Chapter 29. Small Islands

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Contents

Executive Summary

Distinguishing small islands. Small islands are distinguished by their limited size, insular setting, maritime climates, small populations and economies, poor land resource base, and frequently their exposure to weather-climate- and ocean-related natural hazards. The small island states and territories considered here are mainly located in the tropics in the southern, central and western Pacific Ocean, central and western Indian Ocean, the Caribbean Sea, the eastern Atlantic off the west coast of Africa, and the more temperate Mediterranean Sea. The concerns of small island states and their needs in relation to future climate change differ in many ways from those of larger countries and continental regions. They also differ among themselves because of their cultural, economic and political diversity as well as in their contrasting physical and ecological characteristics and land and marine resources.

Sea level, inundation and erosion. Small islands have a long length of coast in proportion to island size. Their small land area and often low elevation coasts makes them particularly vulnerable to rising sea levels and impacts such as inundation, saltwater intrusion into ground water lenses and shoreline change. The *very likely* contribution of future mean sea level rise and increased extreme sea levels, coupled with the *likely* increase in tropical cyclone maximum wind speed is a specific issue for small island states (SREX Box 3-4). Observed impacts of past sea-level rise on small islands are not well documented. A sea-level rise signal cannot be discriminated from those of climate variability (e.g. ENSO) or storms in cases of inundation and seawater over-wash and intrusion into ground water lenses on small islands. [29.3.1.1] Similarly in the few studies of shoreline change on atoll and reef islands over the last few years and decades, a general coastal erosion trend has not been identified. [29.3.1.2] Thus, we have *low confidence* that sea-level rise will cause widespread destruction of islands in the next few decades, except in those locations that are presently experiencing coastal erosion and inundation and where human impacts have had major effects. [29.3.3.1, 29.6.1]

Coastal environments and stresses. Coral reefs, mangrove forests and sea grass beds are important marine resources in most tropical small islands and the well-being of island communities and many businesses (eg tourism) is intimately linked to their on-going function. We have *high confidence* that reefs, mangrove and seagrass environments that are presently stressed by non-climatic factors are more at risk to the effects of climate change than those that are not so stressed. [29.3.1.3, 29.3.1.4] Increases in the frequency and extent of coral bleaching have been forecast and landward movement of mangroves is frequently constrained by coastal structures. [29.4.1.1] There is a need to fully understand the potential impacts of sea-level rise, increases in sea surface temperature and ocean acidification on these important small island littoral environments.

Freshwater availability and quality. Freshwater availability and quality has been a major issue on many small islands. On atolls there is no surface water and on high limestone and volcanic islands catchments are small and steep. Model projections (SRES A1B) of future rainfall by 2100 across four small island' regions show an overall annual decrease of about 12 % in the Caribbean and a 3-5 % increase in the Indian and Pacific small island regions. [29.4.1.1, Table 29-1] But in addition to input precipitation many other factors are involved in the supply and quality of potable water on small islands. [29.3.2.2]

Local impacts; distant origins. Many impacts on small islands are generated from well beyond the borders of an individual nation or island. These trans-boundary impacts may originate in distant regions including continental countries. Most trans-boundary processes have negative impacts. These include: airborne dust from the Sahara and Asia reaching small islands far down-drift from the desert source; and, large ocean swells generated by extra tropical cyclones and high latitude low pressure systems. [29.5.1.1, 29.5.1.2] Given the *likely* poleward shift in the main northern and southern hemisphere extra-tropical storm tracks it is possible that there will be a decline in the magnitude and frequency of such swell events in the future (SREX Chapter 3). Other trans-boundary impacts result from invasive plant and animal species that reach the warmth of small islands and the spread of aquatic pathogens that may have implications for human health. For island communities the trans-boundary implications of existing and future 'invasions' and human health challenges are projected to increase in a changing climate. [29.3.3.3, 29.5.4]

Observed versus projected impacts. The distinction between *observed impacts* of climate change and *projected impacts* is often not clear-cut in the literature on small islands. In fact many publications deal with both types of impact, often using a recent 'observed' impact relating to some extreme weather- climate- or ocean-related event as an analogy to what may happen in the future. Moreover, much of the literature on projected (future) climate change impacts on small islands is not specific about the scenario (s) used in impact studies, partly because of the difficulty in moving from global-scale scenarios and models to the scale of small islands. Downscaling has been a perennial problem. One implication of this blurring of the distinction between observed and projected is our *low confidence* in the scale of future impacts. However, on a positive note in-roads are now being made to redress this situation and three examples are given including of the use of downscaled SRES scenarios in a comprehensive assessment of the vulnerability of the fisheries in 22 Pacific island countries. If such studies are duplicated elsewhere confidence in projected impacts will increase.

Vulnerability indices: Inadequate to date. Several attempts have been made to assess levels of vulnerability and identify gaps through national level indices. None provide a complete picture of island vulnerability. We have *low confidence* in any indicators of vulnerability that do not capture the essence of small islands. Rather we encourage the use of multiple measures of vulnerability (e.g. Table 29-3; Figure 29-3). Although lessons learned from adaptation experiences on one island may offer some helpful guidance to other small island states, we have *low confidence* in the wholesale transfer of adaptation options when the lenses through which they are viewed differ from one community to the next, based on ecological, socio-economic, cultural and political values. [29.8]

Vulnerability and experience. Island vulnerability to climate change may be related to the experience and perceptions of islanders to both climate and non-climate stressors. Islands and islanders are recognized for their long experience of adapting to a host of hazards including weather-climate- and ocean-related hazards and for their resilience in coping with such events. We have *medium confidence* that adaptive capacity is better when the frequency of hazards is greater, but there may be limits to this capacity when small islands are going through rapid socio-economic change. We also recognize the need to combine indigenous or local knowledge and experience with modern technology into adaptation planning and execution. [29.6.2.1]

Climate change and multiple stressors. For most small islands climate change is just one of a series of multiple stresses that they must cope with, and often it is not the most important one. Increasingly there are arguments that priority in the short-term should be given to addressing immediate development problems such as water supply, waste management, deteriorating ecosystems and food security. We agree that addressing the critical social, economic and environmental issues of the day will *likely* increase human and environmental resilience to the longer-term impacts of climate change.

Constraints to adaptation. Whilst lack of access to adequate financial, technology and human resources is often cited as the most critical constraint to implementing various climate change response strategies, there is evidence to show that endogenous factors such as culture, ethics, knowledge and attitudes to risk are equally important in making adaptation choices both at the national and community level *(high confidence*). [29.6.3] Mainstreaming and integrating climate change into contemporary development plans is seen as an appropriate goal, though several case studies document the difficulties in achieving that goal.

Adaptation and mitigation. There is now a convergence of views that adaptation and mitigation on small islands are not trade-offs, but can be regarded as complementary components in the response to climate change (*medium confidence).* At least three key areas for adaptation-mitigation inter-linkages in small islands are identified here: coastal forestry, energy supply and tourism. The alignment of these sectors for potential emission reductions together with adaptation needs offers co-benefits in small islands, especially in the energy sector.

Adaptation and mal-adaptation. Whilst there is agreement that assistance from the international community is vital for supporting adaptation and mitigation programs in small islands, there is increasing concern that some types of interventions may actually be maladaptive. [29.8, Box 29-1] Thus, caution is needed to ensure that donors are not driving the adaptation and mitigation agenda in small islands, as there is a risk that donor-driven adaptation or mitigation will not address the salient challenges on small islands (*high agreement*). This may lead to inadequate adaptation or a waste of scarce resources and may unintentionally cause enhanced vulnerability by supporting adaptation strategies that are externally derived, rather than optimizing the benefits of local practices that have proven to be efficacious through time. [29.6.2.3, 29.6.3, 29.8]

Community engagement. Decisions about adaptation choices and their implementation are best facilitated where there is constructive engagement with the communities at risk, in a manner that fosters transparency, trust and genuine commitment to the process (*high confidence*). Participatory stakeholder involvement can yield valuable information about the priorities and expectations that communities attach to the sector for which adaptation is being sought. [29.6.2.1, 29.6.2.3, 29.6.4, 29.8]

29.1. Introduction

It has long been recognized that greenhouse gas emissions from small islands are negligible in relation to global emissions, but that the threats of climate change and sea-level rise to small islands are very real. Indeed, it has been suggested that the very existence of some atoll nations are threatened by rising sea levels associated with global warming. Whilst such extreme scenarios are not applicable to all small island nations, there is no doubt that on the whole the impacts of climate change on small islands will have serious negative effects especially on socio-economic conditions and bio-physical resources – although impacts will be ameliorated by the extent and effectiveness of adaptation.

The small islands considered in this chapter are principally sovereign states and territories located within the tropics of the southern and western Pacific Ocean, central and western Indian Ocean, the Caribbean Sea, and the eastern Atlantic off the coast of west Africa, as well as in the more temperate Mediterranean Sea.

Although these small islands nations are by no means homogenous politically, socially, or culturally, or in terms of physical size and character or economic development, there has been a tendency to generalise about the potential impacts on small islands and their adaptive capacity. In this chapter we attempt to strike a balance between identifying the differences between small islands as well as recognising that small islands tend to share a number of common characteristics that have distinguished them as a particular group in international affairs. Also in this chapter we reiterate some of the frequently voiced and key concerns relating to climate change impacts, vulnerability and adaptation whilst emphasising a number of additional themes that have emerged in the literature on small islands since the IPCC Fourth Assessment. These include situating climate change within the context of multiple stresses; the relationships between climate change policy, activities and development issues; externally generated trans-boundary impacts; and the implications of risk in relation to adaptation and the adaptive capacity of small island nations.

29.2. Major Conclusions from Previous Assessments

Small islands were not given a separate chapter in the IPCC First Assessment (FAR) in1990 though they were discussed in the chapter on ‘World Oceans and Coastal Zones’ (Tsyban *et al.*, 1990). Two points were highlighted. First, that a 30-50 cm sea-level rise projected by 2050 would threaten low islands, and that a 1 m rise by 2100 ‘would render some island countries uninhabitable’ (Tegart *et al.*, 1990: 4). Second, the costs of protection works to combat sea-level rise would be extremely high for small island nations. Indeed, as a percentage of GDP the Maldives, Kiribati, Tuvalu, Tokelau, Anguilla, Turks and Caicos, Marshall Islands and Seychelles were ranked among the ten nations with the highest protection costs in relation to GDP (Tsyban *et al.*, 1990: 6. 4). Over twenty years later these two points continue to be emphasized. For instance, although small islands represent only a fraction of total global damage projected to occur due to a sea-level rise of 1.0 m by 2100 (SRES A1 scenario) the actual damage costs for the small island states is enormous in relation to the size of their economies (Anthoff *et al.*, 2010: 328) with several small island nations (Nauru, Marshall Islands, Palau, Federated States of Micronesia) being included in the group of ten countries with the highest relative impact in 2100 (Anthoff *et al.*, 2010: 328-330).

The Second Assessment (SAR) in 1995 confirmed the vulnerable state of small islands, now included in a specific chapter titled ‘Coastal Zones and Small Islands’ (Bijlsma, *et al.*, 1996). However, importantly the SAR recognized that both vulnerability and impacts would be highly variable between small islands and that impacts were ‘likely to be greatest where local environments are already under stress as a result of human activities’ (Bijlsma, *et al.*, 1996: 290-291). The report also summarized results from the application of a common methodology for vulnerability and adaptation analysis that gave new insights into the socio-economic implications of sea-level rise for small islands including:

- Negative impacts on virtually all sectors including tourism, freshwater resources, fisheries and agriculture, human settlements, financial services and human health;
- Protection is likely to be very costly; and,
- Adaptation would involve a series of tradeoffs.

It also noted that major constraints to adaptation on small islands included: lack of technology and human resource capacity, serious financial limitations, lack of cultural and social acceptability and uncertain political and legal frameworks. Integrated coastal and island management was seen as a way of overcoming some of these constraints.

The Third Assessment (TAR) in 2001 included a specific chapter on ‘Small Island States’. In confirming previously identified concerns of small island states two important factors were highlighted, the first relating to sustainability noting that ‘with limited resources and low adaptive capacity, these islands face the considerable challenge of meeting the social and economic needs of their populations in a manner that is sustainable’ (Nurse *et al.*, 2001: 845). And the second, that there were other issues faced by small island states concluding that ‘for most small islands the reality of climate change is just one of many serious challenges with which they are confronted’ (Nurse *et al.*, 2001: 846). Both of these themes are further developed in the present assessment.

Until the Fourth Assessment (AR4) in 2007, sea-level rise had dominated vulnerability and impact studies of small island states. Whilst a broader range of climate change drivers and geographical spread of islands was included in the ‘Small Islands’ chapter, Mimura *et al.* (2007) prefaced their assessment by noting that the number of ‘independent scientific studies on climate change and small islands since the TAR’ had been quite limited and in their view ‘the volume of literature in refereed international journals relating to small islands and climate change since publication of the TAR is rather less than that between the SAR in 1995 and TAR in 2001' (Mimura *et al.*, 2007: 690).

Since AR4 the literature on small islands and climate change has increased substantially. A number of features distinguish the literature we review here from that included in earlier assessments. First, the literature appears more sophisticated and does not shirk from dealing with the complexity of small island vulnerability, impacts and adaptation or the differences between island states. Second, and related to the first, the literature is less one-dimensional, and deals with climate change in a multidimensional manner as just one of several stressors on small island nations. Third, there has also been a tendency to critique some aspects of climate change policy, notably in relation to development and security, and to suggest that adaptations for the future are being placed above critical needs of the present. As a result, it is argued, there is a reduction in resilience that will have serious ramifications for small island adaptation in the future.

The present chapter builds on these earlier assessments. Inevitably there is some repetition of the key impacts, vulnerability and adaptation to climate change and sea level rise of small islands. Such themes continue in this assessment, though we also raise a number of new concerns as well as some hopeful signs for the future.

29.3. Observed Impacts of Climate Change, including Detection and Attribution

The distinction between *observed* impacts of climate change and *projected* impacts is often unclear in the small islands literature and discussions. Publications frequently deal with both aspects of impacts interchangeably, and use observed impacts from, for instance an extreme seasonal event, as an analogy to what may happen in the future due to climate change (e.g. Lo-Yat *et al.,* 2011). The key climate and ocean drivers of change that impact small islands include variations in air and ocean temperatures, ocean chemistry, rainfall, wind strength and direction, sea-levels and wave climate and particularly the extremes such as tropical cyclones, drought and distant storm swell events. All have varying impacts, dependent on the magnitude and frequency and temporal and spatial extent, as well as on the bio-physical nature of the island and its social, economic and political setting.

29.3.1. Observed Impacts on Coastal and Marine Biophysical Systems

29.3.1.1. Sea Level and Inundation

Sea-level rise poses one of the most widely recognized climate change threats to low-lying coastal areas (Church and White 2011; Cazenave and Llovel, 2010; Nicholls and Cazenave, 2010). This is particularly important in the case of small islands where the great majority of human communities and infrastructure are located in coastal zones with limited resettlement opportunities. This is especially so on atoll islands where entire land masses are seldom more than 1.0 - 1.5m above current high spring tide level (Woodroffe, 2008; Yamano *et al.,* 2007) (Figure 29-1).

[INSERT FIGURE 29-1 HERE
Figure 29-1: Small island regions vulnerable to coastal flooding caused by future relative or climate-induced sea-level rise. At highest risk are coastal zones with dense populations, low elevations, appreciable rates of subsidence, and/or inadequate adaptive capacity (Nicholls and Cazenave, 2010).]

