IPCC WGII Fourth Assessment Report – Draft for Expert Review

Chapter 16 – Small Islands

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Executive Summary

The findings of the AR-4 confirm and strengthen previous observations reported in the TAR. For example many islands are already experiencing some negative effects of global warming; they have low adaptive capacity and limited ability to recover from natural and man-induced shock; adaptation costs are high relative to GDP; experience gained from coping with past climate variability and extremes can be beneficial to adaptation planning.

Special characteristics of Small Islands

- Small Islands are especially vulnerable to the effects of climate change, sea-level rise and extreme events, because of their characteristics (limited size, proneness to natural hazards and external shocks, etc), and their limited adaptive capacity. These factors combined with local socio-economic and environmental conditions put the long-term sustainability of societies of Small Island at great risk.

Observed and Projected trends

- Observational data for the last Century show that on average, air temperature increased by 0.1°C per decade, and long-term sea level observational records show sea-level rise at an average rate of about 2 mm per year. The rate of increase in air temperature in the Pacific and Caribbean exceeded the global average of about 0.6°C.
- Projections from coupled atmosphere-ocean general circulation models suggest a general increase in surface air temperature for the regions of Small Islands. Rainfall shows no consistent trend, with increases and decreases of more than 10 percent projected for three 30-year periods by the end of this Century.
- Multi-decadal variations in tropical cyclone activity in the Caribbean have been attributed to changes in the SST structure in the Atlantic. The possibility therefore exists that the unprecedented active hurricane activity since 1995 is the result of a combination of the multi-decadal-scale changes in Atlantic SSTs and vertical shear, along with the additional increase in SSTs resulting from the long-term warming trend.
- Maximum tropical cyclone intensity is likely to increase 5 to 10 percent by around 2050 with increase of peak precipitation rates by 25 percent. The behaviour of tropical cyclones is also strongly influenced by ENSO and other factors.

Key future impacts and vulnerabilities

- Since publication of the TAR, new research findings based both on projections and observation, reinforce the view that for Small Islands, the effects of climate change will largely be adverse.
- Dependency on rainfall significantly increases the vulnerability of Small Islands to future changes and distribution of rainfall. For example, a 10 percent reduction in average rainfall by 2050 is likely to correspond to a 20 percent reduction in the size of the freshwater lens on Tarawa Atoll, Kiribati. Moreover, a reduction in the size of the island due to sea-level rise is likely to reduce the thickness of the freshwater lens on atolls. Less rainfall coupled with accelerated sea-level rise would compound this threat.
- Coral reefs, fisheries and other ocean-based resources are likely to be heavily impacted by climate change and climate variability. Small island states have large EEZs, the sustainable exploitation of which requires appropriate expertise and financial resources. Small island states generally have very limited capacity in this regard and this has serious implications for the sustainable management of the oceans under their jurisdiction.
- Subsistence and commercial agriculture on Small Islands will be further impacted by climate change and sea-level rise, as a result of inundation, seawater intrusion into freshwater lenses, soil salinization, decline in water supply and deterioration of water quality. In the absence of

adaptation, the economic damage could reach 2-3 percent to 17-18 percent of 2002 GDP, by 2050 depending on island countries.

- There is growing concern over the adverse effects of climate change and sea-level rise on human health. In the Pacific islands, the rate of diarrhoea will increase with increase of average temperature and decrease of water availability. Climate change is also likely to result in an increase in the incidence of vector-borne diseases such as dengue fever and malaria. Caribbean countries are at greatest risk to dengue fever transmission. Shortages of fresh water and poor water quality during droughts, as well as contamination of water supplies during floods and storms will lead to increased risk of disease including cholera, diarrhoea, and dengue fever.
- The infrastructural base that supports the vital socio-economic sectors of island economies tends to occupy coastal locations which will be affected and sometimes destroyed as a result of sea-level rise and extreme events. The resulting disruption would impact other key dependent sectors and services including tourism, agriculture, the delivery of health care, freshwater, food security and market supplies.
- The process of globalization is forcing Small Islands to increase their dependence on sectors such as tourism (which is largely based on environmental assets). This not only makes them more vulnerable to the adverse consequences of climate change, but also increases their exposure to external shocks.
- Small Islands are sensitive to climate change and sea-level rise and can be considered an early warning to the rest of the world, because the adverse consequences of climate change are already a reality for many inhabitants of Small Islands.

Adaptation and sustainable development

- There is an urgent need to adapt to climate change, climate variability and sea-level rise, given that islands are already experiencing the adverse effects of these phenomena. The literature now provides wide support for the view that while various sectors will be affected in different ways, an appropriate adaptation framework for Small Islands may be one that seeks to enhance socio-economic and ecological resilience *in an integrated manner*, rather than one that applies a sectoral approach.
- Individuals, communities and governments of Small Islands have continually adapted to environmental variability and change in climate and sea conditions over a long period of time. This experience will be of value in dealing with the longer-term mean changes in climate and sea level. However, in many islands traditional mechanisms for coping with environmental hazards is being or has been lost.
- A serious dilemma confronting Small Islands is that while they must adapt to the consequences of climate change, their already low adaptive capacity is being further eroded by external factors such as globalization and internal changes of society.
- Adaptation measures should be conducive to sustainable development, even without the connection with climate change. The measures, which leads to the lessening of pressure on natural resources, improving environmental risk management and increasing the social well-being of the poor, not only reduces the vulnerability of developing countries to climate change, but also puts them on a solid path towards sustainable development.
- The assessment highlights the need for Governments to take urgent, practical action in mainstreaming climate change adaptation strategies and resilience building, into existing national development planning. Some islands countries may be able to achieve varying degrees of vulnerability reduction through the implementation of mechanisms (e.g. national physical development plans, disaster management plans, environmental action plans, biodiversity strategy and action plans) that are already being pursued.
- Finally, climate change will be a major impediment to the achievement of sustainable development in small islands, as all economic and social sectors are likely to be adversely

affected, and the cost of adaptation will be disproportionately high, relative to GDP. In attempting to mainstream adaptation strategies into their sustainable development agendas, small islands will be confronted by many challenges including insufficient resources, the possibility of internal conflict among groups related to equity considerations arising from the allocation of resources for adaptation and prioritization of adaptation measures, and uncertainties associated with choice of adaptation pathways.

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 economies, low adaptive capacity) that enhance their vulnerability and reduce their resilience to climate variability and change. Analysis of observational data showed a temperature increase of around 0.1°C per decade, while mean sea level rose by about 2 mm yr^{-1} although sea level trends are complicated by the El Niño Southern Oscillation (ENSO). The rate of increase in air temperature in the Pacific and Caribbean exceeded the global average of about 0.6^{o}C. 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.

Given their high vulnerability and low adaptive capacity, Small Islands have legitimate concerns about their future, based on observational records and climate model projections. Although emitting less than 1 percent of global greenhouse gases, Small Islands have already been forced to re-allocate scarce resources away from economic development and poverty alleviation, to the implementation of strategies to adapt to the growing threats posed by global warming. While some spatial variation within and among regions is expected, sea level is projected to rise at an average rate of about 4 mm yr^{-1} over the 21st century. The TAR concluded 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.

Given the sea level and temperature projections for the next 50–100 years coupled with anthropogenic stress, the coastal assets of small islands (e.g. corals, mangroves, sea grasses and reef fish), will be at greater risk. The natural resilience of coastal areas will be reduced, while the "costs" of adaptation would increase. Additionally, apart from unfavourable shifts in the biotic composition in islands, competition among some species is expected to be adversely affected. Moreover, anticipated land loss, soil salinization and low water availability, will threaten the sustainability of island agriculture.

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 were attributed partly to temperature and rainfall changes some linked to ENSO. The TAR also noted most settlements and infrastructure of small islands are located in coastal areas, which are highly vulnerable not only to sea-level rise 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 identified to be adversely affected by 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.

The TAR concluded that Small Islands should focus their efforts on resilience building, and implement appropriate adaptation measures as urgent priorities. Thus, integration of risk reduction strategies into key sectoral activities (e.g. sustainable development, 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 will assess the latest scientific information on vulnerability to climate change and se-level rise, adaptation to their effects, and implications of climate related policies including adaptation to sustainable development of Small Islands. We attempt to present the assessment results in a quantitative manner wherever possible, with near, middle, and far time frames in this century, though much of the Small Islands' literature is not precise about the time-scales involved in impact, vulnerability and adaptation studies. The present chapter deals not only with independent Small Island States but also with small islands in the continental and large archipelago countries, though the focus is still mainly on the Small Island States in the tropical and subtropical regions, a focus that very much reflects the emphasis in the literature..

16.2 Current sensitivity and vulnerability

16.2.1 Special characteristics of Small Islands

Small Islands are highly vulnerable to climate change and sea level rise (IPCC, 2001). By definition they comprise small land masses surrounded by large expanses of ocean, and are frequently located in regions highly prone to natural disasters, often of a hydrometeorological nature. Generally they host large populations with high growth rates and densities, many with poorly developed infrastructure and limited natural, human and economic resources, and most heavily dependent on marine resources to meet their people's daily protein needs. Most of their economies are exposed to, and influenced by, strong external forces, such as globalisation. These are some of the indicative characteristics that contribute to the special sensitivity and vulnerability of Small Islands to climate change and sea-level rise.

16.2.2 Climate and weather

The climates of Small Islands are both varied and varying, and differences in rainfall, rather than temperature, are of primary significance in defining the climatic regimes of Small Islands in low and mid-latitudes.

The climates of islands in the tropical Pacific are influenced by several contributing factors: trade wind regimes, paired Hadley cells and Walker circulation, seasonally varying Convergence Zones, semi-permanent subtropical high-pressure belts, and zonal westerlies to the south, with the El Niño Southern Oscillation (ENSO) as the dominating mode (Fitzharris, 2001; Folland *et al*., 2002; Griffiths *et al*., 2003). The Madden-Julian Oscillation (MJO) also is a major mode of variability of the tropical atmosphere-ocean system of the Pacific on times scales of 30 to 70 days (Revell, 2004), while the leading mode with decadal time-scale is the Interdecadal Pacific Oscillation (IPO) (Salinger *et al*., 2001). On longer time scales, a number of studies suggest the influence of global warming could be a major factor in changing the climate of the region (Hay *et al*., 2003; Folland *et al*., 2003).

