1.79	0.99 to 3.11

Table 16.2. *Projected change in precipitation (%) by region, relative to the 1961–1990 period.*

Region	2010–2039	2040–2069	2070–2099
Mediterranean	–35.6 to +55.1	–52.6 to +38.3	–61.0 to +6.2
Caribbean	–14.2 to +13.7	–36.3 to +34.2	–49.3 to +28.9
Indian Ocean	–5.4 to +6.0	–6.9 to +12.4	–9.8 to +14.7
Northern Pacific	–6.3 to +9.1	–19.2 to +21.3	–2.7 to +25.8
Southern Pacific	–3. 9 to +3.4	–8.23 to +6.7	–14.0 to +14.6

16.3.1.2 Sea levels

Sea-level changes are of special significance, not only for the low-lying atoll islands but for many high islands where settlements, infrastructure and facilities are concentrated in the coastal zone. Projected globally averaged sea-level rise at the end of the 21st century (2090 to 2099), relative to 1980 to 1999 for the six SRES scenarios, ranges from 0.19 to 0.58 m (Meehl et al., 2007). In all SRES scenarios, the average rate of sea-level rise during the 21st century very probably exceeds the 1961 to 2003 average rate (1.8 ± 0.5 mm/yr). Climate models also indicate a geographical variation of sea-level rise due to non-uniform distribution of temperature and salinity and changes in ocean circulation. Furthermore, regional variations and local differences depend on several factors, including non-climate-related factors such as island tectonic setting and postglacial isostatic adjustment. While Mörner et al. (2004) suggest that the increased risk of flooding during the 21st century for the Maldives has been overstated, Woodworth (2005) concludes that a rise in sea level of approximately 50 cm during the 21st century remains the most reliable scenario to employ in future studies of the Maldives.

16.3.1.3 Extreme events

Global warming from anthropogenic forcing suggests increased convective activity but there is a possible trade-off between localised versus organised convection (IPCC, 2001). While increases in SSTs favour more and stronger tropical cyclones, increased isolated convection stabilises the tropical troposphere and this, in turn, suppresses organised convection, making conditions less favourable for vigorous tropical cyclones to develop. Thus, the IPCC (2001) noted that changes in atmospheric stability and circulation may produce offsetting tendencies.

Recent analyses (e.g., Brazdil et al., 2002; Mason, 2004) since the TAR confirm these findings. Climate modelling with improved resolutions has demonstrated the capability to diagnose the probability of occurrence of short-term extreme events under global warming (Meehl et al., 2007). Vassie et al. (2004) suggest that scientists engaged in climate change impact studies should also consider possible changes in swell direction and incidence and their potential impacts on the coasts of small islands. With an increasing number of people living close to the coast, deep ocean swell generation, and its potential modifications as a consequence of climate change, is clearly an issue that needs attention, alongside the more intensively studied topics of changes in mean sea level and storm surges.

Although there is as yet no convincing evidence in the observed record of changes in tropical cyclone behaviour, a synthesis of the recent model results indicates that, for the future warmer climate, tropical cyclones will show increased peak wind speed and increased mean and peak precipitation intensities. The number of intense cyclones is likely to increase, although the total number may decrease on a global scale (Meehl et al., 2007). It is likely that maximum tropical cyclone wind intensities could increase, by 5 to 10% by around 2050 (Walsh, 2004). Under this scenario, peak precipitation rates are likely to increase by 25% as a result of increases in maximum tropical cyclone wind intensities, which in turn cause higher storm surges. Although it is exceptionally unlikely that there will be significant changes in regions of formation, the rate of formation is very likely to change in some regions. Changes in tropical cyclone tracks are closely associated with ENSO and other local climate conditions. These suggest a strong possibility of higher risks of more persistent and devastating tropical cyclones in a warmer world.

Mid-latitude islands, such as islands in the Gulf of St. Lawrence and off the coast of Newfoundland (St. Pierre et Miquelon), are exposed to impacts from tropical, post-tropical, and extra-tropical storms that can produce storm-surge flooding, large waves, coastal erosion, and (in some winter storms) direct sea ice damage to infrastructure and property. Possible increases in storm intensity, rising sea levels, and changes in ice duration and concentration, are projected to increase the severity of negative impacts progressively, particularly by mid-century (Forbes et al., 2004). In the Queen Charlotte Islands (Haida Gwaii) off the Canadian Pacific coast, winter storm damage is exacerbated by large sea-level anomalies resulting from ENSO variability (Walker and Barrie, 2006).

16.3.2 Other relevant conditions

Populations on many small islands have long developed and maintained unique lifestyles, adapted to their natural environment. Traditional knowledge, practices and cultures, where they are still practised, are strongly based on community support networks and, in many islands, a subsistence economy is still predominant (Berkes and Jolly, 2001; Fox, 2003; Sutherland et al., 2005). Societal changes such as population growth, increased cash economy, migration of people to urban centres and coastal areas, growth of major cities, increasing dependency on imported goods which create waste management problems, and development of modern industries such as tourism have changed traditional lifestyles in many small islands. Trade liberalisation also has major implications for the economic and social well-being of the people of small islands. For example, the phasing out of the Lomé Convention and the implementation of the Cotonou Agreement will be important. The end of the Lomé Convention means that the prices the EU pays for certain agricultural commodities, such as sugar, will decline. Such countries as Fiji, Jamaica and Mauritius may experience significant contractions in GDP as a result of declining sugar prices (Milner et al., 2004). In Fiji, for example, where 25% of the workforce is in the sugar sector, the replacement of the Lomé Convention with the terms of the Cotonou Agreement is likely to result in significant unemployment and deeper impoverishment of many of the 23,000 smallholder farmers, many of whom already live below the poverty line (Prasad, 2003). Such declines in the agricultural sector, resulting from trade liberalisation, heighten social vulnerability to climate change. These changes, together with the gradual disintegration of traditional communities, will continue to weaken traditional human support networks, with additional feedback effects of social breakdown and loss of traditional values, social cohesion, dignity and confidence, which have been a major component of the resilience of local communities in Pacific islands.

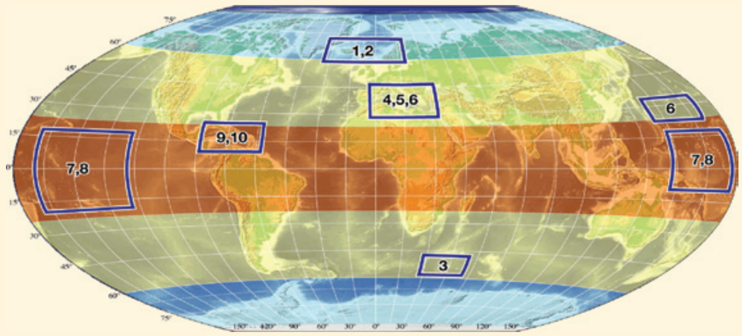
16.4 Key future impacts and vulnerabilities

The special characteristics of small islands, as described in Section 16.2.1, make them prone to a large range of potential impacts from climate change, some of which are already being experienced. Examples of that range, thematically and geographically, are shown in Box 16.1. Further details on sectors that are especially vulnerable in small islands are expanded upon below.

16.4.1 Water resources

Owing to factors of limited size, availability, and geology and topography, water resources in small islands are extremely vulnerable to changes and variations in climate, especially in rainfall (IPCC, 2001). In most regions of small islands, projected future changes in seasonal and annual precipitation are uncertain, although in a few instances precipitation is likely to

Box 16.1. Range of future impacts and vulnerabilities in small islands



* Numbers in bold relate to the regions defined on the map

Region* and system at risk	Scenario and reference	Changed parameters	Impacts and vulnerability
1. Iceland and isolated Arctic islands of Svalbard and the Faroe Islands: Marine ecosystem and plant species	SRES A1 and B2 ACIA (2005)	Projected rise in temperature	• The imbalance of species loss and replacement leads to an initial loss in diversity. Northward expansion of dwarf-shrub and tree-dominated vegetation into areas rich in rare endemic species results in their loss. • Large reduction in, or even a complete collapse of, the Icelandic capelin stock leads to considerable negative impacts on most commercial fish stocks, whales, and seabirds.
2. High-latitude islands (Faroe Islands): Plant species	Scenario I / II: temperature increase / decrease by 2°C. Fosaa et al. (2004)	Changes in soil temperature, snow cover and growing degree days	• Scenario 1: Species most affected by warming are restricted to the uppermost parts of mountains. For other species, the effect will mainly be upward migration. • Scenario II: Species affected by cooling are those at lower altitudes.
3. Sub-Antarctic Marion Islands: Ecosystem	Own scenarios Smith (2002)	Projected changes in temperature and precipitation	• Changes will directly affect the indigenous biota. An even greater threat is that a warmer climate will increase the ease with which the islands can be invaded by alien species.
4. Mediterranean Basin five islands: Ecosystems	SRES A1FI and B1 Gritti et al. (2006)	Alien plant invasion under climatic and disturbance scenarios	• Climate change impacts are negligible in many simulated marine ecosystems. • Invasion into island ecosystems become an increasing problem. In the longer term, ecosystems will be dominated by exotic plants irrespective of disturbance rates.
5. Mediterranean: Migratory birds (Pied flycatchers – *Ficedula hypoleuca*)	None (GLM/ STATISTICA model) Sanz et al. (2003)	Temperature increase, changes in water levels and vegetation index	• Some fitness components of pied flycatchers suffer from climate change in two of the southernmost European breeding populations, with adverse effects on reproductive output of pied flycatchers.
6. Pacific and Mediterranean: Siam weed (*Chromolaena odorata*)	None (CLIMEX model) Kriticos et al. (2005)	Increase in moisture, cold, heat and dry stress	• Pacific islands at risk of invasion by Siam weed. • Mediterranean semi-arid and temperate climates predicted to be unsuitable for invasion.
7. Pacific small islands: Coastal erosion, water resources and human settlement	SRES A2 and B2 World Bank (2000)	Changes in temperature and rainfall, and sea-level rise	• Accelerated coastal erosion, saline intrusion into freshwater lenses and increased flooding from the sea cause large effects on human settlements. • Less rainfall coupled with accelerated sea-level rise compound the threat on water resources; a 10% reduction in average rainfall by 2050 is likely to correspond to a 20% reduction in the size of the freshwater lens on Tarawa Atoll, Kiribati.
8. American Samoa; 15 other Pacific islands: Mangroves	Sea-level rise 0.88 m to 2100 Gilman et al. (2006)	Projected rise in sea level	• 50% loss of mangrove area in American Samoa; 12% reduction in mangrove area in 15 other Pacific islands.
9. Caribbean (Bonaire, Netherlands Antilles): Beach erosion and sea turtle nesting habitats	SRES A1, A1FI, B1, A2, B2 Fish et al. (2005)	Projected rise in sea level	• On average, up to 38% (±24% SD) of the total current beach could be lost with a 0.5 m rise in sea level, with lower narrower beaches being the most vulnerable, reducing turtle nesting habitat by one-third.
10. Caribbean (Bonaire, Barbados): Tourism	None Uyarra et al. (2005)	Changes to marine wildlife, health, terrestrial features and sea conditions	• The beach-based tourism industry in Barbados and the marine diving based ecotourism industry in Bonaire are both negatively affected by climate change through beach erosion in Barbados and coral bleaching in Bonaire.

increase slightly during December, January and February (DJF) in the Indian Ocean and southern Pacific and during June, July and August (JJA) in the northern Pacific (Christensen et al., 2007). Even so, the scarcity of fresh water is often a limiting factor for social and economic development in small islands. Burns (2002) has also cautioned that with the rapid growth of tourism and service industries in many small islands, there is a need both for augmentation of the existing water resources and for more efficient planning and management of those resources. Measures to reduce water demand and promote conservation are also especially important on small islands, where infrastructure deterioration resulting in major leakage is common, and water pollution from soil erosion, herbicide and pesticide runoff, livestock waste, and liquid and solid waste disposal results in high costs, crudely estimated at around 3% of GDP in Rarotonga, Cook Islands (Hajkowicz, 2006).