Rates of global average sea-level rise have continued at approximately 3.3 mm yr $^{-1}$ between 1993 and 2011 and acceleration is detected in longer records since 1870 (Merrifield *et al.,* 2009; Cazenave and Remy, 2011; Church and White, 2011) (See Chapter 13, Working Group 1 for details). Rates of sea-level rise are however not uniform across the globe and large regional differences have been detected in the south Indian Ocean, tropical Pacific, north Pacific, and northwestern Atlantic where rates have been significantly higher than the global average (Meyssignac *et al.,* 2012). In the case of the tropical western Pacific region where a large number of small island and atoll communities exist, rates up to four times the global average (approximately 12 mm yr $^{-1}$) have been measured by satellite altimetry between 1993 and 2009 (Becker *et al.,* 2012; Meyssignac *et al.,* 2012).

Whilst this rapid increase is of immediate concern it is important to note these elevated rates are derived from relatively short records collected with satellite altimetry and are thought to describe transient sea-level change associated with natural cyclic climate phenomena, e.g. ENSO (El Niño-Southern Oscillation), NAO (North Atlantic Oscillation), PDO (Pacific Decadal Oscillation) (Cazenave and Remy, 2011). ENSO for example, has a strong influence over mean sea level in the tropical western Pacific region decreasing sea levels during El Niño (~ 30cm) and increasing sea level during La Nina (~ 30cm) (Becker *et al.,* 2012).

Related to persistent La Nina conditions through 2010 – 2011, sea level gauges in Majuro (Marshall Islands), Manus Island (Papua New Guinea), Pohnpei (Federated States of Micronesia) and Apia (Samoa) recorded some of their highest monthly mean levels on their approximate 20 year gauge records (SPSLCMP, 2012). The islands of Yap, Pohnpei and Chuuk (Federated States of Micronesia), Saipan and Guam (Mariana Islands), Rabaul (Papua New Guinea) and Honiara (Solomon Islands) have also been subject to very high rates of sea-level rise since 1993 (up to 11+/- 3mm yr $^{-1}$) again due to strong and persistent La Nina conditions superimposed over incremental sea-level rise (Becker *et al.,* 2012). At Nauru, Funafuti (Tuvalu), Pago Pago (American Samoa), Papeete (French Polynesia), Noumea (New Caledonia), and Tarawa (Kiribati), overall rates of sea-level rise have been significantly higher than the global average from 1950 – 2009 (Becker *et al., 2*012). In the wider Caribbean estimated rates of absolute sea level change vary greatly between locations, ranging between Jamaica (- 4 mm yr $^{-1}$) and Barbados (+3 mm yr $^{-1}$). Likewise rates of relative sea-level change vary from Honduras (+ 8. 6 mm yr $^{-1}$) to Jamaica (- 6. 4 mm yr $^{-1}$) due to the interaction of vertical tectonic motion of differing land mass (Sutherland *et al.*, 2008).

Inundation associated with high spring tide conditions at Fongafale Island, Funafuti Atoll, Tuvalu, has been well publicized and study has shown that areas of the central portion of Fongafale are below sea-level at high spring tide (Yamano *et al.,* 2007). Regular saline flooding of internal low areas of Fongafale occurs routinely and given the relationship of land height to mean sea level, flooding is expected to become more frequent and extensive in the future (Yamano *et al.,* 2007). Such low-lying central areas on atoll islands are common features and are often associated with subsistence agriculture and these can be expected to become increasingly subject to flooding due to sea-level rise (Woodroffe 2008; Yamano *et al.,* 2007; Webb, 2007).

Tectonic vertical subsidence is also important to understand when interpreting sea-level rise impact as is coastal engineering that can disturb shoreline processes. Communities on the Torres Islands, Vanuatu have been displaced due to increasing inundation of low-lying settlement areas (Ballu *et al.,* 2011). From 1997 – 2009 sea-level rise was estimated to have been approximately 150mm however tectonic subsidence also estimated at -117 +/- 30mm over the same period doubled the apparent rate of sea-level rise at this location in a very short period of time (Ballu *et al.,* 2011). A rural community on Abaiang Atoll, Kiribati has also been impacted by tidal inundation and saline incursion into garden areas (Webb, 2006). In this location adjustments to shoreline processes following the closure of an ocean passage had resulted in shoreline instability and rapid erosion, exacerbating shoreline vulnerability and tidal flooding (Webb, 2006). Whilst the available documented cases of inundation frequently have additional extenuating circumstances which interact with climate change related sea-level rise, these examples serve to highlight the innately vulnerable nature of these locations to sea-level rise.

29.3.1.2. Beaches and Coasts

Shoreline resilience in tropical carbonate systems is inextricably linked to sediment supply from the adjacent living reef systems (Perry *et al.,* 2011) and maintained structural integrity of reefs is critical to wave energy mediation. The incidence of coral bleaching has risen over the last century (Veron *et al.,* 2009; Oliver *et al.*, 2009) and *in situ* cores from *Porites* in the Great Barrier Reef (GBR) show that coral calcification rates in the GBR have declined over 14 per cent since 1990 (De'ath *et al.*, 2009). Likewise, Tanzil et al. (2009) showed that calcification rates and linear extension of the coral *Porites lutea* from eight sites in Southern Thailand had decreased by 23.5% and 19.4 to 23.4% over an approximate 20 year period. In respect to small islands the waters of the greater Caribbean (Turks Caicos, Lesser Antilles and Jamaica) have been shown to now be exposed to decreasing aragonite saturation levels, caused by increasing CO_2 concentration (acidification) and this has negative implications to the on-going productivity, structure and composition of those reef systems (Gledhill *et al.*, 2008). Important species of coralline algae that contribute to the structural integrity of reefs have also been shown to be sensitive to increased CO_2 concentration

(Kuffner *et al.,* 2007; Anthony *et al.,* 2008). Given the critical role reefs play to sediment supply and wave energy mediation in carbonate shoreline systems any disturbance in reef productivity or structure can be expected to influence shoreline processes.

Additional research providing insights into island shoreline response to sea-level rise has become available since AR4 and this is summarised below. Historical shoreline position change over the last 20 – 60 years measured in 27 Central Pacific atoll islands showed that 86 per cent of these islands either had remained stable or had increased in their land area (Webb and Kench, 2010). Similar, dynamic equilibrium was found in a four year study of 17 relatively pristine islands on two additional Central Pacific atolls, this study concluded that at this time sea level rise was unlikely to be a main influencing factor in these shoreline dynamics (Rankey, 2011). On the uninhabited Raine Island on the Great Barrier Reef, Dawson and Smithers (2010) found that processes were dynamic but that both island area and volume increased 6 per cent and 4 per cent, respectively between 1967 and 2007. These and other studies conclude that at this time, normal seasonal erosion and accretion processes predominate over any measured long-term morphological trends or signals associated with climate change (Kench and Brander, 2006; Kench *et al*., 2009; Dawson and Smithers, 2010). It is important to note that the concerns of vulnerability from inundation to on-going incremental sea-level rise in low-lying islands (especially atolls) provided in AR4, remains unchanged.

The possibility of shoreline resilience presents opportunities in that resilient shores are better able to provide wave protection, suggesting an imperative for small island communities to protect natural shoreline systems from direct human interference. Changing patterns of human settlement and direct impacts on shoreline processes present immediate erosion challenges in populated islands and coastal zones (Yamano *et al*., 2007; Storey and Hunter, 2010; Novelo-Casanova and Suarez, 2010; Ford, 2012) and mask attribution. A study of widespread erosion on Majuro Atoll found that erosion was common however attribution of this shoreline instability to factors like sea level rise were masked by pervasive anthropogenic impacts to the natural coastal systems (Ford, 2012). Likewise, Cambers (2009) measured average beach erosion rates of 0.5 m yr $^{-1}$ in eight Caribbean islands from 1985-2000, but was unable to easily quantify the extent of attribution to anthropogenic factors, natural climate variability and / or climate change and sea-level rise.

29.3.1.3. Coral Reefs and Reef Fishes

Coral reef ecosystems are one of the most important resources in small tropical islands and the culture and wellbeing of island communities is inextricably linked to their on-going function, biodiversity and productivity. Coral reefs provide habitat for a host of marine species upon which many island communities are deeply dependent for subsistence diets as well as underpinning key beach and reef-based touristic economic activity (Bell *et al.,* 2011; Perch-Nielsen, 2010). The documented sensitivity of coral reef ecosystems to climate change (e.g. Stokes *et al.,* 2010; Lough and van Oppen, 2009; Hoegh-Guldberg *et al.,* 2007) cannot be considered in the context of small islands without consideration of the immediate interdependence of human wellbeing in tropical island settings.

Increased coral bleaching due to thermal stress and reduced calcification rates due to increasing CO_2 concentration are expected to affect the function and viability of living reef systems (Hoegh-Guldberg *et al.,* 2007; Eakin *et al.,* 2009) and some studies are starting to observe impacts consistent with a regional decline (De'ath *et al*., 2009; Tanzil *et al.,* 2009; Cantin *et al.,* 2010). Unprecedented bleaching events in small islands have also been recorded in some of the most pristine, uninhabited locations on Earth. Surveys in 2004 in the remote Phoenix Group of Kiribati found that there had been near 100 per cent coral mortality in the lagoon environment and 62 per cent mortality on the outer leeward slopes of the otherwise pristine reefs of Kanton Atoll during 2002 / 2003 (Alling *et al*., 2007). Similar patterns of mortality were observed in four other atolls in the Phoenix group during the same study and temperature-induced coral bleaching has also been recorded in remote and unpopulated Palmyra Atoll during the 2009 ENSO event (Williams *et al*., 2010). In 2005 extensive bleaching was recording at 22 sites around Rodrigues Island in the western Indian Ocean with up to 75% of the dominant species affected in some areas (Hardman *et al.,* 2007) and in 2005 a reef survey around Barbados following a Caribbean regional bleaching event revealed the most severe bleaching ever recorded with approximately 70% of corals impacted (Oxenford *et al.,* 2008). Globally, the incidence and implications of temperature-related coral bleaching is well documented and the synergistic implication of increasing ocean acidification is likewise considered a major threat to the long-term survival of today's coral reef ecosystems (De'ath, *et al.*, 2009; Veron *et al.*, 2009).

Islands have limited response options to thermal stress and acidification however, there is evidence to show that coral reef resilience is enhanced in the absence of additional environmental stress such as declining water quality. In Belize chronologies of growth rates in massive corals *Montastraea faveolata* over the past 75–150 years showed that the bleaching event in 1998 was unprecedented in the past century but that the severity of the response also appeared to stem from reduced thermal tolerance resulting from the direct interactive effects of human coastal development (Carilli *et al.*, 2010). Likewise a study over a 40 year period (1960's – 2008) in the Grand Recif of Tulear, Madagascar concluded that severe degradation was evident, however this was mostly ascribed to direct anthropogenic disturbance of the near shore marine environment, despite an average 1^0C increase in temperature over this period (Harris *et al.*, 2009). Coral recovery following the 2004 bleaching event in the central Pacific atolls Tarawa and Abaiang was also noted to likely be improved in the absence of direct human impacts (Donner *et al.,* 2010). The implementation of an appropriate reef management policy as a measure to promote reef ecosystem resilience appears to be a sound strategy in small island environments.

The loss of coral reef habitat has dire implications to coastal fisheries resources (Pratchett *et al.,* 2009) and nowhere more so than in small islands where reef based subsistence and tourism activities are so intimately linked to the wellbeing and economies of these islands (Bell *et al.,* 2011). In Kimbe Bay, Papua New Guinea it was estimated that 65% of coastal fish are dependent on living reefs at some stage in their life cycles and that most of these declined in abundance following reef degradation (Jones *et al.,* 2004). Even where coral reef recovery occurs following bleaching, reef associated species composition may not recover to its original state (Pratchett *et al.,* 2009; Donner *et al.,* 2010) and even where bleaching is not the immediate threat, SST anomaly events like that reported by Lo-Yat *et al.* (2011) between 1996 and 2000, showed an associated lag in larval supply of coral reef fishes in near shore waters of Rangiroa Atoll, French Polynesia. Higher temperatures have also been implicated in negative affects to spawning of adult reef species (Munday *et al.*, 2009; Donelson *et al.*, 2010).

29.3.1.4. Coastal Wetlands: Mangroves and Seagrasses

Like coral reefs, mangroves and sea grass environments provide a range of vital ecosystem goods and services (Polidoro *et al.*, 2010 and Waycott *et al.*, 2008). Both habitats play a significant role in the wellbeing of small island communities and mangroves in particular perform a host of commercial and subsistence uses as well as providing natural coastal protection from erosion and storm events (Ellison, 2009; Krauss *et al.,* 2010; Waycott *et al.,* 2011).

Sea-level rise is reported as the most significant climate change threat to the survival of mangroves (McKee *et al.,* 2007; Waycott *et al.,* 2011) and the loss of seaward edge of mangroves at Hungry Bay, Bermuda has been recorded by Ellison (1993) who attributes this to ongoing sea-level rise and the inability of mangroves to tolerate the increased inundation at the seaward margin. In other island studies in the Caribbean and the tropical Pacific there is varying observations in regards to the potential for sedimentation rates in mangroves forests to be able to keep pace with sea level rise (McKee *et al.,* 2007; Krauss *et al.,* 2003; 2010). In Kosrae and Pohnpei Islands in the Federated States of Micronesia, Krauss *et al.* (2010) found significant variability in mangrove average soil elevation changes due to deposition and this ranged from a deficit of 4.95 mm y^{-1} to a surplus of 3.28 mm y^{-1} relative to their sea-level rise estimates. This depositional potential is mostly reported from high island studies via the addition of terrigenous inputs. However, Rankey's (2011) study of shoreline processes in atolls in Kiribati also noted significant natural seaward migration (up to 40m) of some mangrove areas between 1969 and 2009. Likewise Webb (2007) found similar patterns in both mangroves and sea grass environments on Pinglap Atoll, Federated States of Micronesia between 1941 and 2006. This suggests sediment accretion can also occur in the absence of terrigenous inputs. Otherwise, in the absence of vertical accretion landward migration may occur where accommodation space permits (Gilman *et al.*, 2008), however coastal or back-beach areas in small islands are seldom extensive and observations on Martinique Island, in the Caribbean, show sea-level rise combined with coastal development is reducing the resilience or migration possibilities of the island's coastal wetland environments (Schleupner, 2008).

The response of sea grass to climate change stress is likely to be complex, regionally variable and potentially manifest in quite different ways even in the same location over foreseeable temporal time frames. A study of seven species of sea grasses from tropical Green Island, Australia highlighted the variability in response to heat and light stress (Campbell *et al.*, 2006) and likewise Koch and Erskine (2001) showed that sea grasses in Florida Lagoon only showed a dieback response to increased light and temperature conditions if ambient sulphide concentrations were also increased. Connolly's (2009) review of climate change impacts on sea grasses suggests increasing atmospheric CO_2 concentrations are likely to initially increase productivity and biomass of sea grass meadows. However, light reduction may be a limiting factor to sea grass growth due to increased depth (Ralph *et al.,* 2007) and Ogston and Field (2010) observed that a 20 cm rise in sea level may double suspended sediment loads and turbidity in the water column on Hawaii's Molokai Island's fringing reefs, negatively impacting benthic photosynthetic species such as sea grasses. Otherwise, temperature stress is most commonly reported as the main expected climate change impact on sea grass (e.g. Marbá and Duarte 2010; Campbell *et al.,* 2006; Waycott *et al.,* 2011). Literature on observational data of diebacks in small islands is scarce but research in the Balearic Islands (Western Mediterranean) has shown that over a six-year study, sea grass shoot mortality and recruitment rates were negatively influenced by higher temperature (Marbá and Duarte 2010).