Caribbean climate can be broadly characterised as dry winter and wet summer with orography and elevation being significant modifiers on the sub-regional scale. The dominant influence is the North

Atlantic subtropical High (NAH). During the 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 cold ocean and reduced atmospheric humidity, the region generally is at its driest during the winter. With the onset of spring, the NAH moves northward, the trade wind intensity decreases, and the southern flank of the NAH becomes convergent [refer to Chapter 11, IPCC WGI AR4 (in prep) for details].

Island climates in the Indian Ocean are dominated by the Asian monsoon, the most important feature being the seasonal alternation of atmospheric flow patterns which result in two distinct climatic regimes; the southwest or summer monsoon and the northeast or the winter monsoon, with clear association with ENSO events.

The climate of islands in the Mediterranean is dominated by influences from bordering lands [see Chapter 11, IPCC WGI AR4 (in prep) for details]. Commonly the islands receive most of their rainfall during the winter months and may go 4-5 months during the summer without having any precipitation. Temperatures are generally moderate with a comparatively small range of temperatures between the winter low and summer high.

16.2.3 Other stresses

Climate change and sea-level rise are not unique contributors to the extreme vulnerability of Small Islands. Other contributors include external pressures such as deteriorating terms of trade, impacts of globalisation, both positive and negative, financial crises and other 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). In Small Islands, most settlements, with the exception of some of the larger Melanesian and Caribbean Islands, are located in coastal locations, with the prime city or town also serving as the main port, international airport and centre of government activities. 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 and basic needs. While concentrations of population makes them more vulnerable to short term physical and biological hazards such as tropical cyclones and diseases, it also increases their vulnerability to climate change and sea-level rise.

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 current levels of rainfall input and extraction of groundwater such that demand is often outstripping supply. Moreover, pollution of water is often a major problem. 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 health effects on Small Islands (Ebi, *et al*., 2004).

It is virtually certain that 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 (e.g. ADB, 2004 for the case of the Pacific Islands). 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, analyses of coral reef surveys over three decades has revealed that coral cover right across reefs in the Caribbean has declined by 80 percent in just 30 years, largely as a result of continued pollution, sedimentation and over-fishing (Gardner *et al*., 2003). In the case of mangrove forests, the impact of sea-level rise will depend on the vertical accretion rate of sediments and on adequate space for horizontal migration inland by mangroves. Such features as infrastructure, roads, property boundaries and buildings will often limit the latter.

Globalisation is also a major stress. It has been argued that globalisation 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 the transformation of global capitalism (Pelling, *et al.*, 2001). Nevertheless, in the last few years the rate of change and ubiquitous nature of globalisation has increased, and the small island states have had to contend with new forms of non-territorial economic, political and social organisation such as multinational corporations, trans-national social movements, international regulatory agencies and global communications networks. In the present context, these factors take on a new relevance, as they may directly increase the vulnerability of Small Islands by reducing their resilience and adaptive capacity.

16.2.4 Current adaptation

Past studies of adaptation options for Small Islands have been 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 (IPCC, 2001) show that the costs of overall infrastructure and settlement protection is a significant proportion of GDP, and well beyond the financial means of most small island states, a problem not normally shared by the islands of metropolitan countries. 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 share of renewable energy in the energy supply, and optimized energy consumption. Proposed adaptation strategies have 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, 2005a; UNDP, 2005b).

16.3 Assumptions about future trends

16.3.1 Climate and sea-level change

16.3.3.1 Temperature and precipitation

Since the TAR, future climate change projections for Small Islands (e.g. Shea *et al.*, 2001; Hay *et al.*, 2003; Ruosteenoja *et al.*, 2003) have been updated. These analyses reaffirm previous IPCC projections that suggest a gradual warming of sea-surface temperature (SST) and a general warming trend in surface air temperature in all Small Islands' regions and seasons (IPCC, 2001).

Shea *et al*., (2001) suggested a general warming of about 1^{o}C across the tropical Pacific region over the next 20 to 45 years with the area of warming generally resembling a horseshoe-shaped pattern that is concentrated north and slightly south of the equator east of the dateline. The warming in the equatorial East Pacific is projected to be greater during a peak El Niño season.

Ruosteenoja *et al.*, (2003) study, using seven coupled atmosphere-ocean general circulation models (AOGCMs), the greenhouse gas and aerosol forcing being inferred from the IPCC SRES emission scenarios A1FI, A2, B1 and B2, projected changes in seasonal surface air temperature and precipitation for the three 30-year periods (2010-2039, 2040-2069 and 2070-2099) relative to the baseline period 1961-1990, for all the sub-continental scale regions of the world, including those of the Small Islands.

All seven models projected increased surface air temperature and precipitation for all regions of the Small Islands. The ranges of projected increase for each region are shown in Table 16.1 and 16.2. Ruosteenoja *et al.*, (2003) projected that increases fall within previous IPCC surface air temperature projection assessments, except for the Mediterranean Sea. Although the increases in surface air temperature are projected to be more or less uniform in both seasons, for the Mediterranean Sea, warming is projected to be greater during the summer than winter. Regarding precipitation, the range of projections is still large, and even the direction of change is not clear.

Table 16.1: *Projected increase in air temperature (°C) by region*

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

Table 16.2: *Projected change in precipitation (%) by region*

Regions	2010-2039	2040-2069	2070-2099
Mediterranean	-35.6 - 55.1	-52.6 - 38.3	-61.0 - 6.2
Caribbean	-14.2 - 13.7	-36.3 - 34.2	-49.3 - 28.9
Indian Ocean	-5.4 - 6.0	-6. 9 - 12.4	-9.8 - 14.7
Northern Pacific	-6.3 - 9.1	-19.2 - 21.3	-2.7 - 25.8
Southern Pacific	-3. 9 - 3.4	-8.23 - 6.7	-14.0 - 14.6

16.3.3.2 Sea levels

For Small Islands the level of the sea and its rate of change are of especial 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. Estimates of global sea-level rise of from 1-7 mm yr^{-1} provide a backdrop for regional variations and local differences dependent on several factors, including non-climate related factors such as island tectonic setting. For instance, Hay *et al.*, (2003) summarised regional mean future sea level projections for selected Pacific Island locations for 2020 to 2040 and 2080 to 2099, relative to the period 1961 to 1990 (See Figure 16.1).

16.3.3.3 Extreme events

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

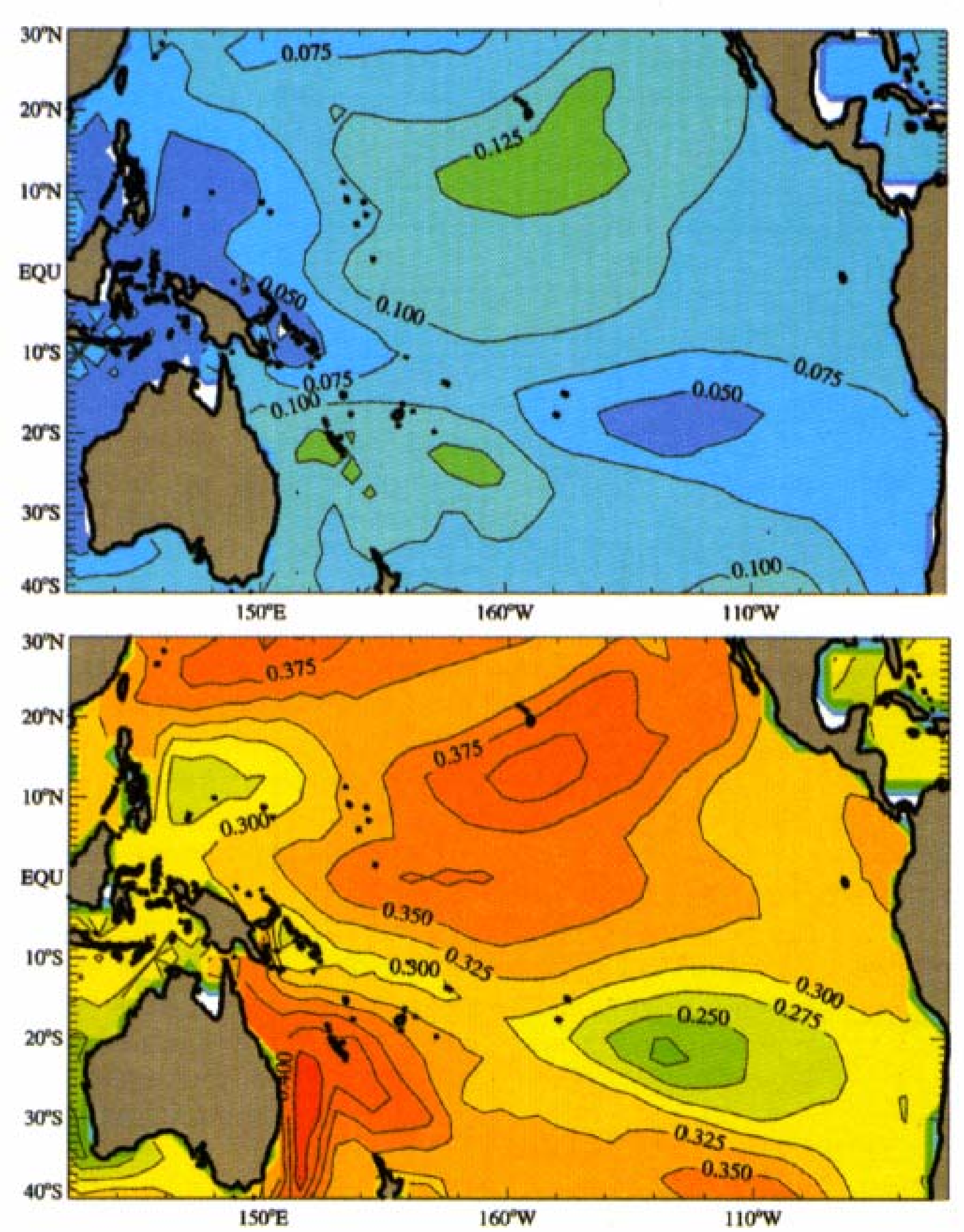


***Figure 16.1:** Projected changes in mean sea level (m) for 2020-2040 (upper) and 2080-2099 (lower), relative to 1961-1990 (Hay J.E. et al., 2003 produced after Shea et al., 2001)*

Recent analyses (e.g., Bradzil *et al*., 2002; Mason, 2004; Burgess, 2004) since the TAR reaffirm these findings. More recent climate modelling with improved resolutions have demonstrated the capability to diagnose the probability of occurrence of short-term extreme events under global warming [see Chapter 11, IPCC WG I AR 4 (in prep)].