This dependency on rainfall significantly increases the vulnerability of small islands to future changes in distribution of rainfall. For example, model projections suggest that a 10% reduction in average rainfall by 2050 is likely to correspond to a 20% reduction in the size of the freshwater lens on Tarawa Atoll, Kiribati. Moreover, a reduction in the size of the island, resulting from land loss accompanying sea-level rise, is likely to reduce the thickness of the freshwater lens on atolls by as much as 29% (World Bank, 2000). Less rainfall coupled with accelerated sea-level rise would compound this threat. Studies conducted on Bonriki Island in Tarawa, Kiribati, showed that a 50 cm rise in sea level accompanied by a reduction in rainfall of 25% would reduce the freshwater lens by 65% (World Bank, 2000). Increases in sea level may also shift watertables close to or above the surface, resulting in increased evapotranspiration, thus diminishing the resource (Burns, 2000).

Lower rainfall typically leads to a reduction in the amount of water that can be physically harvested, to a reduction in river flow, and to a slower rate of recharge of the freshwater lens, which can result in prolonged drought impacts. Recent modelling of the current and future water resource availability on several small islands in the Caribbean, using a macro-scale hydrological model and the SRES scenarios (Arnell, 2004), found that many of these islands would be exposed to severe water stress under all SRES scenarios, and especially so under A2 and B2. Since most of the islands are dependent upon surface water catchments for water supply, it is highly likely that demand could not be met during periods of low rainfall.

The wet and dry cycles associated with ENSO episodes can have serious impacts on water supply and island economies. For instance the strong La Niña of 1998 to 2000 was responsible for acute water shortages in many islands in the Indian and Pacific Oceans (Shea et al., 2001; Hay et al., 2003), which resulted in partial shut-downs in the tourism and industrial sectors. In Fiji and Mauritius, borehole yields decreased by 40% during the dry periods, and export crops including sugar cane were also severely affected (World Bank, 2000). The situation was exacerbated by the lack of adequate infrastructure such as reservoirs and water distribution networks in most islands.

Increases in demand related to population and economic growth, in particular tourism, continue to place serious stress on existing water resources. Excessive damming, over-pumping and increasing pollution are all threats that will continue to increase in the future. Groundwater resources are especially at risk from pollution in many small islands (UNEP, 2000), and in countries such as the Comoros, the polluted waters are linked to outbreaks of yellow fever and cholera (Hay et al., 2003).

Access to safe potable water varies across countries. There is very good access in countries such as Singapore, Mauritius and most Caribbean islands, whereas in states such as Kiribati and Comoros it has been estimated that only 44% and 50% of the population, respectively, have access to safe water. Given the major investments needed to develop storage and provide treatment and distribution of water, it is evident that climate change would further decrease the ability of many islands to meet their future requirements.

Several small island countries have begun to invest, at great financial cost, in the implementation of various augmentation and adaptation strategies to offset current water shortages. The Bahamas, Antigua and Barbuda, Barbados, Maldives, Seychelles, Singapore, Tuvalu and others have invested in desalination plants. However, in the Pacific, some of the systems are now only being used during the dry season, owing to operational problems and high maintenance costs. Options such as large storage reservoirs and improved water harvesting are now being explored more widely, although such practices have been in existence in countries such as the Maldives since the early 1900s. In other cases, countries are beginning to invest in improving the scientific database that could be used for future adaptation plans. In the Cook Islands, for example, a useful index for estimating drought intensity was recently developed based on analysis of more than 70 years of rainfall data; this will be a valuable tool in the long-term planning of water resources in these islands (Parakoti and Scott, 2002).

16.4.2 Coastal systems and resources

The coastlines of small islands are long relative to island area. They are also diverse and resource-rich, providing a range of goods and services, many of which are threatened by a combination of human pressures and climate change and variability arising especially from sea-level rise, increases in sea surface temperature, and possible increases in extreme weather events. Key impacts will almost certainly include accelerated coastal erosion, saline intrusion into freshwater lenses, and increased flooding from the sea. An extreme example of the ultimate impact of sea-level rise on small islands – island abandonment – has been documented by Gibbons and Nicholls (2006) in Chesapeake Bay.

It has long been recognised that islands on coral atolls are especially vulnerable to this combination of impacts, and the long-term viability of some atoll states has been questioned. Indeed, Barnett and Adger (2003) argue that the risk from climate-induced factors constitutes a dangerous level of climatic change to atoll countries by potentially undermining their sovereignty (see Section 16.5.4).

The future of atoll island geomorphology has been predicted using both geological analogues and simulation modelling approaches. Using a modified shoreline translation model, Kench and Cowell (2001) and Cowell and Kench (2001) found that, with sea-level rise, ocean shores will be eroded and sediment redeposited further lagoonward, assuming that the volume of island sediment remains constant. Simulations also show that changes in sediment supply can cause physical alteration of atoll islands by an equivalent or greater amount than by sea-level rise alone. Geological reconstructions of the relationship between sea level and island evolution in the mid- to late Holocene, however, do not provide consistent interpretations. For instance, chronic island erosion resulting from increased water depth across reefs with global warming and sea-level rise is envisaged for some islands in the Pacific (Dickinson, 1999), while Kench et al. (2005) present data and a model which suggest that uninhabited islands of the Maldives are morphologically resilient rather than fragile systems, and are expected to persist under current scenarios of future climate change and sea-level rise. The impact of the Sumatran tsunami on such islands appears to confirm this resilience (Kench et al., 2006) and implies that islands which have been subject to substantial human modification are inherently more vulnerable than those that have not been modified.

On topographically higher and geologically more complex islands, beach erosion presents a particular hazard to coastal tourism facilities, which provide the main economic thrust for many small island states. *Ad hoc* approaches to addressing this problem have recently given way to the integrated coastal zone management approach as summarised in the TAR (McLean et al., 2001), which involves data collection, analysis of coastal processes, and assessment of impacts. Daniel and Abkowitz (2003, 2005) present the results of such an approach in the Caribbean, which involves the development of tools for integrating spatial and non-spatial coastal data, estimating long-term beach erosion/accretion trends and storm-induced beach erosion at individual beaches, identifying erosion-sensitive beaches, and mapping beach-erosion hazards. Coastal erosion on arctic islands has additional climate sensitivity through the impact of warming on permafrost and extensive ground ice, which can lead to accelerated erosion and volume loss, and the potential for higher wave energy if the diminished sea ice results in longer over-water fetch (see Chapter 6, Section 6.2.5; Chapter 15, Section 15.4.6).

While erosion is intuitively the most common response of island shorelines to sea-level rise, it should be recognised that coasts are not passive systems. Instead, they will respond dynamically in different ways dependent on many factors including: the geological setting; coastal type, whether soft or hard shores; the rate of sediment supply relative to rate of submergence; sediment type, sand or gravel; presence or absence of natural shore protection structures such as beach rock or conglomerate outcrops; presence or absence of biotic protection such as mangroves and other strand vegetation; and the health of coral reefs. That several of these factors are interrelated can be illustrated by a model study by Sheppard et al. (2005), who suggest that mass coral mortality over the past decade at some sites in the Seychelles has resulted in a reduction in the level of the fringing reef surface, a consequent rise in wave energy over the reef, and increased coastal erosion. Further declines in reef health are expected to accelerate this trend.

Global change is also creating a number of other stress factors that are very likely to influence the health of coral reefs around islands, as a result of increasing sea surface temperature and sea level, damage from tropical cyclones, and possible decreases in growth rates due to the effects of higher CO_2 concentrations on ocean chemistry. Impacts on coral reefs from those factors will not be uniform throughout the small-island realm. For instance, the geographical variability in the required thermal adaptation derived from models and emissions scenarios presented by Donner et al. (2005) suggest that coral reefs in some regions, such as Micronesia and western Polynesia, may be particularly vulnerable to climate change. In addition to these primarily climate-driven factors, the impacts of which are detailed in Chapter 6, Section 6.2.1, there are those associated mainly with other human activities, which combine to subject island coral reefs to multiple stresses, as illustrated in Box 16.2.

16.4.3 Agriculture, fisheries and food security

Small islands have traditionally depended upon subsistence and cash crops for survival and economic development. While subsistence agriculture provides local food security, cash crops (such as sugar cane, bananas and forest products) are exported in order to earn foreign exchange. In Mauritius, the sugar cane industry has provided economic growth and has contributed to the diversification of the economy through linkages with tourism and other related industries (Government of Mauritius, 2002). However, exports have depended upon preferential access to major developed-country markets, which are slowly eroding. Many island states have also experienced a decrease in GDP contributions from agriculture, partly due to the drop in competitiveness of cash crops, cheaper imports from larger countries, increased costs of maintaining soil fertility, and competing uses for water resources, especially from tourism (FAO, 2004).

Local food production is vital to small islands, even those with very limited land areas. In the Pacific islands subsistence agriculture has existed for several hundred years. The ecological dependency of small island economies and societies is well recognised (ADB, 2004). A report by the FAO Commission on Genetic Resources found that some countries' dependence on plant genetic resources ranged from 91% in Comoros, 88% in Jamaica, 85% in Seychelles to 65% in Fiji, 59% in the Bahamas and 37% in Vanuatu (Ximena, 1998).