29.3.2. Observed Impacts on Terrestrial Biophysical Systems

29.3.2.1. Biodiversity and Forests

Climate change impacts such as sea level rise and increasing temperatures has been linked with disturbance of terrestrial species, communities and ecosystems within islands however those climate change impacts reported are frequently seen as one of several drivers operating simultaneously to threaten biodiversity within small islands (Blackburn *et al.*, 2004; Didham *et al.,* 2005).

Sea level rise in conjunction with more frequent and intense hurricanes, have been observed to threaten the long-term persistence of freshwater-dependent ecosystems within low-lying islands in the Florida Keys (Goodman *et al.*, 2012; Ross *et al.,* 2008). On Sugarloaf Key, Ross *et al.* (2009) found pine forest area declined from 88 to 30 h from 1935 to 1991 due to increasing salinization and rising ground water, with vegetation transitioning to more saline tolerant species such as mangroves. Likewise observations on two carbonate islands in the Bahamas demonstrate the synergistic impacts of increasing sea level and reduced rainfall. Greaver and Sternberg (2010) found that during periods of reduced rainfall the shallow freshwater lens subsides and contracts landward and ocean water infiltrates further inland below coastal strand vegetation. The combination of drier conditions and saline incursion in deeper soils impacts vegetation formerly reliant on deeper freshwater reserves.

Increasing global temperatures also leads to altitudinal species range shifts and contractions have also been recorded within high islands with an upward creep of the tree line and associated faunal species (Benning *et al.*, 2002). Comparative vegetation distribution and composition from 1906 to 2006 in the Central Mountain Range of Taiwan found an upwards shift of about 3.6 m per year in the upper altitudinal limits of vegetation distributions (Jump *et al.*, 2012) and in sub-Antarctic Marion Island, Parolo and Rossi (2008) found an altitudinal shift of 3.4 m per year for plant species. Reduction in the numbers and sizes of endemic populations caused by such habitat constriction and changes in species composition in mountain systems may result in demise and possibly extinction of endemic species (Chen *et al.*, 2009; Pauli *et al.*, 2007; Sekercioglu *et al.,* 2008). Likewise, vegetation cover within the grass communities on the Falkland Islands was observed to decrease after two years of warming (0.7° C), with two species (*Poa annua* and *Aira praecox*) disappearing (Bokhorst *et al.*, 2007). Similarly, decreased population growth rates have also been recorded for soil arthropod communities on the Falkland islands (Bokhorst e*t al.*, 2008) and for soil oribatid mites on Svalbard (Webb *et al.*, 1998) due to temperature increases of 1 to 2 ° C.

Changes in precipitation also interact with changing temperature and in manipulative experiments on Marion Island, results indicate that continued warming and drying may lead to a population decline of the 'keystone' species such as the cushion plant (*Azorella selago*) (Le Roux *et al.*, 2005). Recent study of the tropical bird species the Mauritius kestrel suggests that changing rainfall conditions in Mauritius over the last 50 years have resulted in this species having reduced reproductive success due to a mismatch between the timing of breeding and peak food abundance

(Senapathi *et al*., 2011). Otherwise, altitudinal temperature change has also been reported to influence the distribution for disease vectors such as mosquitoes potentially threatening biota unaccustomed to such vectors (Freed *et al*., 2005). Changing climatic conditions have also been documented to enhance conditions necessary for the spread of exotic and pest species within the mid-latitude islands (Kudo *et al*., 2004) as well as within species poor sub-Arctic/Antarctic islands (Chapuis *et al.,* 2004; Frenot *et al*., 2005), leading to changes in species assemblages and ecosystem function (Chown and Convey, 2007).

29.3.2.2. Hydrology and Water Resources

Freshwater supply in small island environments has always presented challenges and has been an issue raised in all previous IPCC reports. On high volcanic and granitic islands small and steep river catchments respond rapidly to rainfall events and watersheds generally have restricted storage capacity. On porous limestone and low atoll islands surface runoff is minimal and water rapidly passes through the substrate into the ground water lens. Rainwater harvest is also an important contribution to freshwater access and complex alternatives like desalination has mixed success in small island settings due to operational costs and complexity (White and Falkland, 2010). Detection of long-term statistical change in precipitation is thus a key prerequisite to understanding the impacts of climate change in small island hydrology and water resources.

Rapidly growing demand, land use change, urbanisation and tourism are already placing significant strain on the limited freshwater reserves in small island environments (Cashman *et al*., 2010; Emmanuel and Spence, 2009; White and Falkland, 2010; Moglia *et al.,* 2008a, 2008b; White *et al*., 2007). In the Caribbean there is considerable variation in the types of freshwater supplies utilised, including groundwater, surface flow, rainwater harvest and desalinization, nevertheless concern over the status of freshwater availability has been expressed for at least the past 30 years (Cashman *et al*., 2010). Rainfall records averaged for the Caribbean region over the past 100 years also show a consistent 0.18 mm/year reduction in rainfall, a trend that is projected to continue (Jury and Winter, 2010), The situation of water availability in the Caribbean is likely to deteriorate unless astutely managed.

Saline intrusion into fresh groundwater reserves on atoll islands is frequently attributed to incremental sea-level rise yet there is a paucity of empirical evidence to support this premise (e.g. Rozell and Wong, 2010). White and Falkland's (2010) review of existing small island studies indicates that a sea level increase of up to 1 m would have negligible salinity impacts on small island groundwater lenses so long as there is adequate vertical accommodation space, island shores remain intact, rainfall patterns do not change and direct human impacts are managed. However, wave overtopping and wash over can be expected to become more frequent with sea level rise and this has been shown to impact freshwater lenses dramatically. On Pukapuka Atoll, Cook Islands storm surge over-wash occurred in 2005 and caused the fresh water lenses to become immediately brackish and took some 11 months to recover to conductivity levels appropriate for human use (Terry and Falkland, 2010). The ability of freshwater lens' to float upwards within the matrix of the island in step with incremental sea level rise also means that in low-lying and central areas of many atolls the lens may 'express' at the surface. This phenomenon already occurs in very low-lying central areas of Fongafale Island, Tuvalu, and during 'king' tides large areas of the inner part of the island become inundated with brackish waters (Yamano *et al*., 2007; Webb 2006; 2007).

29.3.3. Observed Impacts on Human Systems

29.3.3.1. Settlements and Infrastructure

Traditional patterns of settlement and the more recent interest in tourism have resulted in the great majority of infrastructure and development being located in the coastal fringe of small islands. In the case of atoll islands, land area is seldom more than 1 km wide from lagoon to ocean coasts and frequently far less. As such, all development and settlement on atolls is essentially coastal. It follows that populations, infrastructure, agricultural areas and fresh groundwater supplies are all vulnerable to extreme tides, wave and surge events and sea level rise. Population drift from outer islands or from inland on high islands, together with rapid population growth in main centers, further exacerbates these problems and the lack of accommodation space drives growing populations into ever more vulnerable locations. Additionally, without adequate resources and planning, engineering solutions such as shoreline reclamation also frequently place communities and infrastructure in positions of increased risk (Schleupner, 2008; Yamano *et al*., 2007).

Many of the environmental stresses that have been attributed to Tuvalu, the Marshall Islands and Maldives are in fact appropriate only to the major center and its surrounds, that is Funafuti, Majuro and Male respectively. As an example Storey and Hunter (2010) indicate the ‘Kiribati’ problem does not refer to the whole of Kiribati but is generally restricted to the southern half of Tarawa atoll where preexisting issues of severe overcrowding, proliferation of informal housing and unplanned settlement, inadequate water supply, poor sanitation and solid waste disposal, pollution and conflict over land ownership are of immediate importance. These problems require immediate resolution if the vulnerability of the South Tarawa community to the ‘real and alarming treat’ of climate change is to be managed effectively (Storey and Hunter, 2010).

The issue of ‘coastal squeeze’ remains a concern for many small islands in the Caribbean, the Pacific, Indian Ocean and the Mediterranean, as there is a constant struggle to manage the requirements for physical development against the need to maintain ecological balance (Fish *et al.,* 2008; Sano *et al.,* 2010; Gero *et al*., 2011; Mycoo, 2011). The island of Martinique in the Caribbean exemplifies the point, where physical infrastructure prevents the beach and wetlands from retreating landward as a spontaneous adaptation response to increased rates of coastal erosion (Schleupner, 2008). Moreover, intensive coastal development in the limited coastal zone combined with population growth and tourism have placed great stress on the coast and has resulted in dense aggregations of infrastructure and people in potentially vulnerable conditions.

Rapid unplanned urban development patterns on Majuro Atoll also highlight the unavoidable abandonment of traditional settlement patterns where the original settings for villages coincided with the least vulnerable locations on the island (Spennemann, 1996). Likewise, geophysical studies of Fongafale Island, the capital of Tuvalu, show that engineering works during World War II, and rapid development and population growth since independence, has lead to the settlement of inappropriate shoreline and swampland areas leaving communities in heightened conditions of vulnerability (e.g. Yamano *et al*., 2007). Ascribing direct climate change impacts in such disturbed environments is problematic due to the existing multiple lines of stress on the island’s biophysical and social systems. However, it is clear that such pre-existing conditions of vulnerability add to the threat of climate change in such locations.

29.3.3.2.Tourism and Recreation

Linkages between weather, climate and tourism in small islands have been assessed on several occasions, including in IPCC assessments. Weather conditions affect decisions by tourists to visit certain destinations and not others, particularly when seasonal variations are pronounced, as in the case of island destinations located in the temperate zone. In a study of Mediterranean tourism Moreno (2010) confirms the importance of climate as a destination attribute, but he argues that ‘heat waves’ may be considered ‘not too negative’ by tourists, and such conditions may not have adverse impacts on the tourism trade. ‘Ideal weather’ for beach tourism is associated with temperatures of approximately 28°C, light breezes and a blue sky. If these conditions were to be found in more temperate countries as a result of climate change, it would have only a moderate effect on destination choice. This assertion is to an extent supported by Gossling *et al.* (2006) with regard to tourism on the island of Zanzibar. They suggest that climate change affects tourism performance, not only because of actual impacts, but also because of perceptions of tourists regarding other climate variables, such as more rain, storms, and high humidity. These are more likely to negatively influence travel decisions than higher temperatures alone, the latter not necessarily perceived as negative.

Climate can also impact directly on the resources that support tourism in small islands. Observed impacts include coastal erosion are a result of coral bleaching and extreme wave action (Sheppard *et al*., 2005). In a recent study in the Caribbean, it was found that more than 80% of tourists in Bonaire and Barbados would be unwilling to undertake repeat visits in cases of coral bleaching and coastal erosion (Uyarra *et al*., 2005). Extreme drought events linked to climate change also impacts on tourism, especially on islands that depend upon natural sources of water to feed the water requirements of the tourism industry (Payet & Agricole, 2006). As a consequence some islands with strong tourism are investing in coral reef restoration, beach rehabilitation and desalination plants in attempts to reverse the negative publicity arising from those observed impacts. Such impacts also cause concern among investors in the tourism industry, especially in terms of insurance premiums and the additional costs of adaptation.

29.3.3.3. Human Health

Many small island states currently suffer from climate-sensitive health outcomes, including morbidity and mortality from extreme weather events, certain vector-and food- and water-borne diseases (Ebi, *et al*., 2006). Extreme weather and climate events such as tropical cyclones, storm surges, flooding, and drought can have both short-and long-term effects on human health, including drowning, injuries, increased disease transmission, and health problems associated with deterioration of water quality and quantity. Most small island nations are in tropical areas with weather conducive to the transmission of diseases such as malaria, dengue, filariasis, and schistosomiasis.

The linkages between human health, climate variability and seasonal weather have been demonstrated in several recent studies. Leptospirosis is an infectious disease that has been identified in the Caribbean as a 'highly endemic zone for leptospirosis' with Guadeloupe, Barbados, and Jamaica representing the highest annual incidence (13 to 7.8 per 100,000 population) in the world with only the Seychelles being higher (43.2 per 100,000 population) (Pappas *et al.,* 2008). Studies conducted in Guadeloupe demonstrated a link between El Niño occurrence and leptospirosis incidence with rates increasing to 13 per 100,00 population in El Nino years as opposed to 4.5 cases per 100,00 inhabitants in La Niña and neutral years (Herrmann-Storck *et al.,* 2008). In addition, epidemiological studies conducted in Trinidad reviewed the incidence of leptospirosis during the period 1996-2007 and showed seasonal patterns in the occurrence of confirmed leptospirosis cases, with significantly ($P<0.001$) more cases or 75% of all cases occurring in the wet season, May to November (193 cases), than during the dry season, December to May (66 cases) (Mohan *et al*., 2009). Recently changes in the epidemiology of leptospirosis have been detected especially in tropical islands with the main factors being climatic and anthropogenic (Pappas *et al*., 2008).

It is expected that these problems will increase as a consequence of climate change with increases in ambient temperature and changes in precipitation, vegetation and water availability (Russell, 2009). In the Pacific islands where the rates of diseases such as malaria and dengue fever are increasing, especially endemic dengue in Samoa, Tonga and Kiribati, other health threats as a consequence of climate change are expected to include outbreaks of cholera and ciguatera (Russell, 2009).

In a recent review of health governance and the impact of climate change on islands of the Pacific, Lovell (2011: 50) indicates that 'food security and access to fresh drinking water are already recognized as primary threats to the public health of many Pacific nations as saline intrusions into ground water tables is brought about by rising sea levels and increases in extreme weather events'. She also notes that many of the anticipated health effects of climate change in the Pacific are anticipated to be indirect, connected to the increased stress and declining well-being that comes with property damage, loss of economic livelihood and threatened communities and she suggests that 'human health in the Pacific is being shaped by processes of global environmental change that extend beyond climate change' and asks 'whether the current funding on surveillance is intended to distinguish between the effects of human induced climate change from other sources of environmental change in order to determine international obligations' (Lovell, 2011: 55).

Ciguatera fish poisoning (CFP) occurs in tropical regions worldwide and, globally, is the most common non-bacterial food-borne illness associated with consumption of fish (Baden *et al*., 1995; Ansdell, 2009). Distribution and abundance of the organisms that produce these toxins, chiefly dinoflagellates of the genus Gambierdiscus, are reported to correlate positively with water temperature. Consequently, there is growing concern that increasing temperatures associated with climate change could increase the incidence of CFP. One of the objectives of this study was to characterize the relationships between sea surface temperatures (SSTs) and CFP incidence rates in the Caribbean. This was done in tandem with a series of experiments designed to determine the effects of temperature on the growth rate of organisms responsible for CFP. High rates in the Lesser Antilles occur in areas which experience the warmest water temperatures and which show the least temperature variability. There are also high rates in the Pacific in Tokelau, Tuvalu, Kiribati, Cook Islands and Vanuatu.

The influence of climatic factors on malaria vector density and parasite development is well established (Beguin *et al.,* 2011; Chaves and Koenraadt, 2010). Previous studies have assessed the potential influence of climate change on malaria, using deterministic or statistical models (Gething *et al*., 2010; Hay *et al.,* 2006, 2009; Martens *et al*., 1999; Parham and Michael, 2010; Pascual *et al*., 2006). In the Caribbean, the occurrence of autochthonous malaria in non-endemic island countries in the last ten years, suggests that all of the essential malaria transmission conditions now exist, and Rawlins *et al*. (2008) call for enhanced surveillance, recognizing the possible impact of climate change on the spread of anopheles and malaria transmission.