Although there is not yet convincing evidence in the observed record of changes in tropical cyclone behaviour, it is likely that the maximum tropical cyclone intensities will increase 5 to 10 percent by around 2050 (Walsh, 2004). Under this scenario, peak precipitation rates are likely to increase by 25 percent in response to increases in maximum and mean tropical cyclone intensities. Although it is exceptionally unlikely there will be significant changes in regions of formation, the rate of formation is very likely to change in some regions. The behaviour of tropical cyclones also is strongly influenced by ENSO and other factors.

Recent calculation presented a more concrete estimate, using a 20 km-mesh, high-resolution global atmospheric model (Oouchi *et al.*, 2005). The tropical cyclone frequency observed in the warm-climate experiment is reduced by about 30 percent globally, compared to the present-day-climate experiment. However, it is likely that tropical cyclones will last longer in the warmer world and that the number of strong tropical cyclones increase. The maximum surface wind speed of the stronger tropical cyclones is likely to increase both in the Northern and Southern Hemispheres although this scenario depends on trajectories of future emissions and the response of the climate system [see Chapter 11, WGI AR4 (in prep)]. These suggest a likely possibility of higher risks of more persistent and devastating tropical cyclones in a future warmer climate.

16.3.2 Other relevant considerations

Populations on many Small Islands have long developed and maintained unique lifestyles, adapted to their natural environment. Traditional knowledge, practices, and cultures, were strongly based on community support networks and, in many islands, a subsistence economy was predominant. Societal changes such as population growth, increased cash economy, migration of people to urban centres, growth of major cities, and development of modern industries such as tourism have changed traditional lifestyles in many islands. Such changes, together with the gradual disintegration of traditional communities will continue to weaken traditional human support networks, which has been a major component of the resilience of local communities to adapt, in Pacific Islands. This tendency will continue under the increasing influence of a globalised world.

16.4 Key future impacts and vulnerabilities

The special characteristics of Small Islands described in Section 16.2.1 make them prone to a large range of potential impacts from climate change, some of which have been recently experienced. Sectors that are especially vulnerable are expanded upon below.

16.4.1 Water resources

Owing to factors of limited size, geology and topography, water resources in Small Islands are extremely vulnerable to changes and variations in climate, especially in rainfall (IPCC 2001). Burns (2002) has cautioned that with the rapid growth of tourism and service industries in many Small Islands, there is a need for both augmentation of the existing water resources, and more efficient management of those resources.

Small Islands tend to rely on three main natural sources of water; surface water (rivers, small lakes) rainwater and groundwater and many islands have access to only one source. Dominica in the Caribbean and Seychelles in the Indian Ocean, for example, are almost entirely dependent on surface water from ephemeral and perennial streams. Both countries experienced serious water shortages during the 1997/1998 El Niño (IPS, 2002). Rainwater collection from roofs is the primary source of freshwater in several countries in the Pacific, including Tuvalu and the northern atolls of the Cook

Islands (Taulima, 2002), while on Majuro in the Marshall Islands, runoff from the airport runway is also harvested. Groundwater is a major source of water on many low-lying coral islands such as the Maldives and raised atolls like Nauru, where the freshwater lens can vary in thickness and quality, dependent on the rates of extraction and recharge from rainfall (Falkland and Custodio, 1991).

This dependency on rainfall significantly increases the vulnerability of Small Islands to future changes and distribution of rainfall. Falkland (1999) projected that a 10 percent reduction in average rainfall by 2050 is likely to correspond to a 20 percent 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 percent (East-West Center, 2001). 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 percent would reduce the freshwater lens by 65 percent (Falkland, 1999). Increases in sea-level may also shift water tables close to, or above, the surface resulting in increased evapotranspiration thus diminishing the resource (Burns, 2000).

Low rainfall typically leads to a reduction in the amount of water than 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 droughts. 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 many of these islands would be exposed to severe water stress under all SRES scenarios, but more so under A2/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 low rainfall periods. On the other hand, during the rainy season lack of suitable land areas for dams (e.g. the Seychelles) and high runoff during storms (e.g. Fiji) result in significant loss of surface and stream water to the sea (SPREP, 1999).

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 1998-2000 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 percent during the dry periods, and export crops including sugar cane were also severely affected (East-West Center 2001). The situation was exacerbated due to 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). Furthermore, water supplies are threatened by aging and poorly installed infrastructure that results in water loss from about 40 to 50 percent in the Seychelles (PUC, 2004) to over 70 percent in some Pacific islands (SOPAC, 2001).

Access to safe, potable water varies across countries. There is very high 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 percent and 50 percent respectively, have access to safe water. Given the major investments needed to develop storage, provide treatment and distribution of water, it is evident that climate change would further decrease the ability of many islands to meet 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, Tuvalu and others, have invested in desalination plants (IPCC, 2001; SOPAC, 2001; Ibrahim *et al.* 2002). 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 data base that will be used for future adaptation plans. In the Cook Islands, for example, a useful index for estimating *drought intensity* was recently developed based on the analysis of more than 70 years of rainfall data. It is anticipated that the index 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 coasts 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 variation arising especially from sea-level rise, increases in sea surface temperature, and possible increases in the frequency and/or intensity of extreme weather events. Key impacts will almost certainly include accelerated coastal erosion, saline intrusion into freshwater lenses and increased flooding from the sea.

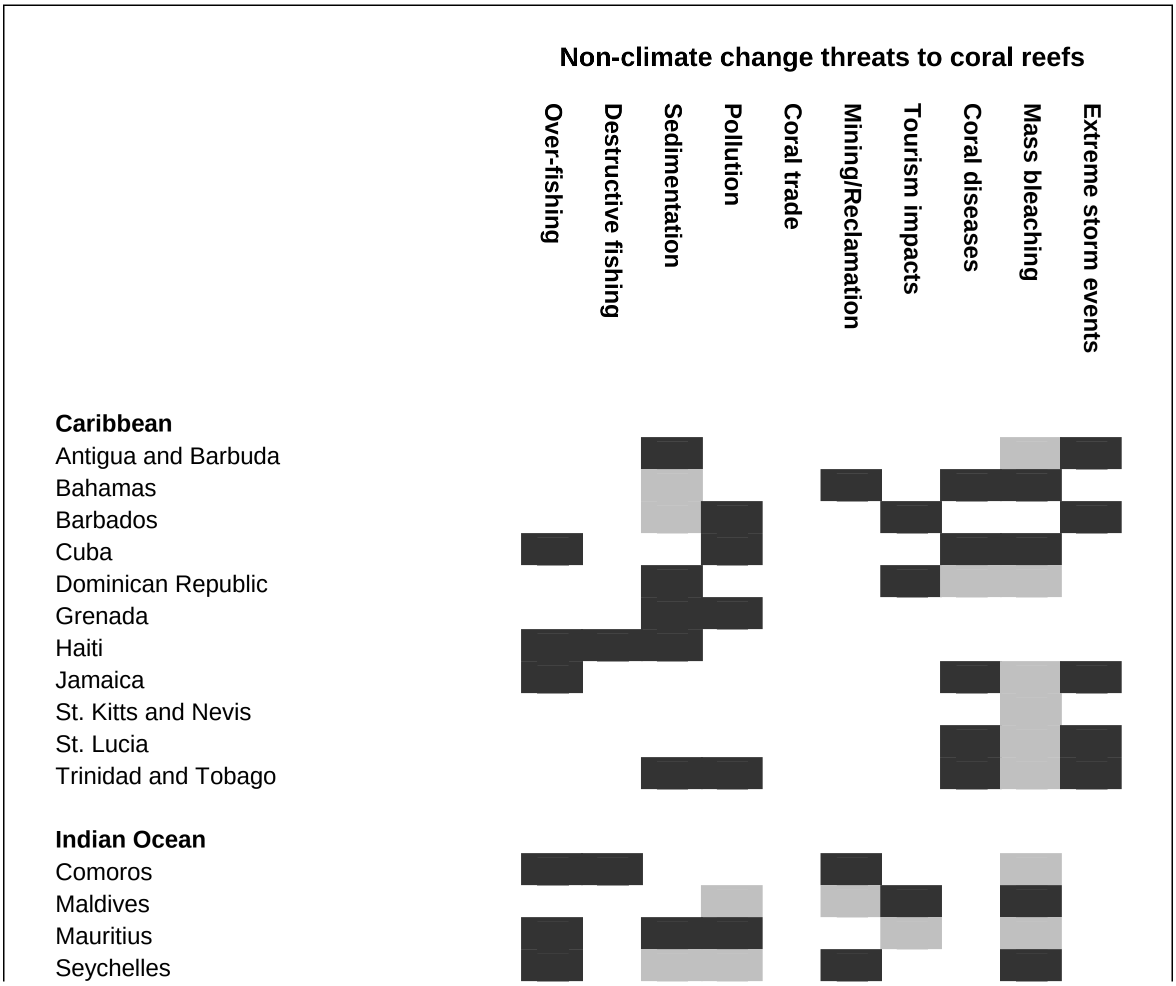
It has long been recognised that islands on coral atolls are especially vulnerable to this combination of impacts, and that the long-term viability of some atoll states has been questioned. Indeed, Barnett and Adger (2003) argue that the risk from climate–induced factors constitutes a dangerous level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

Predicting the future fate of atoll islands has been undertaken 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 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 that suggests 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.

On the topographically higher and geologically more complex islands such as in the Caribbean, beach erosion presents a particular hazard to coastal tourism facilities, which provide the main economic thrust for many small islands states in the region. *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 recommends data collection, analysis of coastal processes and assessment of impacts. Daniel and Abkowitz (2003, 2005) present the results of this effort which include 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.

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 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 Sheppard *et al.*, (2005) who show 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, which has resulted in increased coastal erosion. Further declines in reef health are expected to accelerate coastal recession.