Projected impacts of climate change include extended periods of drought and, on the other hand, loss of soil fertility and degradation as a result of increased precipitation, both of which will negatively impact on agriculture and food security. In a study of the economic and social implications of climate change and variability for selected Pacific islands, the World Bank (2000) found that in the absence of adaptation, a high island such as Viti Levu, Fiji, could experience damages of US$23 million to 52 million/yr by 2050, (equivalent to 2 to 3% of Fiji's GDP in 1998). A group of low islands such as Tarawa, Kiribati, could face average annual damages of more than US$8 million to 16 million/yr (equivalent to 17 to 18% of Kiribati's GDP in 1998) under the SRES A2 and B2 emissions scenarios.

Box 16.2. Non-climate-change threats to coral reefs of small islands

A large number of non-climate-change stresses and disturbances, mainly driven by human activities, can impact coral reefs (Nyström et al., 2000; Hughes et al., 2003). It has been suggested that the 'coral reef crisis' is almost certainly the result of complex and synergistic interactions among global-scale climatic stresses and local-scale, human-imposed stresses (Buddemeier et al., 2004).

In a study by Bryant et al. (1998), four human-threat factors – coastal development, marine pollution, over-exploitation and destructive fishing, and sediment and nutrients from inland – provide a composite indicator of the potential risk to coral reefs associated with human activity for 800 reef sites. Their map (Figure 16.1) identifies low-risk (blue) medium-risk (yellow) and high-risk (red) sites, the first being common in the insular central Indian and Pacific Oceans, the last in maritime South-East Asia and the Caribbean archipelago. Details of reefs at risk in the two highest-risk areas have been documented by Burke et al. (2002) and Burke and Maidens (2004), who indicate that about 50% of the reefs in South-East Asia and 45% in the Caribbean are classed in the high- to very high-risk category. There are, however, significant local and regional differences in the scale and type of threats to coral reefs in both continental and small-island situations.

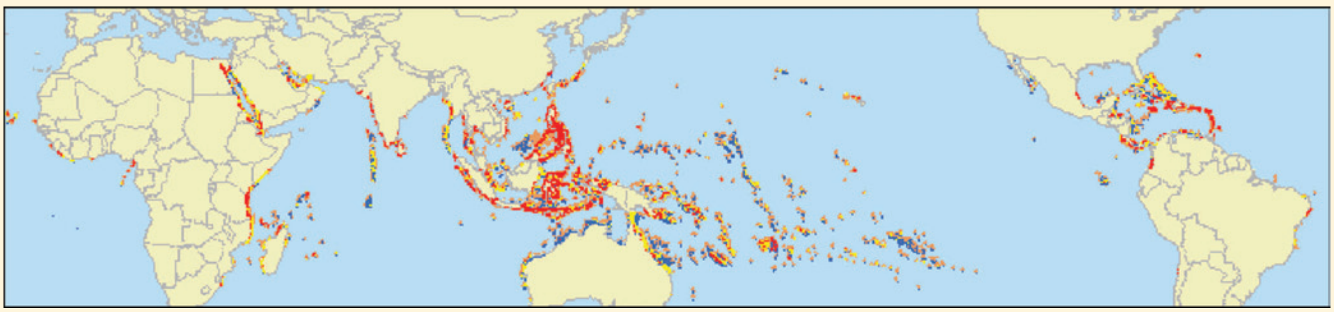


Figure 16.1. *The potential risk to coral reefs from human-threat factors. Low risk (blue), medium risk (yellow) and high risk (red). Source: Bryant et al. (1998).*

Recognising that coral reefs are especially important for many small island states, Wilkinson (2004) notes that reefs on small islands are often subject to a range of non-climate impacts. Some common types of reef disturbance are listed below, with examples from several island regions and specific islands.

1. Impact of coastal developments and modification of shorelines:
   - coastal development on fringing reefs, Langawi Island, Malaysia (Abdullah et al., 2002);
   - coastal resort development and tourism impacts in Mauritius (Ramessur, 2002).
2. Mining and harvesting of corals and reef organisms:
   - coral harvesting in Fiji for the aquarium trade (Vunisea, 2003).
3. Sedimentation and nutrient pollution from the land:
   - sediment smothering reefs in Aria Bay, Palau (Golbuua et al., 2003) and southern islands of Singapore (Dikou and van Woesik, 2006);
   - non-point source pollution, Tutuila Island, American Samoa (Houk et al., 2005);
   - nutrient pollution and eutrophication, fringing reef, Réunion (Chazottes et al., 2002) and Cocos Lagoon, Guam (Kuffner and Paul, 2001).
4. Over-exploitation and damaging fishing practices:
   - blast fishing in the islands of Indonesia (Fox and Caldwell, 2006);
   - intensive fish-farming effluent in Philippines (Villanueva et al., 2006);
   - subsistence exploitation of reef fish in Fiji (Dulvy et al., 2004);
   - giant clam harvesting on reefs, Milne Bay, Papua New Guinea (Kinch, 2002).
5. Introduced and invasive species:
   - Non-indigenous species invasion of coral habitats in Guam (Paulay et al., 2002).

There is another category of 'stress' that may inadvertently result in damage to coral reefs – the human component of poor governance (Goldberg and Wilkinson, 2004). This can accompany political instability, one example being problems with contemporary coastal management in the Solomon Islands (Lane, 2006).

Not all effects of climate change on agriculture are expected to be negative. For example, increased temperatures in high-latitude islands are likely to make conditions more suitable for agriculture and provide opportunities to enhance resilience of local food systems (see also Chapter 15, Section 15.5).

If the intensity of tropical cyclones increases, a concomitant rise in significant damage to food crops and infrastructure is likely. For example, Tropical Cyclone Ofa in 1990 turned Niue (in the Pacific) from a food-exporting country into one dependent on imports for the next two years, and Heta in 2004 had an even greater impact on agricultural production in Niue (Wade, 2005). Hurricane Ivan's impact on Grenada (in the Caribbean) in 2004 caused losses in the agricultural sector equivalent to 10% of GDP. The two main crops, nutmeg and cocoa, both of which have long gestation periods, will not make a contribution to GDP or earn foreign exchange for the next 10 years (OECS, 2004).

Fisheries contribute significantly to GDP on many islands; consequently the socio-economic implications of the impact of climate change on fisheries are likely to be important and would exacerbate other anthropogenic stresses such as over-fishing. For example, in the Maldives, variations in tuna catches are especially significant during El Niño and La Niña years. This was shown during the El Niño years of 1972/1973, 1976, 1982/1983, 1987 and 1992/1994, when the skipjack catches decreased and yellow fin increased, whereas during La Niña years skipjack tuna catches increased, whilst catches of other tuna species decreased (MOHA, 2001). Changes in migration patterns and depth are two main factors affecting the distribution and availability of tuna during those periods, and it is expected that changes in climate would cause migratory shifts in tuna aggregations to other locations (McLean et al., 2001). Apart from the study by Lehodey et al. (2003) of potential changes in tuna fisheries, Aaheim and Sygna (2000) surveyed possible economic impacts in terms of quantities and values, and give examples of macroeconomic impacts. The two main effects of climate change on tuna fishing are likely to be a decline in the total stock and a migration of the stock eastwards, both of which will lead to changes in the catch in different countries.

In contrast to agriculture, the mobility of fish makes it difficult to estimate future changes in marine fish resources. Furthermore, since the life cycles of many species of commercially exploited fisheries range from freshwater to ocean water, land-based and coastal activities will also be likely to affect the populations of those species. Coral reefs and other coastal ecosystems which may be severely affected by climate change will also have an impact on fisheries (Graham et al., 2006).

16.4.4 Biodiversity

Oceanic islands often have a unique biodiversity through high endemism (i.e., with regionally restricted distribution) caused by ecological isolation. Moreover, human well-being on most small islands is heavily reliant on ecosystem services such as amenity value and fisheries (Wong et al., 2005). Historically, isolation – by its very nature – normally implies immunity from threats such as invasive species causing the extinction of endemics. However, it is possible that in mid- and high-latitude islands, higher temperature and the retreat and loss of snow cover could enhance conditions for the spread of invasive species and forest cover (Smith et al., 2003; see also Chapter 15, Section 15.6.3). For example, in species-poor, sub-Antarctic island ecosystems, alien microbes, fungi, plants and animals have been extensively documented as causing substantial loss of local biodiversity and changes to ecosystem function (Frenot et al., 2005). With rapid climate change, even greater numbers of introductions and enhanced colonisation by alien species are likely, with consequent increases in impacts on these island ecosystems. Climate-related ecosystem effects are also already evident in the mid-latitudes, such as on the island of Hokkaido, Japan, where a decrease in alpine flora has been reported (Kudo et al., 2004).

Under the SRES scenarios, small islands are shown to be particularly vulnerable to coastal flooding and decreased extent of coastal vegetated wetlands (Nicholls, 2004). There is also a detectable influence on marine and terrestrial pathogens, such as coral diseases and oyster pathogens, linked to ENSO events (Harvell et al., 2002). These changes are in addition to coral bleaching, which could become an annual or biannual event in the next 30 to 50 years or sooner without an increase in thermal tolerance of 0.2 to 1.0°C (Sheppard, 2003; Donner et al., 2005). Furthermore, in the Caribbean, a 0.5 m sea-level rise is projected to cause a decrease in turtle nesting habitat by up to 35% (Fish et al., 2005).

In islands with cloud forest or high elevations, such as the Hawaiian Islands, large volcanoes have created extreme vegetation gradients, ranging from nearly tropical to alpine (Foster, 2001; Daehler, 2005). In these ecosystems, anthropogenic climate change is likely to combine with past land-use changes and biological invasions to drive several species such as endemic birds to extinction (Benning et al., 2002). This trend among Hawaiian forest birds shows concordance with the spread of avian malaria, which has doubled over a decade at upper elevations and is associated with breeding of mosquitoes and warmer summertime air temperatures (Freed et al., 2005).

In the event of increasing extreme events such as cyclones (hurricanes) (see Section 16.3.1.3) forest biodiversity could be severely affected, as adaptation responses on small islands are expected to be slow, and impacts of storms may be cumulative. For example, Ostertag et al. (2005) examined long-term tropical moist forests on the island of Puerto Rico in the Caribbean. Hurricane-induced mortality of trees after 21 months was 5.2%/yr; more than seven times higher than background mortality levels during the non-hurricane periods. These authors show that resistance of trees to hurricane damage is not only correlated with individual and species characteristics, but also with past disturbance history, which suggests that individual storms cannot be treated as discrete, independent events when interpreting the effects of hurricanes on forest structure.