29.3.3.4. Migration and Resettlement

Since the AR4 there has been an increase in studies of the potential displacement of people from several small island nations as a result of climate change. This is especially the case with the prospect of sea-level rise on low-lying islands and particularly the atoll nations of Kiribati, Marshall Islands, Maldives and Tuvalu which have been described as ‘sinking nations’ (Jarvis, 2010). In fact the last country, Tuvalu, has been the subject of many media reports most of which have suggested that rising sea levels will result in substantial land loss or indeed the disappearance of Tuvalu, though this has been disputed by Farbotko (2010) and Mortreux and Barnett (2009). On the other hand there is evidence for the robustness of atoll islands in the face of tsunami and tropical cyclones (e.g., Kench *et al.,* 2008), as well as examples of some atoll islands in the Maldives accumulating during rising sea level in the mid- to late-Holocene (Kench *et al*., 2005).

Whether the movement of people from one location to another from climate change is an ‘impact’ or ‘adaptation’ is perhaps a theoretical matter. But in recent years a new literature has been spawned relating to climate change-migrants from small islands. Such a consequence has frequently been seen as an equity or human rights issue or ’a moral imperative’ (Aminzadeh, 2007) that deals with the ‘biopolitics of displaced bodies’ (Bastos, 2008) and the need to provide ‘new homes for climate change exiles’ (Byravan and Rajan, 2006). It is also an issue that has important ‘security implications’ that relate not just to out-migration but to the impact on ‘recipient’ countries (Podesta and Ogden, 2007).

However Mortreux and Barnett (2009), in a study on Funafuti (Tuvalu) challenge the view that climate change will result in large-scale migration from Tuvalu. They show that for most people climate change is not a reason for concern, let alone a reason to migrate, and that would-be migrants do not prioritize climate change as a reason to leave the country. Indeed many small islands, including Tuvalu and Kiribati, have a long history of temporary or permanent out-migration, and some countries, for example Cape Verde, have both experience of and resilience in the migration tradition (Akesson, 2008).

A related argument, put forward by Rasmussen *et al*. (2009) with regard to Polynesian outlier islands in Melanesia (Solomon Islands) is that migration has occurred in the past due to various factors, and that in the future climate change factors will be difficult to disentangle from other reasons for resettlement. Populations from outlying islands constantly move to the larger islands and centers for a host of reasons including the breakdown of the traditional population control mechanisms, the search for jobs and health care. Whether climate change could be identified as an independent factor in such movements is doubtful (Rasmussen *et al*., 2009, 2011).

29.4. Projected Integrated Climate Change Impacts

Small islands face many challenges in using climate change projections for policy development and decision-making. Primary among these is the absence of credible regional socio-economic scenarios relevant at the scale at which most decisions are taken. Scenarios are an important tool to help decision makers disaggregate vulnerability to the direct physical impacts of the climate signal from the vulnerability associated with socio-economic conditions and governance. Before building socio-economic scenarios to aid decision making, there has to be scientifically credible simulation of future small island climates. In this regard, there is a serious problem in generating climate scenarios at the scale of small islands since they are generally much smaller than the resolution of the global models. This is because the grid squares in the Global Circulation Models used in the SRES scenarios used over the last decade, were between 200 and 600 km^2, which provides inadequate resolution over the land areas of virtually all small islands. The scale problem has been usually addressed by the implementation of statistical downscaling models that relate the GCM output to the historical climate of a local small island data point. The limitation of this approach is the need for observed data ideally for at least three decades for a number of representative points on the island, in order to establish the statistical relationships between the GCM data and the observations. In most small islands long term quality controlled climate data is generally sparse, however where adequate local data is available for several stations for at least 30 years, downscaling techniques have demonstrated that they can respond to the guidance of the GCMs to closely match the local domain and that they require less computational demand (e.g. Charlery and Nurse, 2011). Even so, most projected changes in climate for the Caribbean, Pacific, Indian Ocean and Mediterranean Islands, generally apply to the regions as a whole and not specific countries.

29.4.1. Projected Impacts for Islands based on Existing SRES Scenarios

The broad synthesis in the AR4 of climate scenario projections and impacts on small island regions and projected impacts from AR4 (e.g. Mimura *et al*., 2007) remains valid. For example, Table 29-1 shows that in general for the SRES A1B more balanced medium emissions scenario, the projections suggest about a 2°C increase in temperature in the Caribbean, Indian Ocean and Pacific Ocean small islands regions by 2100 with an overall annual decrease in precipitation of about 12% in the Caribbean and a 3-5% increase in the Indian and Pacific Oceans small island regions.

[INSERT TABLE 29-1 HERE
Table 29-1: Small islands' regions temperature and precipitation change projections for the SRES A1B scenario over the period 1980-1999 compared to 2080-2099. The table shows the minimum, median (50%) and maximum values of the mean temperature and precipitation responses from each of the 21 AR4 global models (Adapted from Table 11.1 in AR4 WG1).]

In the five main regions in which most tropical or sub-tropical small island developing states are located, there are only a handful of independent peer reviewed scientific publications providing downscaled climate data projections, and virtually none illustrating the experience gained from their use for policy making. We note though the existence of several national reports and consultancies sponsored by donor agencies, however these do not generally pass the test of independent peer review so we decline to quote them here. A projected 2ºC temperature increase by the year 2100 has potential far reaching consequences for sentinel ecosystems such as coral reefs that are important to tropical islands. This is because 'Degree Heating Months' (DHM) >2 ºC-month are the determined threshold for severe coral bleaching (Donner, 2009). For example Donner (2009) in a study of sea surface temperature (SST) across all coral reef regions using CM 2.0 and CM 2.1 GCM ensemble projections forced with five different SRES future emissions scenarios, concluded that even warming in the future from the current accumulation of greenhouse gases in the atmosphere could cause over half of the world's coral reefs to experience harmfully frequent thermal stress by 2080. Further, this timeline could be brought forward to as early as 2030 under the A1B medium emissions scenario. He further states that thermal adaptation of 1.5 ºC would only delay the thermal stress forecast by 50–80 years. Donner (2009) also estimated the year of likelihood of a severe mass coral bleaching event due more than once every 5 years, to be 2074 in the Caribbean, 2074 in the western Indian Ocean, 2082 in the central Indian Ocean, 2065 in Micronesia, 2057 in the central Pacific, 2094 in Polynesia and 2073 in the eastern Pacific small islands regions.

Small island economies can also be objectively shown to be at greater risk from sea-level rise in comparison to other geographic areas. Such a study is the use of the FUND model to assess the economic impact of substantial sea-level rise in a range of socio-economic scenarios downscaled to the national level, including the four SRES storylines (Anthoff *et al.,* 2010). Although this study shows that in magnitude, a few regions experience most of the costs of sea-level rise by 2100, especially East Asia, North America, Europe and South Asia, these same results when expressed as percent of GDP show that most of the top ten and four of the top five most impacted are small islands from the Pacific (Micronesia, Palau, Marshall islands, Nauru) and Caribbean (Bahamas) (Anthoff *et al.,* 2010). The point is made that the damage costs for these small island states are enormous in relation to the size of their economies (Nicholls and Tol 2006) and that together with deltaic areas they will find it most difficult to raise the finances necessary to implement protection (Anthoff *et al*., 2010).

In the Caribbean, downscaled climate projections have been generated for some Caribbean islands using the Hadley Centre PRECIS regional model (Taylor *et al*., 2007, Stephenson *et al.,* 2008). For the SRES A2 and B2 scenarios the PRECIS regional climate model projects an increase in temperature across the Caribbean of 1–4 °C with increasing rainfall during the latter part of the wet season from November–January, in the northern Caribbean (i.e. north of 22°N) and drier conditions in the southern Caribbean with a strong tendency to drying in the traditional wet season from June–October (Whyte *et al*., 2008, Campbell *et al.,* 2010, Taylor *et al.,* 2011, Taylor *et al.,* 2012). Projected lengthening seasonal dry periods, and increasing frequency of drought periods are expected to increase demand for water throughout the region under the SRES A1B scenario (Cashman *et al*., 2010). Decrease in crop yield is also projected in Puerto Rico for the SRES B1 (low), A2 (mid-high) and A1F1 scenarios during September although increased crop yield is suggested during February (Harmsen *et al.,* 2009). Using a tourism demand model linked to the SRES A1F1 A2 B1 and B2 scenarios, the projected climate change heating and drying impacts are also linked to potential aesthetic, physical and thermal effects that are estimated to cause a change in total regional tourist expenditure of about +321, +356, -118 and -146 million US dollars from the least to the most severe emissions scenario respectively (Moore, 2010).

In the Indian Ocean, representative downscaled projections have been generated for Australia's two Indian Ocean territories the Cocos (Keeling) Islands and Christmas Island using the CSIRO Mark 3.0 climate model with the SRES A2 scenario which implies a reduction of the greenhouse gases emissions in a more economic and regional world (Maunsell, 2009). Future climate change projections for the two islands for 2030 and 2070 include quantitative estimates of air and sea temperature increases and sea-level rise as well as estimates of the intensity, frequency and distribution of tropical cyclones and storms.

In the tropical Pacific Ocean, a comprehensive assessment of the vulnerability of the fisheries and aquaculture sectors to climate change in 22 Pacific island countries and territories focussed on two future time-frames (2030 and 2100) and two SRES emissions scenarios, B1 (low emissions) and A2 (high emissions) (Bell *et al*., 2011). The results are not very different from the IPCC AR4 projections with projected temperature increases of about +1.0 to 1.5 ºC by 2100 and an increase in rainfall of 10-20% in equatorial regions. Estimates of the resulting projected changes in habitat area (mangroves, seagrasses, freshwater fish) coral reef cover, demersal fish production, skipjack and bigeye tuna for the two SRES scenarios are given in Table 29-2.

[INSERT TABLE 29-2 HERE
Table 29-2: Projected percentage change in key marine natural habitat or resources in 22 tropical Pacific small islands under the SRES B1 and A2 scenarios (adapted from Bell et al., 2011).]

Most anticipated changes in habitat and resource availability such as the commercial tuna catch are negative, with implications for government revenue and island food security (Bell *et al*., 2011).

In the Mediterranean Sea islands of Mallorca, Corsica, Sardinia, Crete and Lesvos, Gritti *et al.* (2006) simulated the vegetation biogeography and distribution dynamics under the SRES A1F1 and B1 scenarios. The simulations indicate that the effects of climate change are expected to be negligible within most ecosystems except for mountainous areas that are projected to be eventually occupied by exotic vegetation types from warmer, drier conditions. Cruz *et al.* (2009) also report similar results for the terrestrial ecosystems of Madeira Island in the Mediterranean. Downscaled SRES A2 and B2 scenarios for the periods 2040 – 2069 and 2070 – 2099 suggest that the higher altitude native humid forest called the Laurissilva, may expand upwards in altitude, which could lead to a severe reduction of the heath woodland which because it has little upward area to shift may reduce in range or disappear at high altitudes resulting in the loss of rare and endemic species within this ecosystem.

29.4.2. New RCP Projections and Implications for Small Islands of GMST <2.0 Degrees

Utilizing updated historical greenhouse gas emissions data, the scientific community has produced future projections for four plausible new global Representative Concentration Pathways (RCPs) in order to explore a range of global climate signals up to the year 2100 and beyond (e.g. Moss *et al.,* 2010; van Vuuren *et al*., 2010). The RCPs are named according to their global warming potential (e.g. RCP 4.5 W/m^2) and are matched to a global socio-economic scenario storyline. Scientists have strongly cautioned against the specification of detailed sub-global conditions and trends (regional/local) based on these coarser global datasets and models. With these caveats in mind, typical representations of RCP projections for temperature and precipitation for similar times of the year in some small island regions are presented in Figure 29-2 adapted from Annex I WGI AR5. Highlighted in Figure 29-2 is the output of one model, that is the mid-projection representation of each RCP model ensemble. A more comprehensive compilation of global RCP projections can be found in Annex I of the WGI AR5 Report.

[INSERT FIGURE 29-2 HERE
Figure 29-2: RCP Scenario projections to the year 2100 for the four main small island regions (Adapted from AR5 WG1, Annex 1).]

Small Island Developing States (SIDS) have advocated that the Global Mean Surface Temperature (GMST) increase should be limited to no more than 1.5ºC by the year 2100. Inspection of column 1 in Figure 29-2 suggests that for Caribbean, Indian Ocean and Pacific SIDS in the tropics, that is only likely under RCP 2.6 which in each case yields about a 1ºC regional increase by 2100. RCP 2.6 also suggests no significant change in mean rainfall in the Caribbean with a slight increase for Indian and Pacific Ocean SIDS. In the mid-latitude Mediterranean Sea region RCP 2.6 yields about a 2ºC increase in temperature by 2100 and no apparent change in rainfall.

By comparison with regard to temperature, RCP 4.5 in Figure 29-2 suggest a likely less than 2ºC but not less than 1.5ºC temperature increase in Caribbean, Indian Ocean and Pacific SIDS by 2100 and about a 3ºC increase in the Mediterranean. Associated with this, the Caribbean and Mediterranean regions are likely to experience a decrease in mean rainfall while the Indian and Pacific Ocean SIDS are likely to experience increased rainfall. These trends accelerate moderately for RCP 8.0 and steeply for RCP 8.5.

The implications of these preliminary findings are that only scenarios associated with RCP 2.6 W/m^2 are likely to meet the SIDS demand to limit global mean surface temperature (GMST) to <2ºC by 2100 but a further secondary target of RCP 4.5 W/m^2 is likely to limit GMST to <2ºC in the tropical SIDS regions as well. According to Ranger *et al*. (2012) mitigation scenarios with a 50 per cent chance of achieving the 1.5ºC goal with a temporary overshoot of no more than 50 years must have "strong reductions in emissions, with global emissions peaking in 2015 and falling to at most 44–48 GtCO2e in 2020; rapid reductions in annual global emissions after 2020 (of at least 3–4% per year); very low annual global emissions by 2100 (less than 2–4 GtCO2e) and falling to zero (or below) in the 22nd century". Ranger *et al*. (2012) further conclude that the proposed date of review of the 1.5°C goal, set at 2015 by the Ad Hoc Working Group on Long-term Cooperative Action under the Convention from the 16th session of the Conference of the Parties (COP16), may be too late to achieve the necessary scaling up of emissions cuts to achieve this goal.

29.5. Inter- and Intra-Regional Transboundary Impacts

Many impacts on small islands are generated from another region or continent well beyond the borders of an individual nation or island. Some transboundary processes may have positive effects on the receiving small island or nation, though most that are reported have negative impacts. Deciphering a climate change signal in inter- and intra-regional transboundary impacts on small islands is not easy and usually involves a chain of linkages tracing back from island-impact to a distant climate or climate-related bio-physical or human process. Some examples are given below.