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, increased turbidity, nutrients and chemical pollution, damage from tropical cyclones, and possible decreases in growth rates due to the effects of higher carbon dioxide concentrations on ocean chemistry. In addition to these primarily climate-driven factors, the impacts of which are detailed in the coastal chapter (See Chapter 6.2.1, this volume), are those associated mainly with human activity, which combine to subject island coral reefs to multiple stresses (See Figure 6.2)



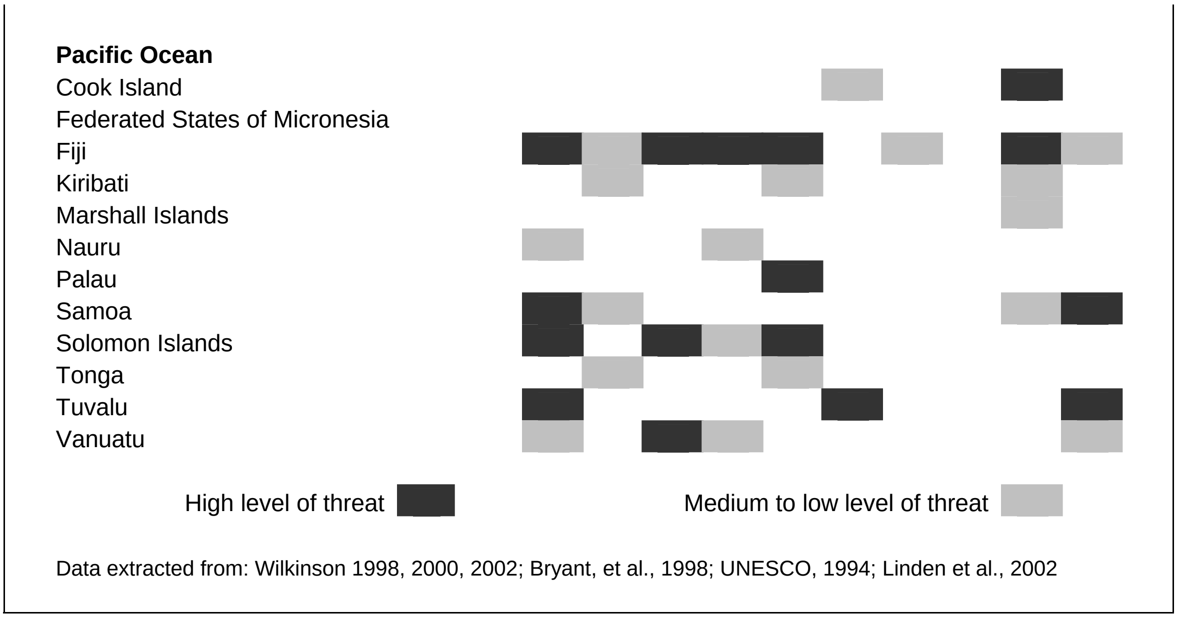


Figure 6.2: *Matrix showing the major non-climate change threats to coral reefs in selected small island states (after Payet, 2003)*

16.4.3 Agriculture, food and food security

Small Islands have traditionally depended upon subsistence and cash crops for survival and economic development. Whilst subsistence agriculture provides local food security, cash crops (such as sugar cane, banana, fish, tropical beverages and forest products) are exported to earn foreign exchange. In Mauritius, the sugar cane industry has provided economic growth and diversification of the economy into 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. Furthermore, many island states have also experienced decrease in GDP contributions from agriculture, partly due to the drop in competitiveness for cash crops, cheaper imports from larger countries, increased costs of maintaining soil fertility and competing uses for water resources, especially with 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 thousand years. The ecological dependency of Small Islands economies and societies is well recognized (ADB, 2004). A report by FAO's Commission on Genetic Resources found that countries' interdependence with regard to plant genetic resources, range from 91 percent in Comoros, 88 percent in Jamaica, 85 percent in Seychelles to 65 percent in Fiji, 59 percent for Bahamas and Vanuatu 37 percent (Ximena, 1998).

Projected impacts of climate change include extended periods of drought, and on the other hand, loss of soil fertility as result of increased precipitation, both of which will negatively impact on agriculture and food security. In the study on the economic and social implications of climate change and variability for selected Pacific Islands, World Bank(2000, 2002) found that in the absence of adaptation, a high island such as Viti Levu, Fiji, could experience damage of 23 million to 52 million USD per year by 2050, (equivalent to 2-3 percent of Fiji’s GDP in 2002). A group of low islands such as Tarawa, Kiribati, could face average annual damages of more than 8 million to 16 million USD a year (equivalent to 17-18 percent of Kiribati’s GDP in 2002).

Research in Guyana has shown that a shortening of the sugar cane growing season leads to an acceleration of maturation and reduced yields, which in turn result in a loss of the order of 29.8 percent when doubling CO_2 concentrations over 2020 to 2040 (Government of Guyana, 2002). In Ste Kitts and Nevis, it is suggested that climatic conditions by the second quarter of this century would be too dry for rain-fed agriculture, and that agricultural yields would be below economically viable level (Government of Ste Kitts and Nevis, 2002). In the Ste Vincent and Grenadines Islands, climate change may cause a 20 percent decrease in productivity with a decline in only precipitation (Government of St. Vincent and the Grenadines, 2000).

Extreme weather events, such as cyclones, freak storms, and droughts also cause irreparable damage to food crops. Extended drought conditions were recorded in Niue, which lasted for 18 months from July 1982 to December 1983. During this event, exports went down, and local cows were slaughtered for food and imports of farm produce increased. The drought also created conditions for leafhopper and aphid invasions on important export crops such as taro (Government of Niue, 2000).

Fisheries in the Small Islands are both for domestic use and commercial, and fish provide the most important local source of protein (IPCC, 2001). Fisheries contribute 9.9 percent of the GDP of the Maldives (MOHA, 2001), and many small island states have become large exporters of fish, especially tuna in the last 20 years. There is however some volatility in fish catch and price; for instance, the market price of tuna has gone from 2,000 USD per ton in 1995 to about 1,300 USD in 2001 due to an over supply.

Since fisheries contribute more than 10 percent of the GDP in many island states, the socio economic implications of impact on fishery will be significant. Variations in tuna catches are especially significant during El Niño and La Niña years. For example in Maldives, the El Niño years of 1972-73, 1976, 1982-83, 1987 and 1992-94, the skipjack catches decreased and yellow fin increased, whereas during the La Niña years skipjack tuna increased, whilst 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 (IPCC, 2001).

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

16.4.4 Biodiversity

Both terrestrial and marine plants and animals contribute to the high biodiversity of small islands, especially the high islands. The biodiversity of upland and coastal forests, including mangroves are threatened by both global change and local factors. More than a quarter of small island states have forest cover of less than 10 percent, as a result of encroachment from infrastructure development or agriculture. Many island states, for example Samoa, Trinidad and Tobago, Guinea Bissau, Comoros, Papua New Guinea and Haiti still rely on wood fuels to meet from 30 to 98 percent of their total energy needs – mostly for cooking purposes (FAO, 2002).

Cloud forest on islands forms at much lower elevations than those on the larger continents, since the water vapour content of air at the foot of the island mountain is expected to be much higher than that over the large continental mountain range. Cloud formations are usually between 100 and 500m, for example on Mahe (Seychelles) and Fiji, and this effect is thought to have led to high levels of endemism on specific islands or even specific upland regions (Raynor, 1995). Hence, observations of cloud forests on tropical Pacific islands might provide a link between changes in the hydrological cycle and the distribution of those endemic species, and thus provide an early warning system of climate changes over island forest ecosystems (Foster, 2001). Furthermore results of GCMs driven by sea surface temperature (SST) increases already suggest a decrease in low-level cloudiness upon SST warming (Foster, 2001).

Increases in extreme events in the short term will severely affect adaptation responses on Small Islands as forests are usually slow growing and regeneration is expected to be slow. In view of their small area, forests on island states can be easily decimated by violent cyclones or freak storms. Samoa lost 92 percent of its plantation estate in 1990 as a result of cyclones Ofa and Val (FAO, 1997), and by 1995 only a few percent had grown back. It is estimated that cyclone Val caused over 300 million USD in damages (Hay *et al*., 2003). In 2001, a storm in Seychelles resulted in the loss of over 1,000 endemic palms and paralysed the tourism industry for several days, and to this date scars of the devastation is still evident (UNEP, 2002).

16.4.5 Human settlements and well-being

The concentration of large settlements along with consequential 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 the sand terrace or on the beach itself, and in the Caribbean more than half of the population lives within 1.5 km of the shoreline. In many small islands such as the north coast of Jamaica and the west and south coasts of Barbados, continuous corridors of development now occupy practically all of the prime coastal lands. Such land is also occupied by a range of other settlements, such as fishing villages, and on many small islands government buildings and important facilities such as hospitals are frequently located close to the shore. Moreover, population growth and inward migration of people is putting additional pressure on coastal settlements, utilities and resources and creating a series of problems in terms of 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 settlements. On the other hand, rural and inland settlements and communities are more likely to be adversely affected by negative impacts upon agriculture, given that they are often directly dependent upon crop production for their nutritional requirements.

An important consideration in relation to settlements is housing. In many parts of the Pacific traditional housing styles, techniques and materials ensured they were resistant to damage or could be repaired quickly. Moves away from traditional housing have increased vulnerability to thermal stress, and in some countries increased use of air conditioning (Hay *et al*., 2003).

There is little doubt that human wellbeing 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, mostly in adverse ways (Hay *et al*., 2003).

Singh *et al.,* (2001) showed that, in the Pacific islands, there was a positive association between annual average temperature and the rate of diarrhoea, and a negative association between water availability and diarrhoea. Their second, more detailed investigation in Fiji, also showed positive associations between diarrhoea and temperature, as well as between diarrhoea incidence and extreme rainfall. These results confirmed other studies that indicate global climate change is likely to exacerbate diarrhoea illness in many Pacific countries.