16.4.5 Human settlements and well-being

The concentration of large settlements along with economic and social activities at or near the coast is a well-documented feature of small islands. On Pacific and Indian Ocean atolls, villages are located on low and narrow islands, and in the Caribbean more than half of the population live within 1.5 km of the shoreline. In many regions of small islands, such as along the north coast of Jamaica and along the west and south coasts of Barbados, continuous corridors of development now occupy practically all of the prime coastal lands. Fishing villages, government buildings and important facilities such as hospitals are frequently located close to the shore. Moreover, population growth and internal migration of people are putting additional pressure on coastal settlements, utilities and resources, and creating problems in areas such as pollution, waste disposal and housing. Changes in sea level, and any changes in the magnitude and frequency of storm events, are likely to have serious consequences for these land uses. On the other hand, rural and inland settlements and communities are more likely to be adversely affected by negative impacts on agriculture, given that they are often dependent upon crop production for many of their nutritional requirements.

An important consideration in relation to settlements is housing. In many parts of the Pacific, traditional housing styles, techniques and materials were resistant to damage and/or could be repaired quickly. Moves away from traditional housing have increased vulnerability to thermal stress, slowed housing reconstruction after storms and flooding, and in some countries increased the use of air-conditioning. As a result, human well-being in several major settlements on islands in the Pacific and Indian Oceans has changed over the past two or three decades, and there is growing concern over the possibility that global climate change and sea-level rise are likely to impact human health and well-being, mostly in adverse ways (Hay et al., 2003).

Many small island states currently suffer severe health burdens from climate-sensitive diseases, including morbidity and mortality from extreme weather events, certain vector-borne diseases, and food- and water-borne diseases (Ebi et al., 2006). Tropical cyclones, storm surges, flooding, and drought have both short- and long-term effects on human health, including drowning, injuries, increased disease transmission, decreases in agricultural productivity, and an increased incidence of common mental disorders (Hajat et al., 2003). Because the impacts are complex and far-reaching, the true health burden is rarely appreciated. For example, threats to health posed by extreme weather events in the Caribbean include insect- and rodent-borne diseases, such as dengue, leptospirosis, malaria and yellow fever; water-borne diseases, including schistosomiasis, cryptosporidium and cholera; food-borne diseases, including diarrhoeal diseases, food poisoning, salmonellosis and typhoid; respiratory diseases, including asthma, bronchitis and respiratory allergies and infections; and malnutrition resulting from disturbances in food production or distribution (WHO, 2003a).

Many small island states lie in tropical or sub-tropical zones with weather conducive to the transmission of diseases such as malaria, dengue, filariasis, schistosomiasis, and food- and water-borne diseases. The rates of many of these diseases are increasing in small island states for a number of reasons, including poor public health practices, inadequate infrastructure, poor waste management practices, increasing global travel and changing climatic conditions (WHO, 2003a). In the Caribbean, the incidence of dengue fever increases during the warm years of ENSO cycles (Rawlins et al., 2005). Because the greatest risk of dengue transmission is during annual wet seasons, vector control programs need to target these periods to reduce disease burdens. The incidence of diarrhoeal diseases is associated with annual average temperature (Singh et al., 2001) and negatively associated with water availability in the Pacific (Singh et al., 2001). Therefore, increasing temperatures and decreasing water availability due to climate change may increase burdens of diarrhoeal and other infectious diseases in some small island states.

Outbreaks of climate-sensitive diseases can be costly in terms of lives and economic impacts. An outbreak of dengue fever in Fiji coincided with the 1997/1998 El Niño; out of a population of approximately 856,000 people, 24,000 were affected, with 13 deaths (World Bank, 2000). The epidemic cost US$3 million to 6 million. Neighbouring islands were also affected.

Ciguatera fish poisoning is common in marine waters, particularly reef waters. Multiple factors contribute to outbreaks of ciguatera poisoning, including pollution and reef degradation. Warmer sea surface temperatures during El Niño events have been associated with ciguatera outbreaks in the Pacific (Hales et al., 1999).

16.4.6 Economic, financial and socio-cultural impacts

Small island states have special economic characteristics which have been documented in several reports (Atkins et al., 2000; ADB, 2004; Briguglio and Kisanga, 2004; Grynberg and Remy, 2004). Small economies are generally more exposed to external shocks, such as extreme events and climate change, than larger countries, because many of them rely on one or a few economic activities such as tourism or fisheries. Recent conflicts in the Gulf region have, for example, affected tourism arrivals in the Maldives and the Seychelles; while internal conflicts associated with coups have had similar effects on the tourism industry in Fiji (Becken, 2004). In the Caribbean, hurricanes cause loss of life, property damage and destruction, and economic losses running into millions of dollars (ECLAC, 2002; OECS, 2004). The reality of island vulnerability is powerfully demonstrated by the near-total devastation experienced on the Caribbean island of Grenada when Hurricane Ivan made landfall in September 2004. Damage assessments indicate that, in real terms, the country's socio-economic development has been set back at least a decade by this single event that lasted for only a few hours (see Box 16.3).

Tourism is a major economic sector in many small islands, and its importance is increasing. Since their economies depend so highly on tourism, the impacts of climate change on tourism resources in small islands will have significant effects, both direct and indirect (Bigano et al., 2005; Viner, 2006). Sea-level rise and increased sea water temperatures are projected to accelerate beach erosion, cause degradation of natural coastal defences such as mangroves and coral reefs, and result in the loss of cultural heritage on coasts affected by inundation and flooding. These impacts will in turn reduce attractions for coastal tourism. For example, the sustainability of island tourism resorts in Malaysia is expected to be compromised by rising sea level, beach erosion and saline contamination of coastal wells, a major source of water supply for island resorts (Tan and Teh, 2001). Shortage of water and increased risk of vector-borne diseases may steer tourists away from small islands, while warmer climates in the higher-latitude countries may also result in a

Box 16.3. Grenada and Hurricane Ivan

Hurricane Ivan struck Grenada on 7 September 2004, as a category 4 system on the Saffir-Simpson scale. Sustained winds reached 140 mph, with gusts exceeding 160 mph. An official OECS/UN-ECLAC Assessment reported the following:

- 28 people killed,
- overall damages calculated at twice the current GDP,
- 90% of housing stock damaged,
- 90% of guest rooms in the tourism sector damaged or destroyed, equivalent to approximately 29% GDP,
- losses in telecommunications equivalent to 13% GDP,
- damage to schools and education infrastructure equivalent to 20% GDP,
- losses in agricultural sector equivalent to 10% GDP. The two main crops, nutmeg and cocoa, which have long gestation periods, will not contribute to GDP or earn foreign exchange for the next 10 years,
- damage to electricity installations totalling 9% GDP,
- heavy damage to eco-tourism and cultural heritage sites, resulting in 60% job losses in the sub-sector,
- prior to Hurricane Ivan, Grenada was on course to experience an economic growth rate of approximately 5.7% *per annum* but negative growth of around –1.4% *per annum* is now forecast.

Source: OECS (2004).

reduction in the number of people who want to visit small islands in the tropical and sub-tropical regions.

Tourism in small island states is also vulnerable to climate change through extreme events and sea-level rise leading to transport and communication interruption. In a study of tourist resorts in Fiji, Becken (2005) suggested that many operators already prepare for climate-related events, and therefore are adapting to potential impacts from climate change. She also concludes that reducing greenhouse gas emissions from tourist facilities is not important to operators; however, decreasing energy costs is practised for economic reasons.

Climate change may also affect important environmental components of holiday destinations, which could have repercussions for tourism-dependent economies. The importance of environmental attributes in determining the choice and enjoyment of tourists visiting Bonaire and Barbados, two Caribbean islands with markedly different tourism markets and infrastructure, and possible changes resulting from climate change (coral bleaching and beach erosion) have been investigated by Uyarra et al. (2005). They concluded that such changes would have significant impacts on destination selection by visitors, and that island-specific strategies, such as focusing resources on the protection of key tourist assets, may provide a means of reducing the environmental impacts and economic costs of climate change. Equally, the attractions of ‘cold water islands’ (e.g., the Falklands, Prince Edward Island, Baffin, Banks and Lulea) could be compromised, as these destinations seek to expand their tourism sectors (Baldacchino, 2006).

16.4.7 Infrastructure and transportation

Like settlements and industry, the infrastructural base that supports the vital socio-economic sectors of island economies tends to occupy coastal locations. Hay et al. (2003) have identified several challenges that will confront the transportation sector in Pacific island countries as a result of climate variability and change. These include closure of roads, airports and bridges due to flooding and landslides, and damage to port facilities. The resulting disruption would not be confined to the transportation sector alone, but would impact other key dependent sectors and services including tourism, agriculture, the delivery of health care, clean water, food security and market supplies.

In most small islands, energy is primarily from non-renewable sources, mainly from imported fossil fuels. In the context of climate change, the main contribution to greenhouse gas emissions is from energy use. The need to introduce and expand renewable energy technologies in small islands has been recognised for many years although progress in implementation has been slow. Often, the advice that small islands receive on options for economic growth is based on the strategies adopted in larger countries, where resources are much greater and alternatives significantly less costly. It has been argued by Roper (2005) that small island states could set an example on green energy use, thereby contributing to local reductions in greenhouse gas emissions and costly imports. Indeed, some have already begun to become ‘renewable energy islands’. La Desirade (Caribbean), Fiji, Samsoe (Denmark), Pellworm (Germany) and La Réunion (Indian Ocean) are cited as presently generating more than 50% of their electricity from renewable energy sources (Jensen, 2000).

Almost without exception, international airports on small islands are sited on or within a few kilometres of the coast, and on tiny coral islands. Likewise, the main (and often only) road network runs along the coast (Walker and Barrie, 2006). In the South Pacific region of small islands, Lal (2004) estimates that, since 1950, mean sea level has risen at a rate of approximately 3.5 mm/yr, and he projects a rise of 25 to 58 cm by the middle of this century. Under these conditions, much of the infrastructure in these countries would be at serious risk from inundation, flooding and physical damage associated with coastal land loss. While the risk will vary from country to country, the small islands of the Indian Ocean and the Caribbean – countries such as Malta and Singapore and mid-latitude islands such as the Îles-de-la-Madeleine in the Gulf of St. Lawrence – may be confronted by similar threats. Raksakulthai (2003) has shown that climate change would also increase the risk to critical facilities on the island of Phuket, a premier tourism island in South-East Asia.

The threat from sea-level rise to infrastructure on small islands could be amplified considerably by the passage of tropical cyclones (hurricanes). It has been shown, for instance, that port facilities at Suva, Fiji, and Apia, Samoa, would experience overtopping, damage to wharves, and flooding of the hinterland if there were a 0.5 m rise in sea level combined with waves associated with a 1-in-50 year cyclone (Hay et al., 2003). In the Caribbean, the damage to coastal infrastructure from storm surge alone has been severe. In November 1999, surge damage in St. Lucia associated with Hurricane Lenny was in excess of US$6 million, even though the storm was centred many kilometres offshore.