29.5.1. Physical Events and Impacts

29.5.1.1. Large Ocean Waves from Distant Sources

Unusually large deep ocean swells, generated from far distant sources in the mid- and high-latitudes cause considerable damage on the coasts of small islands thousands of kilometers away in the tropics. Impacts include sea-flooding and inundation of settlements, infrastructure and tourism facilities as well as severe erosion of beaches. Examples from small islands in the Pacific and Caribbean are common though perhaps the most significant instance, in terms of a harbinger of climate change and sea-level rise, occurred in the Maldives in April 1987 when long period swells originating from the Southern Ocean some 6000 km away caused major flooding, damage to property, destruction of sea defences and erosion of reclaimed land and islands. (Harangozo, 1992). The Maldives and several other island groups in the Indian Ocean have been subject to similar ocean swell events more recently, most notably in May 2007 (Department of Meteorology, 2007).

In the Caribbean northerly swells affecting the coasts of islands have been recognized as a significant coastal hazard ever since the 1950s (Donn and McGuinness, 1959). They cause considerable seasonal damage to beaches, marine ecosystems and coastal infrastructure throughout the Caribbean (Cambers, 2009; Bush *et al*., 2009). These high-energy events manifest themselves as long period, high-amplitude waves generated by extra-tropical cyclones and high latitude lows originating thousands of kilometers away in the North Atlantic. They occur during the northern hemisphere winter and often impact the normally sheltered, low-energy leeward coasts of the islands (Bush *et al.,* 2009; Cambers, 2009). Such swells have even reached the shores of Guyana on the South American mainland as illustrated by a swell event in October 2005 that caused widespread flooding and overtopping and destruction of sea defences (van Ledden *et al*., 2009). Distant origin swells differ from the 'normal' wave climate conditions experienced in the Caribbean, particularly with respect to direction of wave approach, wave height and periodicity. Based on statistical analysis of wave data from voluntary observer ships (VOS), Gulev and Grigorieva (2006) suggest that significant wave heights have increased by between 10 – 40 cm/decade in both the North Atlantic and North Pacific, during the period 1958-2002.

Swells of similar origin and characteristics are also known to occur in the North Pacific. This is exemplified by the case of Oahu Island, Hawaii, where there is documented evidence of damage to coral growth by northerly swell, especially during years with a strong El Nino signal (Fletcher *et al*., 2008). Whereas the origin of the long period ocean swells that impact small islands in the tropical regions come from the mid-and high-latitudes in the Pacific, Indian and Atlantic oceans, there are also instances of unusually large waves generated from tropical cyclones that spread into the mid- and high- latitudes. One example occurred during 1999 when tide gauges at Ascension and St. Helena Islands in the central south Atlantic recorded unusually large deep-ocean swell generated from distant Hurricane Irene (Vassie *et al*., (2004). The impacts of increasing incidence or severity of storms or cyclones is generally considered from the perspective of direct landfall of such systems whereas these instances All of these instances serve to show 'the potential importance of swells to communities on distant, low-lying coasts, particularly if the climatology of swells is modified under future climate change' (Vassie *et al*., 2004: 1095).

29.5.1.2. Trans-Continental Dust Clouds and their Impact

The transport of Saharan dust across the Atlantic and into the Caribbean has engaged the attention of researchers for some time. The resulting dust clouds are known to transport pollen, microbes, insects, bacteria, fungal spores and various chemicals (Prospero *et al*., 2005; Griffin, 2007; Middleton *et al*., 2008; Monteil, 2008). During major events, dust concentrations can exceed 100 μg m^{-3} (Prospero, 2006; Griffin, 2007). Various independent studies using different methodologies have all found a strong positive correlation between dust levels in the Caribbean and periods of drought in the Sahara, while concentrations show a marked decrease during periods of higher rainfall. Consequently, it is argued that higher dust emissions due to increasing aridity in the Sahel and other arid areas could enhance climate effects over large areas, including the eastern Caribbean and the Mediterranean (Prospero and Lamb, 2003; Santese *et al*., 2009). Similar findings have been reported at Cape Verde where dust emission levels were found to be a factor of nine lower during the decade of the 1950s when rainfall was at or above normal, when compared to the 1980s, a period of intense drought in the Sahel region (Nicoll *et al*., 2011). Dust from the Sahara has also long been known to reach into the eastern Mediterranean (e.g., Santese *et al.*, 2010) whilst dust from Asia has been transported across the Pacific and Atlantic oceans and around the world (Uno *et al.*, 2009).

There is evidence that the trans-boundary movement of Saharan dust into the island regions of the Caribbean, Pacific and Mediterranean is associated with various human health diseases including asthma admissions in the Caribbean (Monteil, 2008; Monteil and Antoine, 2009; Prospero *et al.*, 2008), cardiovascular morbidity in Cyprus in the Mediterranean (Middleton *et al.,* 2008) and is found to be a risk factor in respiratory and obstructive pulmonary disease in the Cape Verde islands (Martins *et al.*, 2009). These findings underscore the need for further research into the link between climate change, airborne aerosols and human health in localities, such as oceanic islands far distant from the continental source of the particulates.

29.5.2. Movement and Impact of Introduced and Invasive Species across Boundaries

Invasive species are colonizer species that establish populations outside their normal distribution ranges and spread into natural or local areas. The spread of invasive alien species is regarded as a significant trans-boundary threat to the health of biodiversity and ecosystems, and has emerged as a major factor in species decline, extinction and loss of biodiversity goods and services worldwide. This is particularly true of islands, where both endemicity and vulnerability to introduced species tend to be high (Kenis *et al.*, 2008; Reaser *et al.*, 2007; Westphal *et al.*, 2008; Rocha *et al.*, 2009; Kueffer *et al.*, 2010). The extent to which alien invasive species successfully establish themselves at new locations in a changing climate will be dependent on many variables, but non-climate factors such as ease of access to migration pathways, suitability of the destination, ability to compete and adapt to new environments, and susceptibility to invasion of host ecosystems are deemed to be critical. This is borne out for example by Le Roux *et al.* (2008) who studied the effect of the invasive weed *Miconia calvescens* in New Caledonia, Society Islands and Marquesas islands, by Gillespie and Pau (2008) in an analysis of the spread of *Leucaena leucocephala*, *Miconia calvescens*, *Psidium sp.* and *Schinus terebinthifolius* in the Hawaiia islands, and by Christenhusz and Toivonen (2008) whose work shows the potential for rapid spread and establishment of the oriental vessel fern, *Angiopteris evecta*, from the South Pacific throughout the tropics. Mutualism between an invasive ant and locally honeydew-producing insects has been strongly associated with damage to the native and functionally important tree species*, Pisonia grandis* on Cousine island, Seychelles (Gaigher, *et.al.*, 2011).

Whilst invasive alien species constitute a major threat to biodiversity in small islands, the removal of such species can result in recovery of that condition. This has been demonstrated in Mauritius where some forested areas were weeded of alien plants and after a decade species richness and abundance of seedlings was higher compared to the adjacent non-weeded native forest. Baider and Florens (2011) found that several species that were presumed extinct or critically threatened had recovered dramatically as a result of the removal of the alien invaders. They concluded, given the severity of alien plant invasion in Mauritius, that their example can ‘be seen as a relevant model for a whole swath of other island nations and territories around the world particularly in the Pacific and Indian Oceans’ (Baider and Florens, 2011).

The movement of aquatic and terrestrial invasive fauna within and across regions will almost certainly exacerbate the threat posed by climate change in island regions, and could impose significant environmental, economic and social costs. Englund (2008) has documented the negative effects of invasive species on native aquatic insects on Hawai’i and French Polynesia, and their potential role in the extirpation of native aquatic invertebrates in the Pacific. Similarly, there is evidence that on the island of Oahu introduced slugs appear to be ‘skewing species abundance in favour of certain non-native and native plants’, by altering the ‘rank order of seedling survival rates’, thereby undermining the ability of preferred species (e.g. the endangered *C. Superba*) to compete effectively (Joe and Daehler, 2008).

29.5.3. Spread of Aquatic Pathogens within Island Regions

The mass mortality of the black sea urchin, *Diadema antillarum*, in the Caribbean Basin during the early 1980s demonstrates the ease with which ecological threats in one part of a region can be disseminated to other jurisdictions thousands of kilometres away. The die-off was first observed in the waters off Panama around January 1983, and within 13 months the disease epidemic had spread rapidly through the Caribbean Sea affecting practically all island reefs, as far away as Tobago some 2000 km to the south and Bermuda, some 4000 km to the east. The diadema population in the wider Caribbean declined between 90-95 per cent as a consequence of this single episode (Lessios, 1988, 1995; Lessios et al.,1984; Rotjan and Lewis, 2008; Alvarez-Filip *et al*., 2009; Croquer and Weil, 2009a, 2009b). As *D. antillarum* is one of the principal grazers that removes macroalgae from reefs and thus promotes juvenile coral recruitment, the collateral damage was severe, as the region's corals suffered from high morbidity and mortality for decades thereafter (Carpenter and Edmunds, 2006; Myhre and Acevedo-Gutierrez, 2007; Idjadi *et al*., 2010).

There are other climate-sensitive diseases such as yellow, white and black band, white plague and white pox that travel across national boundaries and infect coral reefs directly. This is variously supported by examples from the Indo-Pacific relating to the role of bacterial infections in white syndrome and yellow band disease (Piskorska *et al*., 2007; Cervino *et al*., 2008), the impact of microbial pathogens as stressors on benthic communities in the Mediterranean associated with warming seawater (Ainsworth *et al*., 2007; Danovaro *et al*., 2009; Rosenberg *et al*., 2009), and an increasing evidence of white, yellow and black band disease associated with Caribbean and Atlantic reefs (Rosenberg *et al*., 2009; Cervino *et al*., 2008; Brandt and McManus, 2009; Croquer and Weil,2009a, 2009b; Miller *et al*., 2009; Weil and Croquer, 2009; McClanahan *et al*,, 2009; Weil and Rogers, 2011).

29.5.4. Transboundary Movements and Human Health

For island communities the trans-boundary implications of existing and future human health challenges are projected to increase in a changing climate. For instance, the aggressive spread of the invasive giant African snail, *Achatina fulica*, throughout the Caribbean, Indo-Pacific islands and Hawaii is not only assessed to be a severe threat to native snails and other fauna (e.g. native gastropods), flora and crop agriculture, but is also identified as a vector for certain human diseases such as meningitis (Reaser *et al*., 2007; Meyer *et al*., 2008; Thiengo *et al*., 2010).

Like other aquatic pathogens ciguatoxins, which cause ciguatera fish poisoning, may be readily dispersed by currents across and within boundaries in tropical and sub-tropical waters. Ciguatoxins are known to be highly temperature-sensitive and may flourish when certain sea water temperature thresholds are reached, as has been noted in the South Pacific (Llewellyn, 2010), Cook Islands (Rongo and van Woesik, 2011), Kiribati (Chan *et al*., 2011), the Caribbean and Atlantic (Morrison *et al*., 2008; Otero *et al*., 2010; Tester *et al*., 2010) and Mediterranean (Aligizaki and Nikolaidis, 2008). (See also 29.3.3.3).

29.6. Adaptation and Management of Risks

29.6.1. Addressing Current Vulnerabilities and Adaptation Gaps

Significant references are made in the literature to the vulnerability of small islands to climate change, the high costs of adapting in small islands, and the potential need for migration from small islands (Nicholls *et al.,* 2011, Gemenne, 2011, Biermann and Boas, 2010). Yet islands are heterogeneous in geomorphology, culture, ecosystems, populations and vulnerability to climate change. Vulnerabilities and adaptation needs are as diverse as the variety of islands between regions and even within nation states (such as the Solomon Islands, see for example Rasmussen et al., 2011).

Attempts have been made to assess the differing levels of vulnerability and to identify the adaptation gaps through national level vulnerability indices, such as indicators of climate impacts and vulnerability (Maplecroft, 2012, DARA and the Climate Vulnerable Forum, 2010); indicators of disaster risk (Peduzzi et al., 2009); indicators of environmental sustainability (Esty *et al.,* 2005), of quality of life (Prescott-Allen, 2001, UNDP, 2011), and of vulnerability (Adger *et al*., 2004, Cardona, 2007, Barr *et al*., 2010). Many of these indicators suffer from lack of data (e.g. Peduzzi et al., 2009) and generic indicators that are not relevant in all islands (Barnett and Campbell, 2010). Depending on the index used, the same islands can be shown to be both vulnerable and resilient. For example, according to Maplecroft (2012) Haiti is the second-most vulnerable country to climate change; according to Esty *et al.* (2005) Haiti is the sixth least environmentally sustainable country. Yet Haiti does not appear in the list of the 20 most vulnerable countries according to Barr *et al.* (2010), nor does it rank among the 20 least developed countries of the 2011 Human Development Index (UNDP, 2011). Each indicator clearly reveals different stresses on island systems, yet none provides a complete picture of island vulnerability.

Indices of vulnerability to climate change can provide only limited evidence of inter-island vulnerability (Barnett *et al.*, 2008), despite attempts to compare between islands (see for example Park *et al.,* 2012). In short, the presence or absence of vulnerability and resilience in small islands cannot be determined using existing vulnerability indicators alone.

Instead of relying on index-based scores to assess island vulnerability, adaptation gaps on islands could be determined through consideration of the civilisation-nature stresses (or syndromes) that islands experience. Petschel-Held *et al.* (1999) argue that there are three major patterns: utilisation syndromes (which relate to production); development syndromes (relating to the quest for economic growth) and sink syndromes (relating to the deposit of civilisations' waste). The presence of each of these syndromes implies a greater vulnerability to any environmental stress – including climate change. Within the island context several of the original syndromes developed by Newton *et al.* (2012), are relevant, see Table 29-3.

[INSERT TABLE 29-3 HERE
Table 29-3: Examples of syndromes affecting islands' vulnerability to climate change.]

Where multiple human-environment pressures already exist, addressing those may be the first step to address the adaptation gap. For example, with coral reef ecosystems – those already under stress from non-climate factors are more at risk from climate change than those that are unstressed (Maina *et al.*, 2011, Hughes *et al.*, 2003). The same argument appears to be true at the island scale: in Majuro (Marshall Islands), evidence from 34-37 years of aerial photography shows that rural areas are experiencing lower rates of erosion than urban areas, suggesting that human activity in coastal areas and interventions in coastal ecosystems are exacerbating erosion associated with sea level rise (Ford, 2012). Islands faced with multiple stressors can therefore be assumed to be more at risk from climate impacts. Recognizing the spectrum of syndromes faced on different islands is one means of assessing the adaptation gaps that exist for each unique island.

Following Smit *et al.* (2000), and Brooks *et al.* (2005), Barnett and Campbell (2010) reinforce the point that island vulnerability to climate change is often a function of four non-climate stressors: socio-economic, geo-physical, and socio-ecological vulnerabilities, as well as the climate stressor. Socio-economic vulnerabilities could be related to on-going challenges of managing urbanisation, pollution and sanitation, for example in Kiribati (Storey and Hunter, 2010). Geo-physical characteristics of islands are varied, some low-lying atolls, some oceanic, some volcanic islands – each of which creates different pre-existing vulnerabilities, for example the Azores (Portugal) face seismic, landslide and tsunami risks (Coutinho *et al.*, 2009). Socio-ecological stresses, such as habitat loss and degradation, invasive species, overexploitation, pollution, and disease are key features in vulnerability (see for example Caujape-Castells *et al.*, 2010, Kingsford *et al.,* 2009, Sax and Gaines, 2008). It is on top of these unique stresses that climate change exerts its impact, so that each of these non-climate vulnerabilities needs to be considered to fully understand the complete picture of island vulnerability to climate change (Rasmussen *et al.*, 2011). To illustrate this issue, Figure 29-3 depicts the severity of the syndromes described in Table 29-3, in four hypothetical island types.