Climate change is also likely to result in an increase in the incidence of vector-borne diseases such as dengue fever and malaria. The various mosquitoes that transmit these diseases, as well as other environmental factors in disease transmission, are clearly influenced by climate. In the small island Pacific, malaria is generally limited to the Melanesian islands, while dengue fever is more widespread in the Pacific as well as elsewhere. In the Caribbean, a retrospective review of dengue fever cases (1980-2002) was carried out in relation to ENSO events (Rawlins *et al.,* (2005). This showed there were greater occurrences of dengue fever in the warmer dryer period of the first and second years of El Niño events, though there was no evidence of the impact of temperature increases. Normally, however, it is in the wet season that Caribbean countries are at greatest risk to dengue fever transmission, suggesting that vector mitigation programs should be targeted at this time of year to reduce mosquito production and dengue fever transmission (Rawlins *et al.*, 2005).

While shortages of fresh water and poor water quality during periods of drought, as well as contamination of fresh water supplies during floods and storms appear to lead to an increased risk of disease including cholera, diarrhoea, and dengue fever, ciguatera fish poisoning is common in marine waters, especially reefal waters. Although multiple factors contribute to c outbreaks of ciguatera poisoning, including pollution, and other forms of reef degradation, warmer sea surface temperatures during El Niño events have also been linked to 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 elaborated in several reports (Atkins *et al*., 2000; Grynberg & Remy, 2004; Briguglio and Cordina, 2004; ADB, 2004). Small economies are generally more exposed to external shocks, such as social conflict, extreme events, and climate change than larger countries, because many of them rely on one or few economic activities such as tourism or fisheries, and most of these are located within small coastal areas. Recent wars in the Gulf region have for example affected tourism arrivals in the Maldives and the Seychelles. In the Caribbean, hurricanes (ECLAC, 2002; OECS 2004) caused many deaths and economic losses running into billions of dollars, often exceeding 100 percent of the country's GDP.

As TAR already mentioned, tourism is a major economic sector in many small islands, and this tendency is increasing. Since their economies depend so highly on tourism, the impacts of climate change on the tourism resources will have significant effects, both directly and indirectly, on them. Sea-level rise and increased sea water temperature will cause accelerated beach erosion, degradation of coral reefs including bleaching, loss of cultural heritages on the coasts by inundation and flooding, which in turn reduce attraction for coastal tourism. Shortage of water and increased danger of vector-born diseases may steer tourists from small islands, while wormer climate in the northern countries also reduce the number of people who want to visit small islands in the tropical and subtropical regions. Thus, in many ways, climate change and sea-level rise has significant effects on the tourism industry in small islands.

Furthermore Small Islands have several disadvantages from an economic and fiscal perspective like small economies of scale, small markets, and small human resource base. In fact in many island states many import competing businesses survive due to a combination of trade protection, subsidies and large resource rents.

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, such as closure of roads, airports and bridges due to flooding and landslides, 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, freshwater, food security and market supplies.

Almost without exception, every international airport in the Small Islands of Indian Ocean, Pacific and Caribbean is sited within a few km of the coast, and on tiny coral islands. The main - and often only - road network runs along the coast. Lal (2004) indicates that since 1950, mean sea level has risen at a rate of approximately 3.5 mm per year in the region of the island nations of the South Pacific, and projects a rise of 25-58 cm by the middle of the current 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 states of the Indian Ocean and the Caribbean and countries such as Malta and Singapore are likely to be confronted by similar threats.

The threat from sea-level rise to infrastructure in these small islands could be amplified considerably with 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 1/50 year cyclone (Hay *et al*., 2003). In the Caribbean, the damage to coastal infrastructure from storm surge alone can be quite severe. In November 1999, surge damage in St. Lucia associated with Hurricane Lenny was in excess of 6.0 million USD, even though the system was many kilometres offshore. 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 one decade, by this single event that lasted for only a few hours (See Box 16.1).

Box 16.1: Grenada and Hurricane Ivan

Ivan struck Grenada on September 7, 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 persons killed
- Overall damages calculated at EC$ 2.2 billion, or twice the current GDP
- 90 per cent of housing stock damaged totalling EC$ 1,381 million, or 38 percent GDP
- 90 per cent of guest rooms in tourism sector damaged or destroyed, totalling EC$ 288 million, or 29 percent of GDP
- Losses in telecommunications – 13 percent of GDP
- Damage to schools and education infrastructure - 20 percent of GDP
- Losses in agricultural sector equivalent to 10 percent of GDP. The two main crops, nutmeg and cocoa which have long gestation periods, will make no contribution to GDP or earn foreign exchange for the next 10 years.

- Damage to electricity installations totalling 9 percent of GDP
- Heavy damage to eco-tourism and cultural heritage sites, resulting in 60 percent job losses in the sub-sector
- Prior to Hurricane Ivan, Grenada was on course to experience an economic growth rate of approximately 5.7 percent, but negative growth of around -1.4 percent is now forecast.

(Source: OECS, 2004)

16. 5 Adaptation: practices, options and constraints

It is clear from the foregoing that small island states are presently subjected to a range of climatic and oceanic impacts, and that these impacts will be exacerbated by on-going 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: (1) the degree of exposure to climate change; (2) their limited capacity to adapt to projected impacts; (3) the fact that adaptation to climate change is not a high priority given more pressing problems that they have to face; and (4) the uncertainty associated with global climate change projections and their local validity (Nurse *et al.*, 2001). The last acts as an obstacle to implementing anticipatory adaptation strategies. 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 concentrate on sectoral adaptation, a theme that is expanded upon in section 16.5.4. Inhabitants of Small Islands, individuals, communities and governments, have continually adapted to inter-annual 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 the inter-annual variability in climate and sea conditions that will accompany the longer-term mean changes in climate and sea level. Certainly in the Pacific Islands, at least in Polynesia, Melanesia and Micronesia, the socio-ecological systems have historically been able to adapt to environmental change (Barnett, 2001). However, it is also true that in many islands traditional mechanisms for coping with environmental hazards is being or has been lost, though paradoxically the value of such mechanisms is being increasingly recognised in the context of adaptation to climate change (e.g. MESD, 1999; Nunn and Mimura, 2005).

Mossler (1996) makes two similar points in suggesting that small island states, often with limited financial, natural and human resources, must: (1) alter their perception of hazards and disasters to move beyond superficial preparedness and costly response and recovery; and (2) make “a particular commitment to efficient, effective vulnerability reduction and increased harmony with dynamic insular environments.”

16.5.1 Adaptation in dynamic insular environments

One group of natural ‘dynamic insular environments’ comprise the tropical rainforests and savannahs 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, 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 high biodiversity 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 well known, though it is less clear how these impacts will be able to be separated from future human activities. 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' or 'spontaneous' adaptation, that is triggered by changes in climatic stimuli, can take place. For instance, corals may be able to adapt to higher sea-surface and air temperatures by hosting more temperature-tolerant algae. They can also grow upwards with the rise in sea level, providing 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 there is horizontal accommodation space, and they are not constrained by the presence of infrastructure and buildings, that is by 'coastal squeeze' (Alongi, 2002).

The natural adaptation of ecosystems is rarely considered in most island states, where attention has been mostly focussed on protecting those ecosystems that are projected to suffer as a consequence of climate change and sea-level rise, and on rehabilitating degraded or destroyed ecosystems that have resulted from socio-economic developments. But, "while development has a strong tendency to undermine ecosystem resilience" Barnett (2001) has observed that "the wealth it confers [on small island states] paradoxically tends to enhance resilience, particularly when it is equitable and when it leads to enrichment of the states."

16.5.2 Adaptation options, priorities and their spatial variations

Since the TAR there have been a number of National Communications to the UNFCCC from small island states that have assessed their vulnerability to climate change and in-country adaptation strategies. These communications give an insight into the concern 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 autonomous/spontaneous and reactive, and that adaptation has been centred on responses to the effects of climate extremes. Moreover, the range of measures considered, and the priority they are assigned, appear closely linked to either the country's key socio-economic sectors, key environmental concerns, 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, while agriculture and human health figure prominently in communications from the Comores (GDE, 2002), Vanuatu (1999), and St. Vincent and the Grenadines (NEAB, 2000). In these instances, sea-level rise is not seen as a critical issue, as it is in the low-lying atoll states such as Kiribati, Tuvalu, Marshall Islands and the Maldives (See Box 16.2). On the other hand all National Communications emphasise the urgency for adaptation action.

Such urgency, over a broad spectrum of sectors, 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 should be employed. Since then a number of projects on adaptation in several small island states and regions have adopted this suggestion Generally, projects aim to build capacities of individuals, communities and governments so that they are able to make informed decisions about adaptation to climate change and to enhance their adaptive capacity in the long run (See Box 16.3)

In spite of differences in emphasis and sectoral priorities, there are two common themes. First, fresh water is seen as a critical issue in all small island states, both in terms of water quality and quantity. Clearly, water is a multi-sectoral resource that impinges on all facets of life and livelihood including security. It is a problem at present and one that will increase in the future. Second, many small island states, including all of the Least Developed States, see the need for more integrated planning and management, be that related to water resources, tourism, health or coastal zone management.

Box 16.2: Adaptive measures in The Maldives

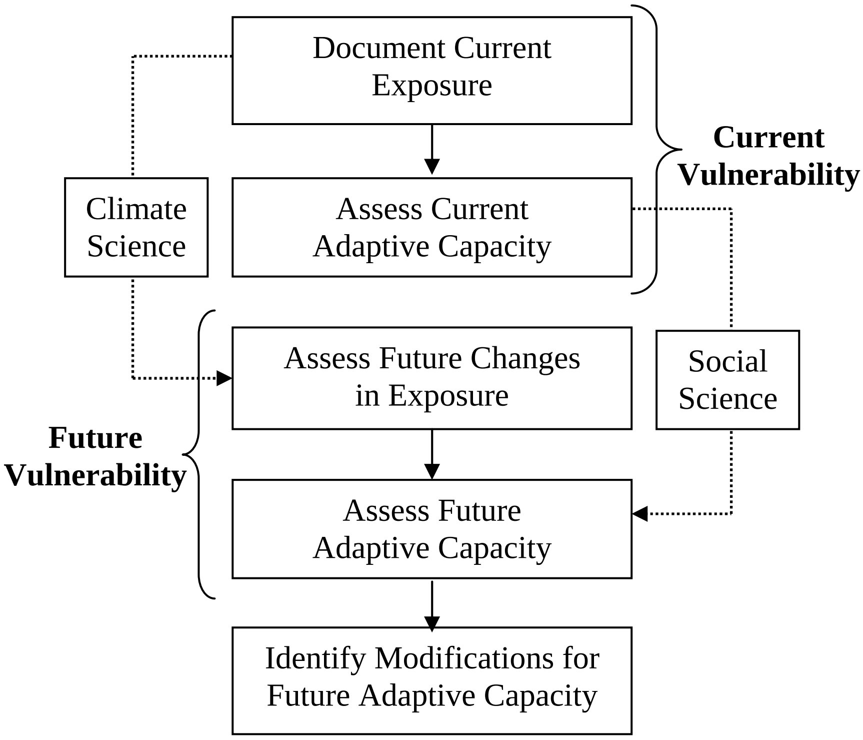
Adaptation options in low-lying islands of the Maldives, which have been identified as especially vulnerable, are limited and response measures to climate change or its adverse impacts are potentially very costly. In the Maldives adaptation covers two main themes: (1) Physical adaptive measures targeted at the sectors that are regarded as the most vulnerable; and, (2) the necessity of enhancing the capacity of the Maldives to adapt to climate change and sea-level rise.