16.5 Adaptation: practices, options and constraints

16.5.1 Role of adaptation in reducing vulnerability and impacts

It is clear from the previous sections that small islands are presently subjected to a range of climatic and oceanic impacts, and that these impacts will be exacerbated by ongoing climate change and sea-level rise. Moreover, the TAR showed that the overall vulnerability of small island states is primarily a function of four interrelated factors:

- the degree of exposure to climate change;
- their limited capacity to adapt to projected impacts;
- the fact that adaptation to climate change is not a high priority, given the more pressing problems that small islands have to face;
- the uncertainty associated with global climate change projections and their local validity (Nurse et al., 2001).

Several other factors that influence vulnerability and impacts on small islands have also been identified in the present chapter, including both global and local processes. This combination of drivers is likely to continue into the future, which raises the possibility that environmental conditions and the socio-economic well-being of populations on small islands will worsen unless adaptation measures are put in place to reduce impacts, as illustrated in Box 16.4.

While it is clear that implementing anticipatory adaptation strategies early on is desirable (see Box 16.4), there are obstacles associated with the uncertainty of the climate change projections. To overcome this uncertainty, Barnett (2001) has suggested that a better strategy for small islands is to enhance the resilience of whole-island socio-ecological systems, rather than concentrating on sectoral adaptation; a theme that is expanded upon in Section 16.5.5. This is the policy of the Organisation of Eastern Caribbean States (OECS, 2000).

Inhabitants of small islands, individuals, communities and governments, have adapted to interannual variability in climate and sea conditions, as well as to extreme events, over a long period of time. There is no doubt that this experience will be of value in dealing with inter-annual variability and extremes in climate and sea conditions that are likely to accompany the longer-term mean changes in climate and sea level. Certainly, in Polynesia, Melanesia and Micronesia, and in the Arctic, the socio-ecological systems have historically been able to adapt to environmental change (Barnett, 2001; Berkes and Jolly, 2001). However, it is also true that in many islands traditional mechanisms for coping with environmental hazards are being, or have been, lost, although paradoxically the value of such mechanisms is being increasingly recognised in the context of adaptation to climate change (e.g., MESD, 1999; Fox, 2003).

16.5.2 Adaptation options and priorities: examples from small island states

What are the adaptation options and priorities for small islands, and especially for small island states? Since the TAR there have been a number of National Communications to the United Nations Framework Convention on Climate Change (UNFCCC) from small island states that have assessed their own vulnerability to climate change and in-country adaptation strategies. These communications give an insight into national concerns about climate change, the country's vulnerability, and the priorities that different small island states place on adaptation options. They also suggest that to date adaptation has been reactive, and has been centred around responses to the effects of climate variability and particularly climate extremes. Moreover, the range of measures considered, and the priority they are assigned, appear closely linked to the country's key socio-economic sectors, their key environmental concerns, and/or the most vulnerable areas to climate change and/or sea-level rise. Some island states such as Malta (MRAE, 2004) emphasise potential adaptations to economic factors including power generation, transport, and waste management, whereas agriculture and human health figure prominently in communications from the Comoros (GDE, 2002), Vanuatu (Republic of Vanuatu, 1999), and St. Vincent and the Grenadines (NEAB, 2000). In these cases, sea-level rise is not seen as a critical issue, though it is in the low-lying atoll states such as Kiribati, Tuvalu, Marshall Islands and the Maldives. The Maldives provides one example of the sectors it sees as being the most vulnerable to climate change, and the adaptive measures required to reduce vulnerability and enhance resilience (see Box 16.5).

In spite of differences in emphasis and sectoral priorities, there are three common themes.

- First, all National Communications emphasise the urgency for adaptation action and the need for financial resources to support such action.
- Second, freshwater is seen as a critical issue in all small island states, both in terms of water quality and quantity.Water is a multi-sectoral resource that impinges on

Box 16.4. Future island conditions and well-being: the value of adaptation

Global change and regional/local change will interact to impact small islands in the future. Both have physical and human dimensions. Two groups of global drivers are identified in the top panel of Figure 16.2: first, climate change including global warming and sea-level rise and, second, externally driven socio-economic changes such as the globalisation of economic activity and international trade (Singh and Grünbühel, 2003). In addition to these global processes, small islands are also subject to important local change influences, such as population pressure and urbanisation, which increase demand on the local resource base and expand the ecological footprint (Pelling and Uitto, 2001).

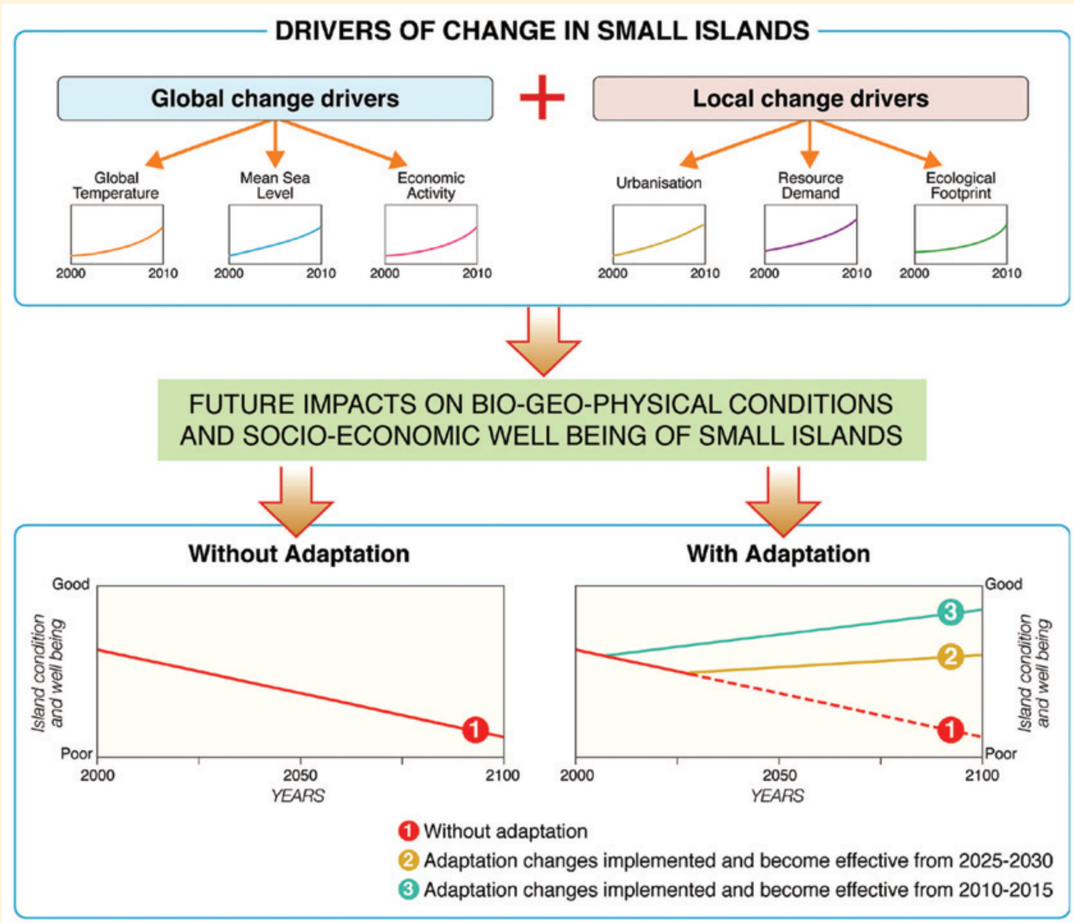


Figure 16.2. *Drivers of change in small islands and the implications for island condition and well-being under no adaptation and the near-term and mid-term implementation of adaptation. Adapted from Harvey et al. (2004).*

In general, both global and local drivers can be expected to show increases in the future. These will probably impact on island environments and their bio-geophysical conditions, as well as on the socio-economic well-being of island communities (Clark, 2004).

Three possible scenarios are illustrated in the lower panel. Implicitly, and without adaptation, environmental conditions and human well-being are likely to get worse in the future (line 1). On the other hand, if effective adaptation strategies are implemented, both the bio-geophysical conditions and socio-economic well-being of islanders should improve. It is suggested that the earlier this is done, the better the outcome (lines 2 and 3).

Source: Harvey et al. (2004).

Box 16.5. Adaptive measures in the Maldives

Adaptation options in low-lying atoll islands which have been identified as especially vulnerable, are limited, and response measures to climate change or its adverse impacts are potentially very costly. In the Maldives adaptation covers two main types of activities. First, there are adaptive measures involving activities targeted at specific sectors where climate change impacts have been identified. Second, there are adaptive measures aimed at enhancing the capacity of the Maldives to effectively implement adaptations to climate change and sea-level rise. Within these two activities the Maldivian Ministry of Home Affairs, Housing and Environment has identified several vulnerable areas and adaptive measures that could be implemented to reduce climate change impacts.

Vulnerable area	Adaptation response
Land loss and beach erosion	Coastal protection Population consolidation i.e., reduction in number of inhabited islands Ban on coral mining
Infrastructure and settlement damage	Protection of international airport Upgrading existing airports Increase elevation in the future
Damage to coral reefs	Reduction of human impacts on coral reefs Assigning protection status for more reefs
Damage to tourism industry	Coastal protection of resort islands Reduce dependency on diving as a primary resort focus Economy diversification
Agriculture and food security	Explore alternate methods of growing fruits, vegetables and other foods Crop production using hydroponic systems
Water resources	Protection of groundwater Increasing rainwater harvesting and storage capacity Use of solar distillation Management of storm water Allocation of groundwater recharge areas in the islands
Lack of capacity to adapt (both financial and technical)	Human resource development Institutional strengthening Research and systematic observation Public awareness and education

Source: MOHA (2001).

all facets of life and livelihood, including security. It is seen as a problem at present and one that will increase in the future.

- Third, many small island states, including all the Least Developed Countries (Small Island Developing States, SIDS), see the need for more integrated planning and management, be that related to water resources, the coastal zone, human health, or tourism.

In a case study of tourism in Fiji, for instance, Becken (2004) argues that the current tourism policy focuses on adaptation and measures that are predominantly reactive rather than proactive, whereas climate change measures that offer win-win situations should be pursued. These include adaptation, mitigation, and wider environmental management measures; examples being reforestation of native forest, water conservation, and the use of renewable energy resources (Becken, 2004). A similar view is held by Stern (2007), who notes that climate change adaptation policies and measures, if implemented in a timely and efficient manner, can generate valuable co-benefits such as enhanced energy security and environmental protection.