[INSERT FIGURE 29-3 HERE
Figure 29-3: Multiple pressures on islands exacerbating island vulnerability to climate change.]

Figure 29-3 simply illustrates the degree of exposure to a spectrum of syndromes that islands could face. Four generic island types (a, b, c, and d) are suggested for illustrative purposes. Island type 'a' is likely to be remote, with little tourism, over-exploited natural resources e.g. fisheries or land based resources, and with a growing waste disposal problem. Island type 'b' has embraced mass tourism, is increasingly depleting its stocks of natural capital, and is facing growing problems with coastal squeeze. Island type 'c' is likely to be a low-lying island with limited land mass. These island types may have pursued mass tourism creating severe waste management problems and growing resource degradation as well as high levels of pressure on land. Island type ‘d’ is likely to be a larger island with an expanding tourism sector, but weak systems in place to manage its waste. The greater the area covered by the polygon in Figure 29-3 the greater the risks to that island from climate change.

29.6.2. Practical Experiences of Adaptation

Despite the often-made assumption that islands are vulnerable to climate change, islands and islanders are also recognized for their long experience of adapting to weather variability and climate hazards and for their resilience in the face of meteor-hydrological hazards (Barnett, 2001). Experiences of effective adaptation are increasingly being documented, these include: building adaptive capacity; developing novel mechanisms for managing risks; working collectively; and finding ways to address long term socio-ecological changes.

29.6.2.1. Building Adaptive Capacity (using Traditional Knowledge, Linking Science with Community Use, Technologies)

As in previous IPCC Assessments, there is continuing strong support for the incorporation of indigenous knowledge into adaptation planning. For example, Samoans have their own seasonal calendar based on observations of local environmental and weather changes. Their ability to forecast the onset of extreme weather and climate events relying predominantly on local environmental changes are tools that could be incorporated in the formulation of climate change adaptation strategies (Lefale, 2010). The point is underscored by one analyst, who suggests that the vulnerability of indigenous groups in small islands cannot be effectively tackled unless indigenous and Western knowledge are combined in ‘a culturally compatible and sustainable manner’ (Mercer et al., 2007: 245). This view converges with that of Gamble *et al.* (2010), who in a study involving sixty farmers in St. Elizabeth Parish, Jamaica, report a high level of agreement between the farmers’ perception of increasing drought incidence and statistical analysis of precipitation and vegetation data for the area. In this case the farmers perceptions clearly validated the observational data and vice versa.

There is a growing awareness of the role of traditional technologies and skills for climate adaptation. Examples of traditional practices that are supporting adaptation in the Solomon Islands are documented in Rasmussen *et al.* (2009). These include: the traditional practice of elevating concrete floors on Ontong Java to keep floors dry during heavy rainfall events; building ‘low, aerodynamic houses and sago palm leaves as roofing material on Tikopia in order to avoid hazards from flying debris such as metal roofs’ as preparedness for tropical cyclones; and in Bellona local perceptions are that houses constructed from modern materials and practices are more easily destroyed by tropical cyclones, implying that traditional construction methods are perceived to be more resilient in the face of extreme weather (Rasmussen *et al.,* 2009: 10).

As is increasingly recognized, frequency of exposure to major hazards appears to contribute to island adaptive capacity. In both the Solomon Islands and the Cayman Islands there is evidence that communities that frequently face, and recover from, hazards have a greater sense of their own resilience to hazards and potentially climate change (Schwarz *et al.,* 2011, Tompkins *et al.*, 2009). There is reasonable agreement about the factors that underpin this resilience to hazards that resonate with earlier work on successful governance of the commons i.e.: community cohesion, effective leadership, and community buy-in to collective action (Schwarz *et al.,* 2011, Tompkins *et al.*, 2008). All of these studies reinforce the earlier work of Barnett (2001), and suggest that supporting community-led approaches to disaster risk reduction and hazard management may contribute to greater community engagement with anticipatory adaptation.

Social organization is a key element of this capacity. Two discrete studies from the Solomon Islands highlight the importance of social organization within communities to support effective adaptation to climate change. Using 50 years of satellite imagery and aerial images, combined with household surveys in Bellona, Solomon Islands, cultural bonds have been found to play a central role in delivering adaptive management strategies for past extreme events (Reenberg *et al.,* 2008). In Tikopia, Solomon Islands, Mertz *et al.* (2010) compared island food security in 2010 with studies undertaken in 1939 and 1982. They concluded that the system of zero external input agriculture has proven sustainable, as agricultural systems are able to cope effectively with extreme events (notably Cyclone Zoe in 1972). In both Tikopia and Bellona, the strategy of relying on traditional systems of organization for farming and land use management have been shown to work effectively – largely as there has been little cultural and demographic change.

Traditional systems appear less effective when multiple civilization-nature stresses are introduced. For example in the island of Makira, Solomon Islands, where there have been high levels of population growth and changing social objectives, these factors appear to have acted as inhibitors of adaptation (Fazey *et al.,* 2011). The importance of taking into account local interests and traditional knowledge in adaptation in small islands is emphasized by Kelman and West (2009) and McNamara and Westoby (2011), yet there also needs to be recognition of its limits, such as in the context of rapid socio-ecological change.

Recent empirical observations from a variety of Pacific Islands have shown that perceptions of self-efficacy in addressing climate stress are an important pre-condition for anticipatory adaptation in islands. In their study of adaptation to water stress on Kiribati. Kuruppu and Liverman (2011) found that individuals' belief in their own ability to cope with water scarcity, largely based on past experience, appears to be a key driver in I-Kiribati attitudes to and choice of adaptation strategy. The resilience of islanders can also be seen in unusual examples of innovation in managing the changing climate. Islanders have long experience of optimising land to secure development gains and even of island building, and there is evidence from the Pacific that innovation based on traditional practices, such as the creation of artificial islands from ocean waste, may provide new opportunities for islands.

Despite this set of examples, there remains limited understanding of how traditional knowledge, technologies and skills are being used to support adaptation. To date research in the Pacific and Caribbean dominates small island climate change work. There is a great need for more detailed studies on small islands in the central and western Indian Ocean and the central eastern Atlantic.

29.6.2.2. Addressing Risks

Options for risk management on islands are influenced by the socio-ecological and geophysical vulnerabilities of islands, as well as the size of the risks faced relative to the set of response options that are available to islanders, and the control the islanders have over the risks (Briguglio, 2010).

Risk transfer can be undertaken through insurance, risk spreading through access to and use of common property resources, livelihood diversification, or mutual support through networks, and risk avoidance through migration. Insurance markets do not necessarily function as effectively in small locations as they do in larger locations, in part due to a small demand for insurance products. For example in the case of insurance for the food sector, following a survey of farmers, processors, retailers, government including extension officers on Grenada, Jamaica, Fiji and Vanuatu, researchers found that a lack of demand for insurance products means that there is an undersupply of customized food insurance products, which in turn contributes to further the lack of demand (Angelucci and Conforti, 2010). Despite our knowledge of the risk of moral hazard from the presence of insurance (whereby the insured under-invest in risk mitigating activities as they know they will be financially recompensed for any losses), researchers have recently suggested that hazard insurance could actively create maladaptation on islands. McNamara and Werner (2008) numerically model coastal dynamics for barrier island systems (such as the developed barrier islands on the US East Coast) with and without tourism resort development and storm protection. They conclude that once islands have developed into resorts with permanent engineered defences and fixed infrastructure, and the infrastructure is insured, these permanent structures prevent natural migration of coastal ecosystems in response to storms and sea level rise. In the longer term, due to the regular post-disaster rebuilding of infrastructure, islands are likely to lose their natural buffering capacity, become inundated and experience higher levels of damage. In short insurance is a risk transfer mechanism that needs to be carefully managed to ensure that it does not reduce capacity to adapt.

Risk spreading can take many forms from reliance on social networks and familial ties to creation of marine protected areas to enhance representation of habitat types and replication of species. For example, in Fiji, after

Cyclone Ami in 2003, those households whose homes were not affected by the cyclone increased their energy and time spent fishing to support those whose homes were damaged (Takasaki, 2011). In this way, risk was spread among the households, and mutual support formed a central pillar for community-based adaptation. In the case of natural systems, risks can be spread through the creation of marine protected areas around key refuges that protect a diversity of habitat, that cover an adequate proportion of the habitat and that protect critical areas such as nursery grounds and fish spawning aggregation areas (McLeod *et al.,* 2009). By creating a network of marine protected areas there is a chance that risks associated with some forms of climate change can be spread and potentially reduced.

29.6.2.3. *Working Collectively to Address Climate Impacts*

In the literature more attention is now being focused on the relevance and application of community-based adaptation (CBA) principles to island communities, as a facilitating factor in adaptation planning and implementation (Warrick, 2009; Kelman *et al*., 2011). Warrick's work in Vanuatu focuses on empowerment that is 'helping people to help themselves', while addressing local priorities and building on local knowledge and capacity. This approach to adaptation is unequivocally being promoted as an appropriate strategy for small states, since it is something done 'with' rather than 'to' communities" (Warrick, 2009). Dumaru (2010) has also documented the outcomes of a pilot community-based adaptation project implemented on Druadrua Island, north-eastern Fiji: more effective management of local water resources through capacity building, enhanced knowledge of climate change, and the establishment of mechanisms to facilitate greater access to technical and financial resources from outside the community. Similarly, review of an adaptation project in coastal Samoa reveals that 'intensive participatory village consultation' and capacity building which take into account traditional practices, can be vital to the success of adaptation initiatives in island communities (Daly, 2010). Case studies from Fiji and Samoa in which multi-stakeholder and multi-sector participatory approaches were used to help enhance resilience of local residents to the adverse impacts of disasters and climate change (Gero *et al.,* 2011), further support this view.

29.6.2.4. *Addressing Long-Term Climate Impacts, and Migration*

There is some speculation that capacity to adapt to short term hazards increases the ability of some islanders to adapt to climate change (such as Lefale, 2010) – the logic being that enhanced short term system resilience reduces the likelihood of systems changing state in the longer term – although there is little evidence to support this. The same speculative discourse has been applied to ecosystems. In the case of coral reefs, those reef systems with low levels of external stress are likely to be most resistant to system changes in the face of climate change (Nystrom *et al*., 2008). For both social and ecological island systems, more work is needed to verify the accuracy of this assumption.

In a world of 4 degrees C warming, recent research suggests that sea levels may rise by 0.5m to 2.5m (Nicholls *et al.,* 2011), however adapting to rising seas at the higher end of this spectrum is likely to cause severe problems for low lying island states. Migration is frequently suggested as a means of addressing this problem (Byravan and Rajan, 2006, Biermann and Boas, 2008). Analogues can provide some insight into environmental stress driven migration, for example by looking at post-hurricane population displacement in the Caribbean (McLeman and Hunter, 2010). One example is the case of internal migration within Papua New Guinea, as a response to inundation during the 2009 extreme high tides. So severe was the threat that the inhabitants of the Carteret Islands loaded their personal effects into fishing nets and secured them at elevation between palm trees, before seeking refuge on neighboring Bougainville island (Jarvis, 2010). It should not however be assumed that migration is a viable option in all such circumstances, as it is unlikely that such movement of people could be so easily accomplished if the receiving island is not part of the same country. Neither would such internal migration be possible within states with all low-lying islands. Recent commentators argue that forced migration is likely to be a maladaptive response, leading to high risk of unemployment, social marginalization, food insecurity and increased morbidity, among other problems (Barnett and O'Neill, 2012: 9). Barnett and O'Neill (2012) reflect that when migration is voluntary and it involves smaller distances (ideally within own sovereign lands) these factors reduce the potentially maladaptive impacts of resettlement.

While the example of the Carteret Islands cannot be described as evidence of climate change adaptation per se, it suggests that under some scenarios entire island communities may need to relocate in the future, whether within the same jurisdiction, or externally – for example in the case of 4 degrees warming (Gemenne, 2011). In the latter case, the international community could find itself confronted with other critical issues such as how to support the legal and political continuity of a state that has lost its territory (Cournil and Gemenne, 2010). (See also 29.3.3.4 and 29.8).

29.6.3. Barriers to Adaptation

Ever since publication of the IPCC SAR in 1996, significant barriers to the implementation of various climate change response strategies in island settings have been discussed in considerable detail. The impediments include inadequate access to financial, technology and human resources, issues related to cultural and social acceptability of measures, and constraints imposed by the existing political and legal framework. Owing to their nature and complexity, these constraints will not be easily eliminated in the short term and will require on-going attention if their impact is to be minimized incrementally over time. While lack of access to adequate financial, technology and human resources is often cited as the most critical constraint, experience has shown that endogenous factors such as culture, ethics, knowledge and attitudes to risk are equally important considerations in making adaptation choices. They can function either as barriers or facilitating factors, depending on the local circumstances. The lack of local support for the development of new infiltration galleries to augment freshwater supply on Tarawa atoll, Kiribati, highlights the importance of social acceptability as a factor in adaptation choices. Although water scarcity is severe, there is much resistance to the use of this simple technology, because it will necessitate encroachment on traditional lands (Moglia et al., 2008a, 2008b). Such considerations have led to the conclusion that there is still much to be learned about the drivers of past adaptation and how ‘mainstreaming’ into national programs and policies, widely acclaimed to be a virtually indispensable strategy, can practically be achieved (Mercer *et al.,* 2007; Adger *et al.,* 2009; Mertz *et al.,* 2009).

Notwithstanding the on-going global debate and the extensive and ever-growing body of literature on the subject, there is still a relatively low level of awareness and understanding at the community level on many islands about the nature of the threat posed by climate change (Nunn, 2009). Lack of awareness, knowledge and understanding can function as an effective barrier to the implementation and ultimate success of adaptation programs. This is borne out by the earlier referenced example from Tarawa atoll, Kiribati, where there was much resistance to the use of infiltration galleries, as an adaptation measure in the water resources sector, and in the case of Fiji where researchers found that spiritual beliefs, traditional governance mechanisms, and a short term approach to planning were barriers to community engagement and understanding of climate change (Lata and Nunn, 2012). Although widely acknowledged to be critical in small islands, few initiatives pay little more than perfunctory attention to the importance of awareness, knowledge and understanding in climate change adaptation planning. Hence, the renewed call for adaptation initiatives to include and focus directly on these elements on an ongoing basis (e.g., Crump, 2008; Kelman and West, 2009; Kelman, 2010; Kuruppu and Liverman, 2011; Gero *et al.,* 2011) is timely, if these barriers are to be eventually removed.

29.6.4. Mainstreaming and Integrating Climate Change into Development Plans and Policies

There is a growing body of literature that discusses the benefits and possibilities of mainstreaming or integrating climate change policies in development policies, and various mechanisms through which development agencies as well as donor and recipient countries can seek to capitalize on the opportunities for so doing are beginning to emerge (see for example Klein *et al.,* 2007; Mertz *et al.,* 2009). This view finds support in the work of Agarwala and van Aalst (2008) who, based on examples from various countries including Fiji, have shown that climate change can be linked to development objectives due to the various synergies (and trade-offs) involved in integrating adaptation to climate change in development cooperation activities, such as the focus on disaster risk reduction, community-based approaches to development, and building adaptive capacity. Yet, Boyd *et al.* (2009) challenge this view, arguing that this is a naive interpretation of the threats from climate change to the development agenda, and that development policy under a changing climate ‘needs to be better, quicker and more coherent than anything that has been seen so far’ (Boyd *et al.,* 2009: 659).