Vulnerable area	Adaptation response
Land loss and beach erosion	Coastal protection
	Population consolidation i.e. reduction in number of inhabited islands
	Ban coral mining
Infrastructure and settlement damage	Protection of international airport
	Upgrading existing airports
	Increase elevation in future
Damage to coral reefs	Reduction of human impacts on coral reefs
	Assigning protective status to 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, vegetable and other foods
	Hydroponic system
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	Human resource development
	Institutional strengthening
	Research and systematic observation
	Public awareness and education

Source: MOHA (2001)

Box 16.3: CAPACITY BUILDING FOR THE DEVELOPMENT OF ADAPTATION MEASURES IN SMALL ISLANDS: A Pacific Island Approach

Capacity-building for development of adaptation measures in Pacific island countries uses a Community Vulnerability and Adaptation Assessment and Action approach, which is participatory, aims to better understand the nature of community vulnerability, and identifies opportunities for strengthening the adaptive capacity of communities. It promotes a combination of bottom-up and top-down approaches to implementation, and supports the engagement of local stakeholders at each stage of the assessment process. This enables integration or 'mainstreaming' of adaptation into national development planning and local decision-making processes. The main steps are outlined below.



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

Adopted from Sutherland *et al.* (2005)

16.5.3 Constraints to adaptation

Underlying this last need is a common constraint confronting most small island states; the lack of in-country adaptive capacity. There are at least two areas where resources are inadequate: financial and human. In most island states the cost of adopting and implementing adaptation options will be prohibitive, and will call on financial resources that are generally not available to government. Similarly, there are inadequate human resources available at present to accommodate, cope with or benefit from the effects of climate change. To overcome this deficiency the adaptive capacity of small island states will need to be built up in four important areas: human resource development, institutional strengthening, research and systematic observation, and public awareness and education.

An extreme example of these needs is Timor Leste (East Timor) which is generally 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 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".

16.5.4 Building resilience through adaptation

This last theme is also developed by Pelling and Uitto (2001) who suggested that change at the global level is found to be a source of new opportunities, as well as constraints, on building local resilience to natural disaster. They argue that small island populations have been mobile both historically, and at present, and that remittances from overseas relatives help moderate economic risk and increase family resiliency on home islands. They also recognise that this is a critical time for Small Islands, which must contend with ongoing developmental pressures, in addition to growing pressures from risks associated with climate change and sea-level rise and economic liberalisation that threaten the physical and economic security of islands. 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 to be seen as separate and largely engineering or land-use planning based realms (Pelling and Uitto(2001).

Many small island societies have proved resilient in the past to social and environmental upheaval (Barnett, 2001). The key parameters of this resilience include, in addition to 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 being undermined as the small island states become increasingly integrated into the world economy, through for example, negotiations for fishery rights in the EEZ 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 small island states to achieve an appropriate degree of sustainability, which is one of the goals of adaptation to climate change. Indeed, for the most vulnerable small island states, Barnett and Adger (2003) suggest that 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. In fact, they go further and argue that from a social science perspective this risk constitutes a 'dangerous' level of climatic change that may well undermine their national sovereignty (See Box 16.4).

Box 16.4: 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)

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 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, Hoffman (2002) has shown that the implementation of traditional marine social institutions, as exemplified in *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 has also occurred in Kiribati (Thomas, 2001).

The utility of traditional knowledge and practices can also be expanded to link with, not only biodiversity conservation, but also 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 indicate that the traditional knowledge, management frameworks and skills are important as components of adaptive capacity in Small Islands.

In terms of integrating risk management and adaptation, a number of areas is outlined, where such integration can occur in the Caribbean, including land use planning; development and field testing of climate change adaptation planning frameworks; sharing of best practices and guidelines; consideration of climate change concerns/risks at the planning phase of investment and development projects; and implementation of adaptation demonstration projects. Risk management implies actions that include insurance to meet the specific needs and concerns of developing countries with respect to adverse effects of climate change, especially on small island developing state (FIELD, 2003).

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 funding of adaptation. Thus, 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 the climate change adaptation and poverty reduction strategies remain underdeveloped. Adger *et al*. (2003) stated 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." The greatest impacts of climate change are likely to be faced by small island populations, who also 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 have been highlighted in various studies (e.g. Huq and Reid, 2004; Hay *et al.*, 2003; Munasinghe, 2003; IUCN, IISD, SEI-B, 2004). These linkages are likely to be highly relevant to Small Islands.

There has, however, been many individual studies on low-lying small island states that highlight climate change as one of the most important challenges to the sustainable development of these states. Majeed and Abdulla (2004) argue that sea-level rise would seriously damage the fishing and the tourism industries of the Maldives, which account for more than 40 percent of the islands state's GDP.

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 pose particularly serious future challenges to improving the life for the population of small island developing states (SIDS). Based on these arguments, Ronneberg proposes a number of innovative solutions which could promote the sustainable development of small island developing states and at the same time strengthen the resilience of SIDS against climate change.

The sustainable development of islands which are not low-lying, is also likely to be impacted by climate change. Briguglio and Cordina (2002) have shown that the climate change impacts on the economic development of Malta, which is not a low-lying island, are likely to be widespread, affecting all sectors of the economy, but particularly tourism, fishing and public utilities.

Sperling (2003) 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 put forward by Hay *et al*., (2003), in the context of the Pacific small island states, as follows: "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, not only reduces the vulnerability of developing countries to climate change, but also puts them on a solid 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) 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.

Many small islands states have considerable experience in taking measures against climate variability. In the case of Cyprus, Tsiourtis (2002) explains that Cyprus has in the past 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, since time immemorial, has led to individual persons and administrations to take measures associated with retreat, accommodation and protection strategies. For example, residential settlements in Malta are generally situated away from low-lying coastal areas, and very primitive settlements on the island tended to be located in elevated places. Maltese houses are built of sturdy material, 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 a considerable experience in adaptation to climate variability.

However, there could be difficulties for Small Islands to mainstream climate change into their sustainable development strategies. The main problem in the case of many small islands, is that they have very limited resources, especially given the indivisibilities involved in adaptation measures, especially in infrastructural projects. Another problem relates to possible social conflicts. Agrawala *et al.*, (2003), for example, explain that in Fiji, the conservation of mangroves for climate change adaptation purposes is not without distributive costs, given that the creation of mangrove land could occur at the expense of land used agricultural, tourism and settlements purposes. In addition, given the existing land tenure system, such changes could also create cultural conflicts. The groups that benefit from mangrove destruction and conservation could therefore be different. Akasaka (2004) refers to the development choices and pathways connected with climate change. Decisions about energy choices, transportation infrastructure and land-use, will critically affect future greenhouse gas emissions, and thereby the rate and magnitude of climate change. Climate change, in turn, poses additional impacts on natural and socio-economic systems which are already subject to natural climate fluctuations such as El Niño which cause widespread disruptions in society's ability to harness natural resources or even survive.

16.7 Key uncertainty and research gaps

Based on the present assessment, the following key uncertainties and research gaps have been identified for Small Islands.

1. Observation and Climate Change Science

- Small Islands are sensitive to climate change and sea-level rise and can be considered an early warning to the rest of the world, because the adverse consequences of climate change are already a reality for many inhabitants of Small Islands. Therefore, observation of impacts should be continued to detect the sign of an early warning.

- Though the future prediction for mean air temperature is rather consistent among climate models, predictions for changes in precipitation, tropical cyclones and sea level is still uncertain, which is critical for Small Islands. Furthermore, advanced models with higher resolution are needed to set reliable climate scenarios for Small Islands.

- Supporting efforts by Small Islands to arrest the decline of observational networks and expand observational networks should be continued.

2. Impacts and Adaptation

- As future changes in socio-economic conditions have not been well presented for Small Islands in the existing assessments(e.g., IPCC, 2001; UNEP, 2002; Millennium Ecosystem Assessment, 2003), it is necessary to develop scenarios appropriate for Small Islands for complete assessment of impacts of climate change on them.

- Methods to project exposures to climate stimuli and other 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, at the local, country and regional level.

- Local capacity should be strengthened for environmental assessment and management, modelling, sustainable economic and social development, equity and institutional analysis which are related to climate change, adaptation and mitigation in Small Islands.

- All climate change scenarios will require Small Islands to implement adaptation strategies due to the unprecedented magnitude of the potential impacts. Responses to climate change and sea-level rise could be coordinated with mainstream policies of socioeconomic development and environmental conservation to facilitate sustainable development**.**

- Natural and human-use systems in Small Islands will continue to face pressures that are not climate related, including population growth, limited carrying capacity and resources, social change and economic transformation. Therefore, integrated approaches toward sustainable development in which multiple stresses and enhancement of resilience are taken into consideration, should be pursued.

3. Mitigation

- Adaptive measures may be integrated with mitigation in the context of sustainable development. The related subjects are:
    1. Continued development of climate friendly and environmentally sound energy services for Small Islands;
    2. Further development of community based initiatives to promote the transfer and implementation of ‘no regrets’ mitigation projects in Small Islands;
    3. Investigate the feasibility and merits of various mitigation mechanisms such as those of Clean Development Mechanism (CDM) as well as assessing the economic impacts of mitigation policies and measures on Small Islands economies.