The need to implement adaptation measures in small islands with some urgency has recently been reinforced by Nurse and Moore (2005), and was also highlighted in the TAR, where it was suggested that risk-reduction strategies, together with other sectoral policy initiatives, in areas such as sustainable development planning, disaster prevention and management, integrated coastal zone management, and health care planning could be usefully employed (Nurse et al., 2001). Since then a number of projects on adaptation in several small islands have adopted this suggestion. These projects aim to build the capacities of individuals, communities and governments so that they are more able to make informed decisions about adaptation to climate change and to enhance their adaptive capacity in the long run.

There are few published studies that have attempted to estimate climate change adaptation costs for small islands, and much more work needs to be undertaken on the subject. The most recent study was conducted by Ng and Mendelsohn (2005), who found coastal protection to be the least-cost strategy to combat sea-level rise in Singapore, under three scenarios. They noted that the annual cost of shoreline protection would increase as sea-level rises, and would range from US$0.3–5.7 million by 2050 to US$0.9–16.8 million by 2100 (Ng and Mendolsohn, 2005). It was concluded that it would be more costly to the country to allow the coast to become inundated than to defend it. Studies of this type could provide useful guidance to island governments in the future, as they are confronted with the difficult task of making adaptation choices.

16.5.3 Adaptation of 'natural' ecosystems in island environments

The natural adaptation of small-island ecosystems is considered in very few National Communications. Instead attention is mostly focused on: (1) protecting those ecosystems that are projected to suffer as a consequence of climate change and sea-level rise; and (2) rehabilitating ecosystems degraded or destroyed as a result of socio-economic developments.

One group of natural island environments in low latitudes are the tropical rainforests, savannas and wetlands that occupy the inland, and often upland, catchment areas of the larger, higher and topographically more complex islands, such as Mauritius in the Indian Ocean, the Solomon Islands in the Pacific, and Dominica in the Caribbean. Very little work has been done on the potential impact of climate change on these highly biodiverse systems, or on their adaptive capacity.

On the other hand, the potential impact of global warming and sea-level rise on natural coastal systems, such as coral reefs and mangrove forests, is now reasonably well known. For these ecosystems several possible adaptation measures have been identified. In those coral reefs and mangrove forests that have not been subjected to significant degradation or destruction as a result of human activities, natural or 'autonomous' adaptation, which represents the system's natural adaptive response and is triggered by changes in climatic stimuli, can take place. For instance, some corals may be able to adapt to higher sea surface and air temperatures by hosting more temperature-tolerant symbiotic algae (see Chapter 4, Box 4.4). They can also grow upwards with the rise in sea level, providing that vertical accommodation space is available (Buddemeier et al., 2004). Similarly, mangrove forests can migrate inland, as they did during the Holocene sea-level transgression, providing that there is horizontal accommodation space and they are not constrained by the presence of infrastructure and buildings; i.e., by 'coastal squeeze' (Alongi, 2002).

In addition to autonomous adaptation, both restoration and rehabilitation of damaged mangrove and reef ecosystems can be seen as 'planned' adaptation mechanisms aimed to increase natural protection against sea-level rise and storms, and to provide resources for coastal communities. In small islands, such projects have usually been community-based and are generally small-scale. In the Pacific islands, successful mangrove rehabilitation projects have been recorded from Kiribati, Northern Mariana Islands, Palau and Tonga, with failed efforts in American Samoa and Papua New Guinea (Gillman et al., 2006). Improved staff training, capacity building, and information sharing between coastal managers is needed for successful mangrove rehabilitation (Lewis, 2005). More ambitious, costly and technical projects include an ecosystem restoration programme in the Seychelles, which aims ultimately to translocate globally threatened coastal birds as well as rehabilitating native coastal woodlands on eleven islands in the country (Henri et al., 2004).

16.5.4 Adaptation: constraints and opportunities

There are several constraints to adaptation that are inherent in the very nature of many small islands, including small size, limited natural resources, and relative isolation, and it is because of these characteristics that some autonomous small islands have been recognised in the United Nations process as either Least Developed Countries (LDCs) or SIDS. Not all small islands satisfy these criteria, notably those linked closely with global finance or trade, as well as the non-autonomous islands within larger countries. While these two groups of islands will share some of the constraints of small island states, they are not emphasised in this section.

16.5.4.1 Lack of adaptive capacity

The main determinants of a country's adaptive capacity to climate change are: economic wealth, technology, information and skills, infrastructure, institutions and equity (WHO, 2003b). A common constraint confronting most small island states is the lack of in-country adaptive capacity, or the ease with which they are able to cope with climate change. In many autonomous small islands the cost of adopting and implementing adaptation options is likely to be prohibitive, and a significant proportion of a country's economic wealth. Financial resources that are generally not available to island governments would need to come from outside (Rasmussen, 2004). This need for international support to assist with the adaptation process in vulnerable, developing countries is also strongly emphasised by Stern (2007). Similarly, there are often inadequate human resources available to accommodate, cope with, or benefit from the effects of climate change; a situation that may be compounded by the out-migration of skilled workers (Voigt-Graf, 2003). To overcome this deficiency, the adaptive capacity of small island states will need to be built up in several important areas including human resource development, institutional strengthening, technology and infrastructure, and public awareness and education.

An extreme example of these deficiencies is the recently independent state of Timor Leste (East Timor). Timor Leste is vulnerable to climate change, as evidenced by existing sensitivities to climate events, for example drought and food shortages in the western highlands, and floods in Suai. Barnett et al. (2003) note that relevant planning would address the present problems as well as future climate risks, and conclude that activities that promote sustainable development, human health, food security, and renewable energy can reduce the risk of future damages caused by climate change as well as improving living standards. In short, "change in climate is a long-term problem for Timor Leste, but climate change policies can be positive opportunities" (Barnett et al., 2003).

16.5.4.2 Adaptation and global integration

This last theme is also developed by Pelling and Uitto (2001), who suggest that change at the global level is a source of new opportunities, as well as constraints, for building local resilience. They argue that small island populations have been mobile, both historically and at present, and that remittances from overseas relatives help to moderate economic risks and increase family resiliency on home islands. They also recognise that this is a critical time for small islands, which must contend with ongoing development pressures, economic liberalisation, and the growing pressures from risks associated with climate change and sea-level rise. They conclude, following a case study of Barbados, that efforts to enhance island resilience must be mainstreamed into general development policy formulation, and that adaptations should not be seen as separate or confined to engineering or land-use planning-based realms (Pelling and Uitto, 2001).

Barnett (2001) discusses the potential impact of economic liberalisation on the resilience of Pacific island communities to climate change. He argues that many small island societies have proved resilient in the past to social and environmental upheaval. The key parameters of this resilience include: opportunities for migration and subsequent remittances; traditional knowledge, institutions and technologies; land and shore tenure regimes; the subsistence economy; and linkages between formal state and customary decision-making processes. However, this resilience may be undermined as the small island states become increasingly integrated into the world economy through, for example, negotiations for fishery rights in their Exclusive Economic Zones, and international tourism (Barnett, 2001).

These global economic processes, together with global warming, sea-level rise, and possibly increased frequency and intensity of extreme weather events, make it difficult for autonomous small islands to achieve an appropriate degree of sustainability, which Barnett and Adger (2003) suggest is one of the goals of adaptation to climate change. They maintain that for the most vulnerable small island states (those composed of low-lying atolls), this combination of global processes interacting with local socio-economic and environmental conditions puts the long-term ability of humans to inhabit atolls at risk, and that this risk constitutes a 'dangerous' level of climatic change that may well undermine their national sovereignty (see Box 16.6).

This discussion highlights the role of resilience – both its biophysical and human aspects – as a critical component in developing the adaptive capacity of small island states, a role that has effectively emerged since publication of the TAR. In a recent study of the Cayman Islands, Tompkins (2005) found that self-efficacy, strong local and international support networks, combined with a willingness to act collectively and to learn from mistakes, appeared to have increased the resilience of the Government to tropical storm risk, implying that such resilience can also contribute to the creation of national level adaptive capacity to climate change, thereby reducing vulnerability.

16.5.4.3 Risk-sharing and insurance

Insurance is another way of reducing vulnerability and is increasingly being discussed in the context of small islands and climate change. However, there are several constraints to transferring or sharing risk in small islands. These include the limited size of the risk pool, and the lack of availability of financial instruments and services for risk management. For instance, in 2004, Cyclone Heta devastated the tiny island of Niue in the South-West Pacific, where no insurance is available against weather extremes, leaving the island almost entirely reliant on overseas aid for reconstruction efforts (Hamilton, 2004). Moreover, the relative costs of natural disasters tend to be far higher in developing countries than in advanced economies. Rasmussen (2004) shows that autonomous small islands are especially vulnerable, with natural disasters in the countries of the Eastern Caribbean shown to have had a discernible macroeconomic impact, including large effects on fiscal and external balances, pointing to an important role for precautionary measures.

Thus, in many small island countries, the implementation of specific instruments and services for risk-sharing may be required. Perhaps recent initiatives on financial risk transfer mechanisms through traditional insurance structures and new financial instruments, such as catastrophe bonds, weather derivatives, micro-insurance, and a regional pooling arrangement for small island states, might provide them with the flexibility for this form of adaptation (Auffret, 2003; Hamilton, 2004; Swiss Re, 2004). However, as Epstein and Mills (2005) point out, the economic costs of adapting to climate-related risks are spread among a range of stakeholders including governments, insurers, business, non-profit entities and individuals. They also note that sustainable development can contribute to managing and maintaining the insurability of climate change risk, though development projects can be stranded where financing is contingent on insurance, particularly with respect to coastlines and shorelines vulnerable to sea-level rise (Epstein and Mills, 2005).

Climate change adaptation projects can also founder in other ways, either at the implementation stage or when projects that rely wholly on external personnel or financing are completed. For this reason, Westmacott (2002) believes that integrated coastal management in the Pacific should incorporate conflict

Box 16.6. Climate dangers and atoll countries

"Climate change puts the long-term sustainability of societies in atoll nations at risk. The potential abandonment of sovereign atoll countries can be used as the benchmark of the 'dangerous' change that the UNFCCC seeks to avoid. This danger is as much associated with the narrowing of adaptation options and the role of expectations of impacts of climate change as it is with uncertain potential climate-driven physical impacts. The challenges for research are to identify the thresholds of change beyond which atoll socio-ecological systems collapse and to assess how likely these thresholds are to be breached. These thresholds may originate from social as well as environmental processes. Further, the challenge is to understand the adaptation strategies that have been adopted in the past and which may be relevant for the future in these societies."

Source: Barnett and Adger (2003).

management that pays particular attention to, for example, the over-extraction or destruction of resources.