Although there are synergies and benefits to be derived from the integration of climate change and development policies, Schipper and Pelling (2010) caution that conflicts in policy responses to address these issues separately can give rise to conflict and an intellectual divide, which may be attributed primarily to a lack of institutional overlap and also to differences in language, method and political relevance. Overall however, there appears to be an emerging consensus around the views expressed by Swart and Raes (2007) that climate change and development strategies should be considered as complementary, and that some elements such as land and water management and urban planning provide important adaptation, development and mitigation opportunities.

29.7. Adaptation and Mitigation Interactions

Greenhouse gas emissions from most small islands are negligible in relation to global emissions, yet small islands will most probably bear the brunt of climate change impact (Srinivasan, 2010). Since small islands’ populations are not responsible for anthropogenic climate change there is little moral imperative for them to reduce greenhouse gas emissions, though most have chosen to do so because of the potential co-benefits and synergies. Malta and Cyprus are obliged to do so in line with EU climate and energy policies. This section considers some of the inter-linkages between adaptation and mitigation on small islands and considers the potential synergies, conflicts, trade-offs and risks. Unfortunately there is relatively little research on the emissions reduction potential of small islands, and far less on the inter-linkages between climate change adaptation and emissions reduction in small islands. Therefore in this section a number of assumptions are made about how and where adaptation and mitigation actions interact.

29.7.1. Assumptions/Uncertainties Associated with Adaptation and Mitigation Responses

Small islands are not homogeneous, they have diverse geo-physical characteristics (e.g. remote, low-lying, mountainous) and economic structures. Following Nunn (2009) we assume that the combination of island geography and economic types informs the extent to which adaptation and mitigation actions might interact. Island geography and location influence sensitivity to hydro-meteorological and related hazards such as cyclones, floods, droughts, invasive alien species, vector borne disease, and landslides. On the other hand the capacity of island residents to cope is often related income levels, access to capital assets and resources, technology and knowledge. Island economies can be grouped into four broad ‘types’, i.e. those that depend on: i) remittances from migrant workers overseas; ii) natural resource extraction and export; iii) earnings from services (mostly tourism); and iv) diversified economies with manufacturing – mostly larger economies (UNCTAD, 1997) These economic types appear to inform the potential for greenhouse gas emissions reduction, as not all of these have the key ‘mitigation’ sectors: that is energy, transport, industry, built environment, agriculture, forestry, or waste management sectors (Metz et al., 2007). For example, many aid dependent small island economies, often do not have extensive industrial development, extensive commercial buildings, or large transport sectors. Hence the opportunities for emissions reductions in these cases are very limited. Far more mitigation opportunities are expected to exist in larger island economies that rely on services, natural resource exports, or manufacturing. Furthermore, Swart and Raes (2007) contend that adaptation and mitigation usually operate at different temporal and spatial scales and are mostly relevant for different economic sectors, so that costs and benefits are distributed differently.

Table 29-4 presents an indicative assessment of potential areas for mitigation activity on small islands by island economy type.

[INSERT TABLE 29-4 HERE
Table 29-4: Economic structure of small islands and areas of potential emissions reduction.]

For many small islands, small domestic markets, limited human capacity and high costs of transporting goods to international markets act as significant barriers to industrial development (Armstrong and Read, 2002) potentially avoiding the need for large scale mitigation responses. Limited land area means that forestry and agriculture sectors are often small scale, or subsistence. Energy supply is often delivered through state-supported monopolies, or imported, due to limited economies of scale, lack of local energy resources and sensitivity of energy supplies (Read, 2010). In short, the geography and economies of islands limits economic diversity, and by extension, the opportunities available for adaptation and mitigation, however there remains scope for both synergies and conflicts between adaptation and mitigation on islands.

Many authors refer to the high relative costs of the impacts of, and adaptation to, climate change in small islands. Bueno *et al*. (2008) examined the potential costs to the island nations of the Caribbean if greenhouse gas emissions continue unchecked and found that for just three categories—increased hurricane damages, loss of tourism revenue, and infrastructure damages—the Caribbean's annual cost of inaction is projected to total $22 billion annually by 2050 and $46 billion by 2100. These costs represent 10 per cent and 22 per cent, respectively, of the current Caribbean economy.

29.7.2. Potential Synergies and Conflicts

Metz *et al*. (2007) suggest that adaptation and mitigation interactions occur in one of four main ways: (i) adaptations that result in greenhouse emissions reduction, (ii) mitigation options that facilitates adaptation, (iii) policy decisions that couple adaptation and mitigation effects, and (iv) trade-offs and synergies between adaptation and mitigation. Each of these opportunities is now considered using three examples: coastal forestry, energy supply, and tourism.

29.7.2.1. Coastal Forestry

Small islands have relatively large coastal zones (in comparison to land area) and most development are located on those coastal zones, therefore coastal adaptation is of critical importance in small islands. Coastal ecosystems (coral reefs, sea grasses and mangroves) can play an important role in protecting coastal communities from wave erosion, tropical cyclones, storm surges, and even moderate tsunami waves of less than 4 m (Cochard *et al*., 2008). Where mangrove 'bioshields' are created from exotic species, there can be a damaging impact on the native ecosystem (Feagin *et al*., 2010). Whilst coastal forests are seen as effective adaptation options in the coastal zones, they also play an important role as carbon sinks hence can be considered as a mitigation option. Research about the relative importance of tropical coastal forests as carbon sinks are well developed (van der Werf *et al*., 2009). Recent research indicates that in the coastal zone initial estimates suggest that tropical wetlands may be among the largest terrestrial stores of carbon (Donato *et al*., 2011) ref. The management and conservation of mangroves therefore has the potential to generate synergies between adaption and mitigation within the context of climate change Despite this knowledge researchers have found that current climate extremes, landslides, and agricultural pressures have made the expansion of forest carbon stocks more challenging (Fox *et al*., 2010). Gilman *et al*. (2008) reassert this, noting that many human activities within tropical wetlands can reduce the buffering capacity of mangrove systems.

Many studies suggest that in the absence of significant mitigation efforts at the global scale, adaptation interventions could become very costly and difficult to implement, once certain thresholds of change are reached. (Nelson, 2010; Rosenzweig and Wilbanks, 2010; Thornton *et al.,* 2010; Birkmann, 2011). Nicholls *et al*. (2011) make a similar observation with respect to coastal protection as a response option to sea level rise. They suggest that if global mean temperatures increase by around 4^0 C, which may lead to sea level rise between 0.5 m and 2 m, the likelihood of successful coastal protection in some locations such as low-lying small islands, will be low. Consequently, it is argued that 'coastal abandonment' would be a likely outcome in such circumstances (Nicholls *et al.,* 2011).

29.7.2.2. Energy Supply

The study of renewable energy resources on small islands has a long history. However it is only recently that they have been considered within the context of long-term energy security (Praene *et al.,* 2012, Chen *et al.,* 2007). Stuart (2006) speculates that the lack of uptake of renewable technologies to date might be due to historical commitments to conventional fossil fuel based infrastructure, and a lack of resources to spend on costly research and development.

Those islands that have introduced renewable energy technologies have often done so with support from international development assistance (Dornan, 2011). Despite highly subsidized (or sometimes free) provision, there remain significant barriers to the wider institutionalization of renewable technologies in small islands. Research in Europe and the United States has shown the mitigation and cost savings benefits of Energy Service Companies (ESCOs). ESCOs are companies that enter into medium-to-long term performance-based contracts with energy users, invest in energy efficiency measures in buildings and firms, and profit from the ensuing energy savings measures for the premises, see for example (Steinberger *et al.,* 2009). Potential benefits exist in creating the opportunity for ESCOs to operate in small islands. Preliminary evidence from Fiji suggests that if the incentive mechanisms can be resolved, and information asymmetries between service providers and users can be aligned, ESCOs could provide an opportunity to expand renewable technologies (Dornan, 2009).

The transition towards renewable energy sources (such as the shift to hydro-power in Fiji), away from fossil fuel dependence has been partly driven by economic reasons, notably to avoid oil price volatility and its impact (Dornan, 2009). The development of hydro-power necessitates protection and management of the water catchment zones, and thus leading to improved management of the water resources – a critical adaptation consideration for areas expected to experience a decrease in average rainfall as a result of climate change. Whilst the cost effectiveness of renewable technologies is critical, placing it within the context of water adaptation can enhance project viability. Cost-benefit analyses have shown that in southeast Mediterranean islands photovoltaic generation and storage systems may be more cost-effective than existing thermal power stations (Kaldellis, 2008; Kaldellis *et al*., 2009). Studies on tourist islands in the Maldives showed that solar power could produce about only 10 per cent of energy demand (van Alphen *et al.,* 2007), or 44.7 per cent (Georgei *et al.,* 2010). With such a disparity in these estimates it is difficult to accurately assess the cost-effectiveness of such technologies.

Energy prices in small islands are among the highest anywhere in the world, mainly due to their dependence on imported fossil, and lack of economies of scale. Recent studies show that the energy sectors in these islands may be transformed into sustainable growth entities mainly through the judicious exploitation of renewable energy sources, combined with the implementation of energy efficiency measures (van Alphen *et al.,* 2008; Banuri, 2009; Mohanty, 2012; Rogers *et al.,* 2012). Realising the potential for such transformation, the countries comprising the Alliance of Small Island States (AOSIS) launched SIDS Dock, which is intended to function as a 'docking station' to connect the energy sector in SIDS with the international finance, technology and carbon markets with the objective of pooling and optimizing energy efficiency goods and services for the benefit of the group. This initiative developed jointly by the Caribbean Community Climate Change Centre (CCCCC) and the Secretariat of the Pacific Regional Environment Programme (SPREP) seeks to increase energy independence in SIDS, while generating financial resources to support low carbon growth and adaptation interventions. Specifically, SIDS Dock will assist these islands in producing at least 50 % of their electricity from renewable sources, reduce petroleum consumption by 20-30 % and increase energy efficiency by 25% relative to 2005 baselines, by 2033 (CEEBIP, 2012)

29.7.2.3. Tourism

Many small islands rely heavily on the foreign exchange from tourism to expand and develop their economies, including address mitigation and adaptation options. . Despite this, globally the tourism sector contributes around 5 per cent of total greenhouse gas emissions (WTO and UNEP, 2008) and recent efforts to tax long-haul air travel as resulted in concern expressed over the impact of this policy on small island economies. Therefore policies that attempt to address mitigation isolation can result in undermining adaption efforts in small islands. When ecosystem services, on which the tourism sector relies (e.g. sewage treatment by coastal ecosystems, or greenhouse gas emissions from electricity production), are costed it becomes evident that reduction of the burden on ecosystems and engagement in more sustainable tourism planning has advantages (Thomas-Hope and Jardine-Comrie, 2007). In Jamaica, Thomas-Hope and Jardine-Comrie (2007) suggest that sustainable tourism planning should include activities undertaken by the industry, that is tertiary treatment of waste, and re-use of water, as well as composting organic material and investing in renewable energy. In contrast, Gossling and Schumacher (2010) suggest that tourists themselves could play a role in becoming carbon neutral, through voluntary offsetting. In their analysis of tourism in the Seychelles they recommend first undertaking a detailed assessment of emissions, and following this with a review of the options for becoming carbon neutral.

29.8. Facilitating Adaptation and Avoiding Maladaptation

While there is a clear consensus that adaptation to the risks posed by global climate change is necessary and urgent in small islands, the implementation of specific strategies and options is a complex process that requires critical evaluation of multiple factors, if expected outcomes are to be achieved (Kelman and West, 2009; Barnett and O'Neill, 2012). These considerations may include, *inter alia*, prior experience with similar or related threats, efficacy of the strategies or options and their co-benefits, costs (monetary and non-monetary), availability of alternatives and social acceptability. In addition, previous work (e.g. Adger *et al*, 2005) has emphasized the relevance of scale as a critical factor when assessing the efficacy and value of adaptation strategies, as the extent to which an option is perceived to be a success, failure or maladaptive may be conditioned by whether it is being assessed as a response to climate variability (shorter-term) or climate change (longer-term). Consequently, although lessons learned from adaptation experiences in one island may offer some helpful guidance to other states, wholesale transfer may not always be advisable, as the 'lenses' through which adaptation options are viewed differ from one community to the next, based on ecological, socio-economic, cultural and political values.

As in other regions, adaptation in islands is locally delivered and context specific (Tompkins *et al.,* 2010). Yet, sectors and communities on small islands are often so intricately linked that there are many potential pathways that may lead to maladaptation, be it via increased greenhouse gas emissions, foreclosure of future options, burdensome opportunity costs on local communities, by unintentionally discouraging adaptation initiatives, or by fostering over-dependence on external support (see for example Box 29-1).

_____ START BOX 29-1 HERE _____

Box 29-1. Resettlement and Migration: Adaptation or Maladaptation?

Whilst there is agreement that assistance from the international community is vital for supporting adaptation programs in small islands, there is a concern that some types of interventions may actually be maladaptive. For example, Barnett and O'Neill (2012) suggest that strategies such as resettlement and migration should be regarded as options of 'last resort' on islands, as they may actually discourage viable adaptation initiatives, by fostering over-dependence on external support. They argue that in the Pacific islands

> "Relying on resettlement forecloses on all other adaptation options…if there is no future for people in the places in which they live, then there is no reason to manage those places sustainably…Thus, if the only answer to climate change is resettlement, then there is no need to do anything else but wait, all other adaptation options will become impossible, and incentives to reduce greenhouse gas emissions will be similarly reduced" (Barnett and O'Neill, 2012, p.10)

_____ END BOX 29-1 HERE _____

Similarly, while insurance is being promoted as an element of the overall climate change response strategy in some island regions, e.g. the Caribbean, where the Caribbean Catastrophe Risk Insurance Facility (a multi-country risk pooling facility established in 2007 and owned by Caribbean governments) has been successfully implemented, concerns have also been expressed in various jurisdictions about possible linkages to maladaptation. The potential consequences include the imposition of exorbitant premiums that are beyond the capacity of resource-scarce communities as the perception of climate change risks increase, discriminatory coverage of sectors that may not align with local priorities, and tacit encouragement for the state, individuals and the private sector to engage in behavior that is not risk-averse, e.g. development in hazard-prone areas (Herweijer *et al.,* 2009; Linnerooth-Bayer *et al.,* 2009; Linnerooth-Bayer *et al.,* 2011; van Nostrand and Nevius, 2011; Thomas and Leichenko, 2011). Likewise, although the exploitation of renewable energy is vital to the sustainable development of small islands, more attention needs to be paid to the development of energy storage technologies, if rapid transition from conventional fuels is to be achieved in an efficient manner. This is especially important in the case of intermittent energy sources (e.g. solar and wind), as the cost of current storage technologies can frustrate achievement of full conversion to renewables. Thus to avoid the possibility of maladaptation in the sector, countries may wish to consider engaging in comprehensive planning, including considerations relating to energy storage (Krajačić *et al.,* 2008; Krajačić *et al.,* 2010; Bazilian *et al.,* 2011).