References

Adger, N., Mace, M.J., Paavola, J., and Razzaque, J., 2003: Justice and equity in adaptation. *Tiempo* 52, 19-22.

Alongi, D.M., 2002: Present state and future of the world's mangrove forests. *Environmental Conservation*, 29 (3) 331-349.

Agrawala, S., T. Ota, J. Risbey, M. Hagenstad, J. Smith, M. van Aalst, K. Koshy and B. Prasad., 2003: *Development and Climate Change in Fiji: Focus on Coastal Mangroves*: OECD

Akasaka, K., 2004: *Global Forum on Sustainable Development: Development and Climate Change* (Conclusions of the Chair). OECD.

Arnell, N.W., 2004: Climate change and global water resources: SRES emissions and socio-economic scenarios. *Global Environmental Change*, 14, 31-52.

Asian Development Bank (ADB), 2004: Pacific Regional Environmental Strategy, 2005-2009, ADB Manila, Philippines, 105 pp.

Aswani, S. and R.J. Hamilton, 2004: Integrating indigenous ecological knowledge and customary sea tenure with marine and social science for conservation of the bumphead parrotfish (*Bolbometopon muricatum*) in Roviana Lagoon, Solomon Islands. *Environmental Conservation*, 31 (1) 69-86.

Atkins, J., Mazzi, S., & Easter, C. 2000 Commonwealth Vulnerability Index for Developing Countries: The Position of Small States. Economic Paper, No. 40. Commonwealth Secretariat, London

Barnett, J., 2001: Adapting to climate change in Pacific Island Countries: The problem of uncertainty. *World Development*, 29, 977-993.

Barnett, J., and W.N. Adger, 2003: Climate dangers and atoll countries. *Climatic Change*, 61, 321-337.

Barnett, J., S. Dessai, and R. Jones, 2003: Climate Change in Timor Lest: Science, Impacts, Policy and Planning, University of Melbourne-CSIRO, 40 pp.

Brazdil, R., T. Carter, B. Garaganga, A. Henderson-Sellers, P. Jones, T. Carl, T. Knustson, R.K. Kolli, M. Manton, L.J. Mata, L. Mearns, G. Meehl, N. Nicholls, L. Pericchi, T. Peterson, C. Price, C. Senior, Q.C. Zeng, and F. Zwiers, 2002: IPCC Workshop on changes in extreme weather and climate events, Workshop Report, Beijing, China, 11-13 July, 2002, 41- 42. Accessed 15.11.2004 at http://www.ipcc.ch/pub/extremes.pdf

Briguglio, L. 2000: Implications of Accelerated Sea-Level Rise (ASLR) for Malta In *Proceeding of SURVAS Expert Workshop on European Vulnerability and Adaptation to impacts of Accelerated Sea-Level Rise (ASLR)*, Hamburg, Germany.

Briguglio, L. and Cordina, G., 2002: The Economic Vulnerability and Potential for Adaptation of the Maltese Islands to Climate Change, In Proceedings of the International Symposium on Climate Change, ISCC, China.

Briguglio, L. and Cordina, G., (eds), 2004: *Economic Vulnerability and Resilience of Small States.* Commonwealth Secretariat and the University of Malta.

Buddemeier, R.W., J. A. Kleypas and R.B. Aronson, 2004: *Coral Reefs and Global Change.* Pew Center on Global Climate Change, Arlington, VA., 44 pp.

Burgess, S., 2004: Southwest Pacific Tropical Cyclones Summary for 2003/04 Season. The Island Climate Update, 45, 4 pp. Retrieved 12.11.2004 from http://www.niwa.co.nz/ncc/icu/2004-06/

Burns, W.C.G., 2000: The impact of climate change on Pacific island developing countries in the 21st century. In *Climate Change in the South Pacific: Impacts and Responses in Australia, New Zealand, and Small Island States*. A. Gillespie and W.C.G. Burns (eds.), Kluwer Academic, Dordrecht, pp. 233-251.

Burns, W.C.G., 2002: Pacific island developing country water resources and climate change. In *The World's Water (3rd Edition)*. P. Gleick (ed), pp. 113-132, (also available from website http://www.internationalwildlifelaw.org/BurnsChapterPDF.pdf).

Cowell, P.J. and Kench, P.S., 2001. The morphological response of atoll islands to sea level rise. Part 1: modifications to the modified shoreface translation model. *Journal of Coastal Research*, 34: 633-644.

Daniel, E.B., and Abkowitz, M.D., 2003. Development of beach analysis tools for Caribbean small islands. *Coastal Management*, 31, 255-275.

Daniel, E.B., and Abkowitz, M.D., 2005. Predicting storm-induced beach erosion in Caribbean small islands. *Coastal Management*, 33, 53-69.

Dickinson, W.R., 1999. Holocene sea-level record on Funafuti and potential impact of global warming on central Pacific atolls. *Quaternary Research*, 51, 124-132.

East-West Center, 2001: *Pacific Island Regional Assessment of the Consequences of Climate Variability and Change*. East-West Center, Honolulu, Hawaii, Chapter 2, p. 27.

Ebi, K.L., N.D. Lewis, J. Patz, and C. Corvalan, 2004: *Climate Variability and Change and their Health Effects on Small Island States: Information for Adaptation Planning in the Health Sector*, Report on Regional Workshops and Conference Convened by WHO, WMO and UNEP, 2000-2003.

ECLAC, 2002: Global Economic developments 2000-2001 LC/CAR/G.683.

Falkland, A., 1999: Impacts of climate change on water resources of Pacific islands. *PACCLIM Workshop, Modelling the Effects of Climate Change and Sea Level Rise in Pacific Island Countries*. Auckland, New Zealand, p. 2.

Falkland, A., and E. Custodio, 1991: Hydrology and water resources of Small Islands: A practical guide. UNESCO contribution to the International Hydrological Programme.

Falkland, T., M. Overmars, and D. Scott, 2002: *Pacific Dialogue on Water and Climate Synthesis Report*. South Pacific Applied Geoscience Commission (SOPAC).

FAO, 1997: Regional Study - The South Pacific. Asia-Pacific Forestry Sector Outlook Study. Working Paper No. APFSOS/WP/01.

FAO, 2002: *Forests and forestry in Small Island Developing States* By Wilkie M.L., Eckelmann C. M., Laverdière M. and A. Mathias. Forest Management Working Papers, Working Paper FM 22. Forest Resources Development Service, Forest Resources Division. FAO, Rome (*unpublished*).

FAO, 2004: FAO and SIDS: Challenges and emerging issues in agriculture, forestry and fisheries. Paper prepared by the Food and Agriculture Organisation (FAO) on the occasion of the inter-regional conference on small island developing states (SIDS), Bahamas 26-30 January 2004, Bahamas. Rome.

FIELD, 2003: Climate change adaptation, risk management, and insurance in small island State context, UNDP-FIELD Brainstorming workshop, Milano, Italy.

Fitzharris, B., 2001: Global energy and climate processes. In: *The Physical Environment. A New Zealand Perspective*. A. Sturman and R. Spronken-Smith (eds.), Oxford University Press, Victoria, Australia, 537pp.

Folland, C.K., J.A. Renwick, M.J. Salinger, N. Jiang, and N.A. Rayner, 2003: Trends and variations in South Pacific Islands and ocean surface temperatures. *J. Climate*., 16, 2859-2874.

Folland, C.K., J.A. Renwick, M.J. Salinger, and A.B. Mullan, 2002: Relative influences of the Interdecadal Pacific Oscillation and ENSO on the South Pacific Convergence Zone. *Geophy. Res. Let.*, 29, 21-1-21-4.

Foster, P. 2001 The potential negative impacts of global climate change on tropical mountain cloud forests. Earth-Science Reviews 55: 73–106

Gardner, T.A., I. Cote, G. Gill, A. Grant, and A. Watkinson, 2003: Long-term region-wide declines in Caribbean corals. *Science*, 301, 958-960.

GDE (General Directorate of Environment, Comoros), 2002: *Initial National Communication on Climate Change, Union des Comoros*, Ministry of Development, Infrastructure, Post and

Telecommunications and International Transports, Union des Comoros, 11 pp.
Government of Guyana, 2002: Guyana Initial Communication to the UNFCCC.
Government of Mauritius, 2002: *Meeting the Challenges of Sustainable Development*. Ministry of Environment, Republic of Mauritius.
Government of St. Kits and Nevis 2000: *Ste Kitts and Nevis Initial National Communication to the UNFCC*.
Government of St. Vincent and the Grenadines, 2000: *Initial National Communication on Climate Change*.
Government of Niue, 2000: *Niue Initial Communication to the UNFCCC.*
Government of Vanuatu, 1999: V*anuatu National Communication to the Conference of the Parties to the United Nations Framework Convention on Climate Change*.
Griffiths, G.M., M.J. Salinger, and I. Leleu, 2003: Trends in extreme daily rainfall across the south pacific and relationship to the South Pacific convergence zone. *J. Climatol.*, 23, 847-869.
Grynberg, R and Remy, J.Y., 2004: Small vulnerable economy issues and the WTO. Paper presented at the 24th Commonwealth Parliamentary Conference, Quebec, September 2004. Available at http://www.cpahq.org/SCC5_pdf_media_public.aspx
Hales, S., P. Weinstein and A. Woodward, 1999: Ciguatera (fish poisoning), El Nino, and sea surface temperature. *Ecosystem Health*, 5, 20-25.
Hay, J., N. Mimura, J. Cambell, S. Fifita, K. Koshy, R.F. McLean, T. Nakalevu, P. Nunn, and N. deWet., 2003: *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.* South Pacific Regional Environment Programme (SPREP), Apia, Samoa, 94 pp.
Hoffmann, T.G., 2002: The reimplementation of the Ra'ui: Coral reef management in Rarotonga, Cook Islands. *Coastal Managemen*t, 30, 401-418.
Huq, S. and Reid, H., 2004: *Mainstreaming Adaptation in Development" in Climate Change and Development.* IDS Institute of Development Studies, 35 (3), 40
Ibrahim S.A., M.R. Bari and L.A. Miles, 2002: Water management in Maldives with special emphasis on desalination. Case study presented as part of Theme 1, Water Resources Management, at the Pacific Regional Consultation on Water in Small Island Countries, Sigatoka, Fiji, 29 July - 3 August 2002.
IPCC, 2001: *Climate Change 2001: The Scientific Basis.* Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881 pp.
IPS (Impact Consultancy Services Inc.), 2002: *Water and Climate Change in the Caribbean.* Impact Consultancy Services Inc., Caribbean Environmental Health Institute (CEHI), and Organization of American States, Unit for Sustainable Development and Environment Publication. Contribution to the Global Dialogue on Water and Climate. 21 pp.
IUCN, IISD, SEI-B and Intercooperation., 2004: *Sustainable Livelihoods and Climate Change Adaptation* (http://www.iisd.org/pdf/2004/envsec_sustainable_livelihoods.pdf)
Kench, P.S. and Cowell, P.J, 2001. The morphological response of atoll islands to sea level rise. Part 2: application of the modified shoreface translation model. *Journal of Coastal Research*, 34: 645-656.
Kench, P.S., McLean, R.F., and Nicholl, S., 2005. New model of reef-island evolution: Maldives, Indian Ocean. *Geology*, 33, 145-148.
Lal, M., 2004: Climate change and small island developing countries of the South Pacific, *Fijian Studies, Special Issue on Sustainable Development*, V2(1), 15-31.
Majeed, A. and Abdulla, A., 2004: Economic and Environmental Vulnerabilities of the Maldives and Graduation from LDC Status, In Briguglio and Cordina (eds) (2004). *Economic Vulnerability*