16.5.4.4 Emigration and resettlement

Emigration as a potentially effective adaptation strategy has been alluded to earlier, particularly in the context of temporary or permanent out-migrants providing remittances to home-island families, thereby enhancing home-island resilience (Barnett, 2001; Pelling and Uitto, 2001). Within-country migration and resettlement schemes have been common trends over the last several decades in many small islands in the Pacific and Indian Oceans. Both Kiribati and the Maldives have ongoing resettlement schemes and, for the past 70 years, the people of Sikaiana Atoll in the Solomon Islands have been migrating away from their atoll, primarily to Honiara, the capital (Donner, 2002). Similarly there has been internal migration from the Cartaret Islands in Papua New Guinea to Bougainville, and from the outer islands of Tuvalu to the capital Funafuti (Connell, 1999), the former as a consequence of inundation from high water levels and storms, the latter primarily in search of wage employment.

In the case of Tuvalu, this internal migration has brought almost half of the national population to Funafuti atoll, with negative environmental consequences, and the Government has indicated that there is also visual evidence of sea-level rise through increased erosion, flooding and salinisation (Connell, 2003). Connell suggests that, as a result, the global media have increasingly emphasised a doomsday scenario for Tuvalu, as a symbol of all threatened small island environments. Farbotko (2005) also indicates that Tuvalu is becoming prominent in connection with climate-change-related sea-level rise. She undertook an analysis of reports in a major Australian newspaper over the past several years, and suggests that implicating climate change in the identity of Tuvaluans as 'vulnerable' operates to silence alternative identities that emphasise resilience. Indeed, she says that her analysis "has highlighted the capacity for vulnerability rhetoric to silence discourse of adaptation" and concludes that "adaptive strategies are significant for island peoples faced with climate change" and that "it is adaptation, perhaps even more than relocation or mitigation initiatives, which is of immediate importance in island places… [especially] in the face of changes brought about by 'global warming'" (Farbotko, 2005).

On the other hand, Adger et al. (2003a) argue that migration is a feasible climate adaptation strategy in particular circumstances, including in small islands. However, they suggest that because of current inequities in labour flows, particularly for international migration, this adaptation strategy is likely to be contested, and may be a limited option in many parts of the world, even for residents from small island states. They suggest that other means of supporting adaptive capacity and enhancing resilience are required, including building on existing coping strategies, or by introducing innovation in terms of technology or institutional development (Adger et al., 2003a).

16.5.5 Enhancing adaptive capacity

16.5.5.1 Traditional knowledge and past experience

Adaptive capacity and resilience can also be strengthened through the application of traditional knowledge and past experience of environmental changes. In the TAR, Nurse et al. (2001) noted that some traditional island assets, including subsistence and traditional technologies, skills and knowledge, and community structures, and coastal areas containing spiritual, cultural and heritage sites, appeared to be at risk from climate change, and particularly sea-level rise. They argued that some of these values and traditions are compatible with modern conservation and environmental practices.

Since then, several examples of such practices have been described. For instance, Hoffmann (2002) has shown that the implementation of traditional marine social institutions, as exemplified in the Ra'ui in Rarotonga, Cook Islands, is an effective conservation management tool, and is improving coral reef health; while Aswani and Hamilton (2004) show how indigenous ecological knowledge and customary sea tenure may be integrated with modern marine and social science to conserve the bumphead parrotfish in Roviana Lagoon, Solomon Islands. Changes in sea tenure, back to more traditional roles, have also occurred in Kiribati (Thomas, 2001).

The utility of traditional knowledge and practices can also be expanded to link not only with biodiversity conservation but also with tourism. For instance, in a coastal village on Vanua Levu, Fiji, the philosophy of *vanua* (which refers to the connection of people with the land through their ancestors and guardian spirits) has served as a guiding principle for the villagers in the management and sustainable use of the rainforest, mangrove forest, coral reefs, and village gardens. Sinha and Bushell (2002) have shown that the same traditional concept can be the basis for biodiversity conservation, because the ecological systems upon which the villagers depend for subsistence are the very same resources that support tourism. These examples indicate that local knowledge, management frameworks and skills could be important components of adaptive capacity in those small islands that still have some traditional foundations.

16.5.5.2 Capacity building, communities and adaptive capacity

Encouraging the active participation of local communities in capacity building and environmental education has become an objective of many development programmes in small islands. For example, Tran (2006) reports on a long-term project that has successfully included the local community of Holbox Island (Mexico) in monitoring coastal pollution in and around their island. A similar approach is being applied by Dolan and Walker (2006) to another community-based project which assesses the vulnerability of island and coastal communities, their adaptive capacity and options in the Queen Charlotte Islands (Haida Gwaii), located off the west coast of Canada. The study highlights determinants of adaptive capacity at the local scale, and recognises that short-term exposure to climate variability is an important source of vulnerability superimposed on long-term change. Thus, they suggest that community perceptions and experiences with climate extremes can identify inherent characteristics that enable or constrain a community to respond, recover and adapt to climate change, in this case ultimately to sea-level rise (Dolan and Walker, 2006).

A similar conceptualisation, which considers current and future community vulnerability and involves methodologies in climate science and social science, provides the basis for building adaptive capacity, as illustrated in Box 16.7. This approach requires community members to identify climate conditions relevant to them, and to assess present and potential adaptive strategies. The methodology was tested in Samoa, and the results from one village (Saoluafata) are discussed by Sutherland et al. (2005). In this case, local residents identified several adaptive measures including building a seawall, the provision of a water-drainage system and water tanks, a ban on tree clearing, some relocation, and renovations to existing infrastructure.

Enhancing adaptive capacity, however, involves more than just the identification of local options which need to be considered within the larger social, political and economic processes. Based on the Samoan experience, Sutherland et al. (2005) suggest that enhancing adaptive capacity will only be successful when it is integrated with other policies such as disaster preparedness, land-use planning, environmental conservation, coastal planning, and national plans for sustainable development.

Given the urgency for adaptation in small island states, there has been an increase in *ad hoc* stand-alone projects, rather than a programmed or strategic approach to the funding of adaptation options and measures. It can be argued that successful adaptation in small islands will depend on supportive institutions, finance, information, and technological support. However, as noted by Richards (2003), disciplinary and institutional barriers mean that synergies between climate change adaptation and poverty reduction strategies remain underdeveloped. Adger et al. (2003b) note that climate change adaptation has implications for equity and justice because "the impacts of climate change, and resources for addressing these impacts, are unevenly distributed". These issues are particularly applicable to small islands, which have a low capacity to deal with, or adapt to, such impacts.

16.6 Conclusions: implications for sustainable development

The economic, social and environmental linkages between climate change and sustainable development, and their implications for poverty alleviation, have been highlighted in various studies (e.g., Hay et al., 2003; Huq and Reid, 2004) and these are highly relevant to small islands. Most recently, one of the 'key findings' of a major study suggested that climate change poses such a serious threat to poor, vulnerable developing countries that if left unchecked, it will become a "…major obstacle to continued poverty reduction" (Stern, 2007). Indeed, it is true to say that many low-lying small islands view climate change as one of the most important challenges to their achievement of sustainable development. For instance, in the Maldives, Majeed and Abdulla (2004) argue that sea-level rise would so seriously damage the fishing and tourism industries that GDP would be reduced by more than 40%.

In another atoll island setting, Ronneberg (2004) uses the Marshall Islands as a case study to explain that the linkages between patterns of consumption and production, and the effects of global climate change, pose serious future challenges to improving the life of the populations of small island developing states. Based on this case study, Ronneberg (2004) proposes a number of innovative solutions including waste-to-energy and ocean thermal energy conversion systems, which could promote the sustainable development of some small islands and at the same time strengthen their resilience in the face of climate change.

The sustainable development of small islands which are not low-lying, and there are many of these, is also likely to be seriously impacted by climate change, although perhaps not to the same extent as the low islands. For example, Briguglio and Cordina (2003) have shown that climate change impacts on the economic development of Malta are likely to be widespread, affecting all sectors of the economy, but particularly tourism, fishing and public utilities.

Sperling (2003), in an examination of poverty and climate change, contends that the negative impacts of climate change are so serious that they threaten to undo decades of development efforts. He also argues that the combined experience of many international organisations suggests that the best way to address climate change impacts is by integrating adaptation measures into sustainable development strategies. A similar argument is advanced by Hay et al. (2003), in the context of the Pacific small island states, who suggest that the most desirable adaptive responses are those that augment actions which would be taken even in the absence of climate change, due to their contributions to sustainable development. Adaptation measures may be conducive to sustainable development, even without the connection with climate change. The link between adaptation to climate change and sustainable development, which leads to the lessening of pressure on natural resources, improving environmental risk management, and increasing the social well-being of the poor, may not only reduce the vulnerability of small islands to climate change, but also may put them on the path towards sustainable development.

Mitigation measures could also be mainstreamed in sustainable development plans and actions. In this regard, Munasinghe (2003) argues that, ultimately, climate change solutions will need to identify and exploit synergies, as well as seek to balance possible trade-offs, among the multiple objectives of development, mitigation, and adaptation policies. Hay et al. (2003) also argue that while climate change mitigation initiatives undertaken by Pacific island countries will have insignificant consequences climatologically, they should nevertheless be pursued because of their valuable contributions to sustainable development.

But what is small island sustainable development about? Kerr (2005) prefaces this question by noting that sustainable development is often stated as an objective of management strategies for small islands, though relatively little work has explicitly considered what sustainable development means in this context. She argues that the problems of small scale and isolation, of specialised economies, and of the opposing forces of globalisation and localisation, may mean that current development in small islands may be unsustainable in terms of its longevity. On the other hand, models of sustainable development may have something to offer islands in terms of internal management of resources, although the islands may have limited control over exogenous threats or the economic

Box 16.7. Capacity building for development of adaptation measures in small islands: a community approach

Capacity building for development of adaptation measures in Pacific island countries uses a Community Vulnerability and Adaptation Assessment and Action approach. Such an approach is participatory, aims to better understand the nature of community vulnerability, and identifies opportunities for strengthening the adaptive capacity of communities. It seeks to promote a combination of bottom-up and top-down mechanisms for implementation, and supports the engagement of local stakeholders at each stage of the assessment process. If successful, this should enable integration or 'mainstreaming' of adaptation into national development planning and local decision-making processes. The main steps of this approach are outlined below (Figure 16.3).