and Resilience of Small States. Commonwealth Secretariat and the University of Malta.
Mason, S., 2004: Simulating climate over western North America using stochastic weather generators. *Climatic Change*, 62, 155-187.
McLean, R.F., A. Tsyban, V. Burkett, J.O. Codignotto, D.L. Forbes, N. Mimura, R.J. Beamish, and V. Ittekkot, 2001: Coastal zones and marine ecosystems. In: *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White (eds.). Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 343-379.
MRAE (Ministry of Rural Affairs and the Environment, Malta), 2004: *The First Communication of Malta to the United Nations Framework Convention on Climate Chang*, Ministry for Rural Affairs and the Environment, Malta
MESD (Ministry of Environment and Social Development, Kiribati), 1999: *Initial Communication Under the United Nations Framework Convention on Climate Change*, Kiribati Government, Tarawa, Kiribati.
Millennium Ecosystem Assessment, 2003: Ecosystems and Human Well-being, Island Press.
MOHA (Ministry of Home Affairs, Maldives), 2001: *First National Communication of the Republic of Maldives to the United Nations Framework Convention on Climate Change*, Ministry of Home Affairs, Housing and Environment, Malé, Republic of Maldives.
Mossler, M., 1996: Environmental hazard analysis and small island states: rethinking academic approaches. *Geographische Zeitschrift*, 84 (2), 86-93.
Munasinghe, M., 2003: *Analysing the Nexus of Sustainable Development and Climate Change: An Overview*. OECD
NEAB (National Environment Advisory Board, St Vincent and the Grenadines), 2000: *Initial National Communication on Climate Change,* National Environment Advisory Board and Ministry of Health and the Environment, 74 pp.
Nunn, P. D. and N. Mimurs, 2005: Promoting sustainability on vulnerable island coasts: a case study of the smaller Pacific Islands, in L. McFadden(ed.): *Managing Coastal Vulnerability: An Integrated Approach* (in press).
Nurse, L., G. Sem, J.E. Hay, A.G. Suarez, P.P. Wong, L. Briguglio and S. Ragoonaden, 2001: Small island states. . In: *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White (eds.). Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 842-975.
Oouchi, K., J. Yoshimura, H. Yoshimura, R. Mizuta, S. Kusunoki and A. Noda, 2005: Tropical cyclone climatology in a global-warming climate as simulated in a 20km-mesh global atmospheric model. J. Meteor. Soc. Japan, Submitted.
Parakoti, B, and D.M. Scott, 2002: Drought index for Rarotonga (Cook Islands). Case study presented as part of Theme 2, Island Vulnerability, at the Pacific Regional Conference.
Payet, R., 2003: Coral reefs in small island states: status, monitoring capacity and management priorities. *International Journal of Island Affairs*, 12 (1) 57-65.
Pelling, M., and J.I. Uitto, 2001: Small island developing states: natural disaster vulnerability and global change. *Environmental Hazards*, 3, 49-62.
Rawlins, S.C., A. Chen, M.Ivey, D. Amarakoon and K. Polson, 2005: The impact of climate change/variability events on the occurrence of dengue fever in parts of the Caribbean: A retrospective study for the period 1980-2002.*West Indian Medical Journa Suppl.*, 53 (2) 54.
Raynor, B., 1995. Montane cloud forests in Micronesia: status and future management. In: Hamilton, L.S., Juvik, J.O., Scatena, Ž. F.N. Eds., Tropical Mountain Cloud Forests: Proceedings of an International Symposium. Springer-Verlag, New York, pp.274–283.

Revell, M., 2004: Pacific Island Weather and the MJO. *The Island Climate Update*, 42, p.4. Retrieved 11.11.2004 from http://www.niwa.co.nz/ncc/icu/2004-03/.

Richards, M. 2003, Poverty Reduction, Equity and Climate Change: Global Governance Synergies or Contradictions? Globalisation and Poverty Programme, Overseas Devlopment Institute, London, United Kingdom.

Ronneberg, 2004: Environmental vulnerability and economic resilience: The case of the Republic of the Marshall Islands, In Briguglio, L. and G. Cordina (eds) *Economic Vulnerability and Resilience of Small States.* Commonwealth Secretariat and the University of Malta

Ruosteenoja, K., T.R. Carter, K, Jylha, and H. Tuomenvirta, 2003: Future climate in world regions: an intercomparison of model-based projections for the new IPCC emissions scenarios. *The Finnish Environment 644*, Finnish Environment Institute, Finland, 83 pp.

Salinger, M.J., 2001: Climate variation in New Zealand and the Southwest Pacific. In *The Physical Environment. A New Zealand Perspective*. A. Sturman, and R. Spronken-Smith (eds.), Oxford University Press, Victoria, Australia, 537pp.

Salinger, M.J., J.A. Renwick, and A.B. Mullan, 2001: Interdecadal Pacific Oscillation and South Pacific climate. *J. Climatol* ., 21, 1705-1721.

Shea, E., G. Dolcemascolo, C.L. Anderson, A. Banston, C.P. Guard, M.P. Hamnett, S.T. Kubota, N. Lewis, J. Loschinigg, and G. Meehls, 2001: *Preparing for a Changing Climate. The Potential Consequences of Climate Variability and Change, Pacific Islands. A Report of the Pacific Islands Regional Assessment Group for the U.S.Global Change Research Program*. East West Center, University of Hawaii, Honolulu, Hawaii, USA, 102 pp.

Sheppard, C., Dixon, D.J., Gourlay, M., Sheppard, A., and Payet, R. 2005: Coral mortality increases wave energy reaching shores protected by reef flats: Examples from the Seychelles. Estuarine, Coastal and Shelf Science, 64, 223-234.

Singh, R.B.K., S. Hales, N.de Wet, R. Raj, M. Hearnden and P. Weinstein, 2001: The influence of climate variation and change on diarrheal disease in the Pacific Islands. *Environmental Health Perspectives*, 109 (2) 155-159.

Sinha, C.C., and Bushell, R., 2002. Understanding the linkage between biodiversity and tourism: A study of ecotourism in a coastal village in Fiji. *Pacific Tourism Review,* 6, 35-50.

SOPAC (South Pacific Applied Geoscience Commission), 2001: *Water resources assessment and sanitation*. Available at http://www.sopac.org.fj/Secretariat/Units/Wru/wateract.html.

Sperling, F., 2003: *Multi-agency Report 2003. Poverty and Climate Change: Reducing the Vulnerability of the Poor through Adaptation*. Washington DC: World Bank

SPREP (South Pacific Regional Environmental Programme), 1999: *Analysis of the Effects of the Kyoto Protocol on Pacific Island Countries, Part 2, Regional Climate Scenarios and Risk Assessment Methods*. SPREP, Apia, Western Samoa.

Sutherland, K., Smit, B., Wulf, V, and Nakalevu, T., 2005: Vulnerability to Climate Change and Adaptive Capacity in Samoa: The Case of Saoluafata Village Tiempo, January 2005.

Taulima F., 2002: Water management in Tuvalu with special emphasis on rainwater harvesting. Case study presented as part of Theme 1, Water Resources Management, at the Pacific Regional Consultation Meeting on Water in Small Island Countries, Sigatoka, Fiji , 29 July - 3 August 2002.

Thomas, F.R., 2001: Remodelling marine tenure on the atolls: a case study from Western Kiribati, Micronesia. *Human Ecology*, 29, 399-423.

Tsiourtis, 2002: CYPRUS-Water Resources Planning and Climate Change Adaptation, In *Water, Wetlands And Climate Change: Building Linkages for their Integrated Management*, IUCN Mediterranean Regional Roundtable.

UNDP(United Nations Development Programme), 2005a: National Adaptation Programme of Action (NAPA), Available online at www.undp.org/cc/napa.htm

UNDP, 2005b: Non-Annex I Parties National Communications, Available online at www.undp.org/cc/nonannexi1.htm.

UNEP (United Nations Environment Programme), 2000: *Overview on Land-Based Pollutant Sources and Activities Affecting the Marine, Coastal, and Freshwater Environment*. Regional Seas Reports and Studies, No. 174. Available at http://www.unep.org/nova/applications/regseas/sprep/english.html .

UNEP, 2002: *Global Environment Outlook 3*, Earthscan.

Walsh, K., 2004: Tropical cyclones and climate change: unresolved issues, *Climate Research*, Vol.27, 77-83.

World Bank, 2000: Cities, Seas and Storms: Managing Change in Pacific Island Economies., World Bank, Washington, D.C.

World Bank, 2002: Cities, Seas and Storms: Managing Change in Pacific Island Economies., World Bank, Washington, D.C.

Ximena Flores Palacios, 1998: Contribution to the Estimation of Countries' Inter-dependence in the Area of Plant Genetic Resources. Commission on Genetic Resources for Food and Agriculture, Background Study Paper no. 7, Rev.1, FAO.