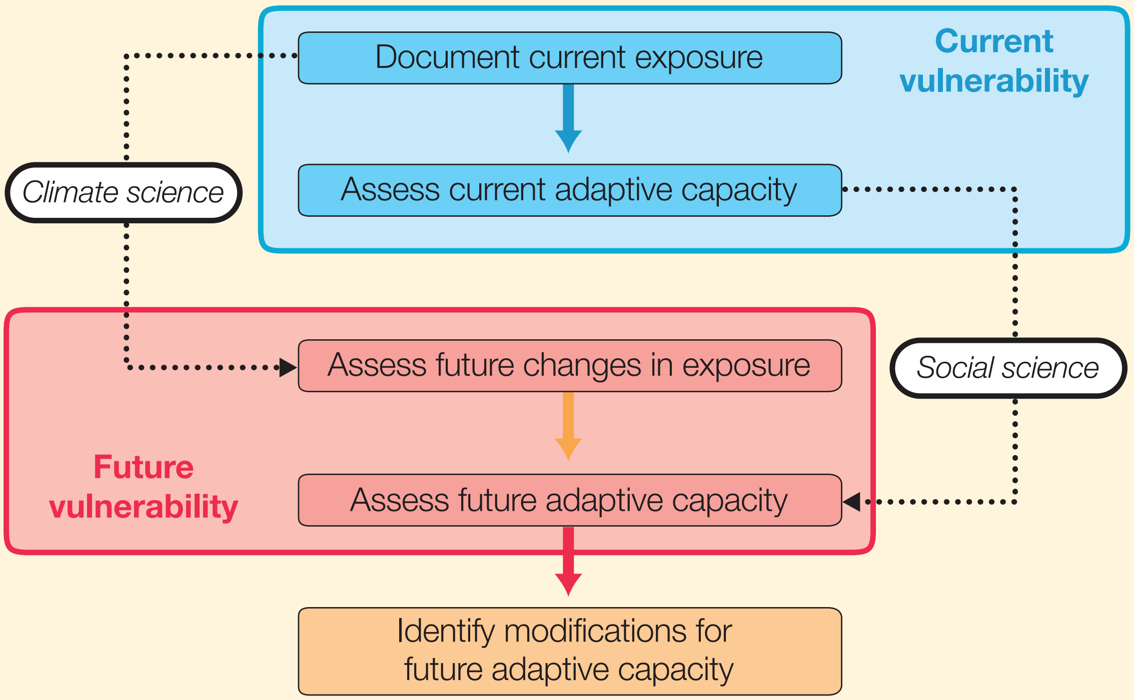


Figure 16.3. *The main steps of a community vulnerability and adaptation assessment and action approach.*

Several pilot communities in the Cook Islands, Fiji, Samoa and Vanuatu are already using this approach to analyse their options and decide on the best course of action to address their vulnerability and adaptation needs.

Source: Sutherland et al. (2005).

drivers of development (Kerr, 2005). In this context, the development of adaptation measures in response to climate change may provide an appropriate avenue to integrate both local and global forces towards island development that is sustainable, providing that local communities are involved (Tran, 2006).

Another positive factor is that many small islands have considerable experience in adapting to climate variability. In the case of Cyprus, for example, Tsiourtis (2002) explains that the island has consistently taken steps to alleviate the adverse effects arising from water scarcity, which is likely to be one of the important effects of climate change. This experience already features in development strategies adopted by Cyprus. A similar argument has also been made by Briguglio (2000) with regard to the Maltese Islands, referring to the islands' exposure to climatic seasonal variability which, historically, has led to individuals and administrations taking measures associated with retreat, accommodation and protection strategies. For example, residential settlements in Malta are generally situated away from low-lying coastal areas, and primitive settlements on the island tended to be located in elevated places. Maltese houses are built of sturdy materials, and are generally able to withstand storms and heavy rains. Temperatures and precipitation rates in Malta change drastically between mid-winter and mid-summer, and this has led to the accumulation of considerable experience in adaptation to climate variability.

However, as mentioned earlier, small islands face many constraints in trying to mainstream climate change into their sustainable development strategies. These include their very limited resources, especially given the indivisibilities of overhead expenditures and hidden costs involved in adaptation measures, particularly in infrastructural projects. Another problem may relate to possible social and/or political conflicts, particularly to do with land use and resources (Westmacott, 2002), though not exclusively (Lane, 2006). Notwithstanding this observation, most decisions regarding the critical issues of land use, energy use and transportation infrastructure in small islands will not have any meaningful influence on the rate and magnitude of climate change worldwide. However, they may have a significant moral and ethical impact in the climate change arena, as well as contributing to reducing their own greenhouse gas emissions and to small island sustainable development.

16.7 Key uncertainties and research gaps

Small islands are sensitive to climate change and sea-level rise, and adverse consequences of climate change and variability are already a 'reality' for many inhabitants of small islands. This assessment has found that many small islands lack adequate observational data and, as noted in the TAR, outputs from AOGCMs are not of sufficiently fine resolution to provide specific information for islands. These deficiencies need to be addressed, so that remaining uncertainties can be reduced, and national and local-scale adaptation strategies for small islands better defined.

As the impacts of climate change become increasingly evident, autonomous small islands, like other countries, will probably be confronted with the need to implement adaptation strategies with greater urgency. However, for these strategies to be effective, they should reflect the fact that natural and human systems in small islands are being simultaneously subjected to other non-climate stresses including population growth, competition for limited resources, ecosystem degradation, and the dynamics of social change and economic transformation. Therefore, responses to climate change need to be properly coordinated and integrated with socio-economic development policies and environmental conservation. The enhancement of resilience at various levels of society, through capacity building, efficient resource allocation and the mainstreaming of climate risk management into development policies at the national and local scale, could constitute a key element of the adaptation strategy.

16.7.1 Observations and climate change science

- Ongoing observation is required to monitor the rate and magnitude of changes and impacts, over different spatial and temporal scales. *In situ* observations of sea level should be strengthened to understand the components of relative sea-level change on regional and local scales. While there has been considerable progress in regional projections of sea level since the TAR, such projections have not been fully utilised in small islands because of the greater uncertainty attached to them, as opposed to global projections.
- Since the TAR, it has also been recognised that other climate-change-induced factors will probably have impacts on coastal systems and marine territories of small islands, including rises in sea temperature and changes in ocean chemistry and wave climate. The monitoring of these and other marine variables in the seas adjacent to small islands would need to be expanded and projections developed.
- Although future projections of mean air temperature are rather consistent among climate models, projections for changes in precipitation, tropical cyclones and wind direction and strength, which are critical concerns for small islands, remain uncertain. Projections based on outputs at finer resolution are needed to inform the development of reliable climate change scenarios for small islands. Regional Climate Models (RCMs) and statistical downscaling techniques may prove to be useful tools in this regard, as the outputs are more applicable to countries at the scale of small islands. These approaches could lead to improved vulnerability assessments and the identification of more appropriate adaptation options.
- Supporting efforts by small islands and their partners to arrest the decline of, and expand, observational networks should be continued. The Pacific Islands Global Climate Observing System (PI-GCOS) and the Intergovernmental Oceanographic Commission Sub-Commission for the Caribbean and Adjacent Regions Global Ocean Observing System (IOCARIBE-GOOS) are two examples of regional observing networks whose coverage should be expanded to cover other island regions.
- Hydrological conditions, water supply and water usage on small islands pose quite different research problems from those in continental situations. These need to be investigated and modelled over the range of island types covering different geology, topography and land cover, and in light of the most recent climate change scenarios and projections.

16.7.2 Impacts and adaptation

- A decade ago, many small islands were the subject of vulnerability assessments to climate change. Such assessments were based on simplistic scenarios, with an emphasis on sea-level rise, and the application of a common methodology that was applied to many small islands throughout the world. The results were initially summarised in the IPCC Second Assessment Report (IPCC, 1996), with later and more comprehensive studies being reported in the TAR. Since then the momentum for vulnerability and impact studies appears to have declined, such that in the present assessment we can cite few robust investigations of climate change impacts on small islands using more recent scenarios and more precise projections. Developing a renewed international agenda to assess the vulnerability of small islands, based on the most recent projections and newly available tools, would provide small islands with a firmer basis for future planning.
- Our assessment has identified several key areas and gaps that are under-represented in contemporary research on the impacts of climate change on small islands. These include:-

- the role of coastal ecosystems such as mangroves, coral reefs and beaches in providing natural defences against sea-level rise and storms;
- establishing the response of terrestrial upland and inland ecosystems, including woodlands, grasslands and wetlands, to changes in mean temperature and rainfall and extremes;
- considering how commercial agriculture, forestry and fisheries, as well as subsistence agriculture, artisanal fishing and food security, will be impacted by the combination of climate change and non-climate-related forces;
- expanding knowledge of climate-sensitive diseases in small islands through national and regional research, not only for vector-borne diseases but for skin, respiratory and water-borne diseases;
- given the diversity of 'island types' and locations, identifying the most vulnerable systems and sectors, according to island type.

• In contrast to the other regions in this assessment, there is also an absence of demographic and socio-economic scenarios and projections for small islands. Nor have future changes in socio-economic conditions on small islands been well presented in existing assessments (e.g., IPCC, 2001; Millennium Ecosystem Assessment, 2003). Developing more appropriate scenarios for assessing the impacts of climate change on the human systems of small islands remains a challenge.
• Methods to project exposures to climate stimuli and non-climate stresses at finer spatial scales should be developed, in order to further improve understanding of the potential consequences of climate variability and change, particularly extreme weather and climate events. In addition, further resources need to be applied to the development of appropriate methods and tools for identifying critical thresholds for both bio-geophysical and socio-economic systems on islands.
• Our evaluation of adaptation in small islands suggests that the understanding of adaptive capacity and adaptation options is still at an early stage of development. Although several potential constraints on, as well as opportunities for, adaptation were identified, two features became apparent. First, the application of some adaptation measures commonly used in continental situations poses particular challenges in a small island setting. Examples include insurance, where there is a small population pool although the propensity for natural disasters is high and where local resilience may be undermined by economic liberalisation. Second, some adaptation measures appear to be advocated particularly for small islands and not elsewhere. Examples include emigration and resettlement, the use of traditional knowledge, and responses to short-term extreme events as a model for adaptation to climate change. Results of studies of each of these issues suggest some ambiguities and the need for further research, including the assessment of practical outcomes that enhance adaptive capacity and resilience.
• With respect to technical measures, countries may wish to pay closer attention to the traditional technologies and skills that have allowed island communities to cope successfully with climate variability in the past. However, as it is uncertain whether the traditional technologies and skills are sufficient to reduce the adverse consequence of climate change, these may need to be combined with modern knowledge and technologies, where appropriate.
• Local capacity should be strengthened in the areas of environmental assessment and management, modelling, economic and social development planning related to climate change, and adaptation and mitigation in small islands. This objective should be pursued through the application of participatory approaches to capacity building and institutional change.
• Access to reliable and affordable energy is a vital element in most small islands, where the high cost of energy is regarded as a barrier to the goal of attaining sustainable development. Research and development into energy options appropriate to small islands could help in both adaptation and mitigation strategies whilst also enhancing the prospect of achieving sustainable growth.

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