Recent studies have demonstrated that opportunities exist in island environments for avoiding maladaptation. It has been shown for example that decisions about adaptation choices and their implementation are best facilitated where there is constructive engagement with the communities at risk, in a manner that fosters transparency, trust and genuine commitment to the process (Fazey *et al.,* 2008; Lopez Marrero, 2008; van Aalst, 2008; Maceda *et al.,* 2009). Further, some analysts argue that adaptation choices are often subjective in nature and suggest that participatory stakeholder involvement can yield valuable information about the priorities and expectations that communities attach to the sector for which adaptation is being sought. The point is underscored by Moreno and Becken (2009), whose study of the tourism sector on the Manamuca islands (Fiji) clearly demonstrates that approaches which explicitly integrate stakeholders into each step of the process from vulnerability assessment right through to consideration of alternatives measures can provide a sound basis for assisting destinations with the implementation of appropriate adaptation interventions. This view is supported by Dulal *et al.* (2009), who argue that the most vulnerable groups in the Caribbean - the poor, elderly, indigenous communities and rural children – will be at greater risk of being marginalized, if adaptation is not informed by similar equitable and participatory frameworks.

Other studies reveal that new paradigms whose adoption can reduce the risk of maladaptation in island environments, are emerging across various sectors. In the area of natural resource management, Hansen *et al.* (2010) suggest that the use of protected areas for climate refugia, reduction of non-climate stressors on ecosystems, adoption of adaptive management approaches combined with reduction of greenhouse gas emissions wherever possible, are likely to be more effective response strategies than traditional conservation approaches. Other strategic approaches, including the implementation of multi-sectoral and cross-sectoral measures, also facilitate adaptation in a more equitable, integrated and sustainable manner. Similarly, 'n*o-regret'* measures such as wastewater recycling, trickle irrigation, conversion to non-fossil fuel based energy and transportation, which make good sense with or without the threat of climate change, and 'l*ow-regret'* strategies, which may only increase existing operational costs marginally, are becoming increasingly attractive options to island governments (Gravelle and Mimura, 2008; Heltberg *et al.,* 2009; Cashman *et al.,* 2010; Howard *et al.,* 2010). Together, these constitute valid risk management approaches, as they are designed to assist communities in making prudent, but necessary decisions, in the face of an uncertain future.

Caution is needed to ensure that donors are not driving the adaptation and mitigation agenda in small islands, as there is a risk that donor-driven adaptation or mitigation will not address the salient challenges on small islands, and may lead to inadequate adaptation or a waste of scarce resources (Barnett, 2010; Nunn, 2009). There is a real concern that donor-led initiatives may unintentionally cause enhanced vulnerability by supporting adaptation strategies that are externally derived, rather than optimizing the benefits of local practices that have proven to be efficacious through time (Reenberg *et al.,* 2008; Kelman and West, 2009; Campbell and Beckford, 2009). For instance, Kelman (2011) citing an example from Samoa, notes that house construction which has traditionally been designed to facilitate easy repair with local materials after cyclones, is beginning to be replaced by more 'modern' practices, that are perceived to be much more costly and less adaptable.

Finally, there is continuing strong support for the view that climate change adaptation strategies in small islands should concurrently be aimed at achieving poverty reduction and sustainable development. Even in low-lying, vulnerable atoll states such as Kiribati, where the threats of climate change are real, other present-day development challenges such as pollution, sewerage and solid waste management should not be sidelined. Indeed, there is considerable agreement among scholars that adaptation planning on small islands is likely to yield the most positive outcomes, where there is a sound understanding of the multiple non-climate stressors that interact with climate change (Kelman and West, 2009; Moreno and Becken, 2009; Storey and Hunter, 2010).

29.9. Research and Data Gaps

It should be evident from the foregoing assessment that significant advances in our understanding of the actual impacts and potential effects of climate change on small islands have been made since the AR4. These advances cover a range of themes including: dynamic downscaling of scenarios appropriate for small islands; impacts of trans-boundary processes generated well beyond the borders of an individual nation or island; barriers to adaptation in small islands and how they may be overcome; the relationships between climate change adaptation and disaster risk reduction; and, the relationships between climate change adaptation, maladaptation and sustainable development.

It is also evident that much further work is required on these topics in small island situations, especially comparative research. There are also important information and data gaps and many uncertainties still exist on impacts, vulnerability and adaptation in small islands. These include:

- **Lack of climate change and socio-economic scenarios and data at the required scale**. For example, projected changes in climate for the Caribbean, Pacific, Indian Ocean and Mediterranean islands, generally apply to the regions as a whole and not to specific countries. However, most socio-economic decisions are taken at smaller scales and as a result a few regional and local studies have been undertaken that are based on downscaled climate or socio-economic data. There is need for further credible simulations of future small island climates and socio-economic conditions.
- **Uncertainty about the potential impacts of climate change**. In several small islands adaptation is being progressed without adequate understanding of past or potential impacts and vulnerability. Whilst assessment of future impacts is hampered because of uncertainty in climate projections at the local island level, alternative scenarios could be used for vulnerability and sensitivity studies to guide adaptation strategies.
- **Need for a range of climate change-related projections beyond temperature and sea-level.** Generally climate-model projections of temperature and sea-level have been satisfactory, but there are strong requirements for projections for other variables that are of critical importance to small islands. These include rainfall and drought, wind direction and strength, tropical storms and wave climate, and recognition that trans-boundary processes are also significant in a small island context.
- **Need to acknowledge the heterogeneity and complexity of small island states and territories.** Although small islands have several characteristics in common, neither the variety or complexity of small islands is sufficiently appreciated. Thus, transferring data and practices from a continental situation, or from one small island state to another, needs to be done with care.
- **Need to develop a typology that classifies small island states into a few groupings based on their social, cultural, economic, physical and ecological characteristics relevant to climate change impacts and vulnerability**. This has been an elusive task to date noting the discussion on vulnerability indicators in 29.6.1. Notwithstanding that discussion as well as the foregoing point there is increasing evidence that such a typology could be developed in stages. For example, an improved understanding of the interactions between vulnerability and 'island type' could provide useful guidance for optimizing scarce adaptation resources at community and local levels.
- **Within country/territory differences need to be better understood**. Many of the environmental and human impacts we have reported have been attributed to the whole country, when in fact they refer only to the major centre or town or region. There is need for more work on rural areas, outer islands and secondary communities and not just in the urban areas where it has hitherto been concentrated. Several examples of such research have been cited in this chapter. Also it should be noted that some small island states are single islands and others highly fragmented multiple islands.
- **Lack of investment and attention to climate and environmental monitoring frameworks in small islands**. A fundamental gap in the ability to improve empirical understanding of present and future climate change impacts is the lack of climate and environmental monitoring frameworks that in turn hampers the level of confidence with which adaptation responses can be designed and implemented.
- **Economic and social costs of climate change impacts and adaptation options are rarely known**. In small island states and territories the costs of past weather, climate and ocean events are poorly known and further research is required to identify such costs, and to determine the economic and societal costs of climate change impacts and the costs of adaptation options to minimize those impacts.

- **Need to integrate adaptation to climate change and development co-operation activities.** There is some evidence to indicate that longer-term climate change adaptation policies and programs in small islands are compromising more immediate development objectives. Avenues need to be developed to redress this situation perhaps through a combined focus on hazard risk reduction and community based approaches to development and adaptation. Synergies between adaptation and development need to be explored.

The foregoing list is a sample of the gaps, needs and research agenda appropriate for small island states. If those gaps are filled, needs satisfied and research achieved, we feel that the general view that small islands are highly vulnerable to climate change, and, that they have low adaptive capacity, may well be challenged by some nations as well as in some sectors and/or regions within small island states.

Frequently Asked Questions

FAQ 29.1: Are small islands experiencing the impacts of climate change?

Observed impacts of climate change on small islands are not conclusive. Whilst the media and some researchers emphasize the vulnerability of small islands and potential future impacts of climate change, there are few studies that have been able to isolate climate change impacts from those associated with climate variability and/or human activities. Even in the case of atolls where inundation from sea-flooding and storm surges and shoreline erosion has occurred, sea-level rise specifically linked to climate change has not been identified as a primary cause. Moreover, in much of the literature on small islands the distinction between observed impacts and projected future impacts is often blurred with impacts relating to some recent extreme weather- or ocean- related event being used as an analogy to what may happen in the future with climate change. This does not mean that small islands are not experiencing the impacts of climate change, but rather that the magnitude of any impact is not sufficient to be clearly associated with climate change. It also reflects the poor level of empirical monitoring which occurs in small island environments to underpin research into attribution of climate change stress.

FAQ 29.2: Why is it difficult to detect and attribute changes on small islands to climate change?

In the last two or three decades many small islands have undergone substantial changes in human settlement patterns and in socio-economic and environmental conditions. Such changes may have masked any clear evidence of climate change. This has resulted in difficulties when attempting to detect and attribute changes on small islands to climate change. One example can be cited. In many small islands coastal erosion has been widespread and has adversely affected important tourist facilities, settlements, utilities and infrastructure. However, specific case studies from islands in the Pacific and Indian oceans and the Caribbean have indicated that attribution of such shoreline instability to factors like sea-level rise associated with climate change have been masked by pervasive human impacts as well as episodic extreme events. Whilst coastal erosion is consistent with models of sea-level rise resulting from climate change, it has not been possible to quantify the extent of attribution of past and on-going coastal erosion to that factor. Given the range of natural processes and human activities that could impact the coasts of small islands in the future, the role of climate change-related processes may continue to be difficult to quantify and attribute.

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Table 29-1: Small islands' regions temperature and precipitation change projections for the SRES A1B scenario over the period 1980-1999 compared to 2080-2099. The table shows the minimum, median (50%) and maximum values of the mean temperature and precipitation responses from each of the 21 AR4 global models (Adapted from Table 11.1 in AR4 WG1).

Small Island Region	**Season (by month)**	**Temperature Change (ºC)**			**Precipitation Change (%)**		
		min	median	max	min	median	max
Caribbean	DJF	1.4	2.1	3.2	-21	-6	10
	MAM	1.3	2.2	3.2	-28	-13	6
	JJA	1.3	2.0	3.2	-57	-20	8
	SON	1.6	2.0	3.4	-38	-6	19
	ANNUAL	1.4	**2.0**	3.2	-39	**-12**	11
Indian Ocean	DJF	1.4	2.1	3.8	-4	4	20
	MAM	1.5	2.2	3.8	0	5	20
	JJA	1.4	2.1	3.7	-3	3	20
	SON	1.4	2.0	3.6	-5	4	21
	ANNUAL	1.4	**2.1**	3.7	-2	**4**	20
North Pacific	DJF	1.5	2.4	3.6	-5	3	17
	MAM	1.4	2.3	3.5	-17	1	17
	JJA	1.4	2.3	3.9	1	8	25
	SON	1.6	2.4	3.9	1	6	22
	ANNUAL	1.5	**2.3**	3.7	0	**5**	19
South Pacific	DJF	1.4	1.8	3.2	-6	4	15
	MAM	1.4	1.9	3.2	-3	6	17
	JJA	1.4	1.8	3.1	-2	3	12
	SON	1.4	1.8	3.0	-8	2	5
	ANNUAL	1.4	**1.8**	3.1	-4	**3**	11

Table 29-2: Projected percentage change in key marine natural habitat or resources in 22 tropical Pacific small islands under the SRES B1 and A2 scenarios (adapted from Bell et al., 2011).

Natural Resource		**2100**	
		B1	**A2**
Mangroves		-50 to -70%	-6 to -80%
Seagrass		-5 to -35%	-10 to -50%
Coral cover		10 to 20%	<2%
Coastal fish		-20%	-20 to -50%
Skipjack tuna		+12%	-7%
Bigeye tuna		-9%	-27%

Table 29-3: Examples of syndromes affecting islands' vulnerability to climate change.

Name of syndrome	*Description*	*Example*	*Source*
Mass Tourism	Environmental destruction for recreational ends	Air quality, and waste problems from tourism in Boracay, Philippines	(Smith et al., 2011)
Waste Dumping	Environmental degradation through (un) controlled disposal of waste	No segregation of waste, and limited waste reduction e.g. recycling /composting in Mauritius	(Foolmaun et al., 2011)
Over-exploitation	Overuse or overexploitation of natural ecosystems	Overfishing of marine resources in Jamaica	(Carr and Heyman, 2009)
Coastal Squeeze	Environmental degradation as environmental stresses force ecosystem retreat to abut coastal infrastructure	Proximity of tourism infrastructure to the Martinique coast prevents coastal ecosystems from migrating	(Schleupner, 2008)

Table 29-4: Economic structure of small islands and areas of potential emissions reduction.

Type of economy	*Sectors with significant emissions reduction potential*						
	Energy supply	Transport	Buildings (commercial /residential)	Industry	Agriculture	Forestry	Waste management and sewage
Aid dependent	X	X	X	X	?	?	X
Services dependent	√	?	√	X	?	X	√
Natural resource exporting	?	X	√	?	√	√	?
Diversified with manufacturing	√	?	√	√	?	?	?

Notes:
X = low potential for emissions reduction due to excessive cost or limited effectiveness
? = possible area for emissions reduction, although may depend on capacities within the islands
√ = rich area for exploring emissions reduction

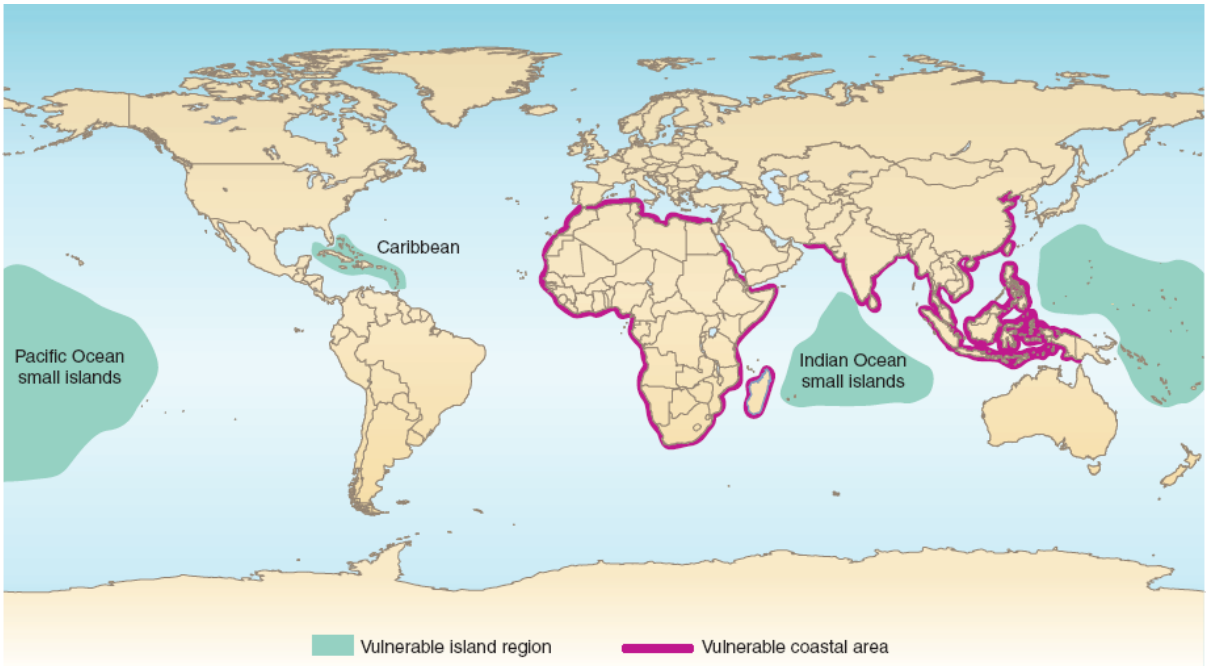

Figure 29-1: Small island regions vulnerable to coastal flooding caused by future relative or climate-induced sea-level rise. At highest risk are coastal zones with dense populations, low elevations, appreciable rates of subsidence, and/or inadequate adaptive capacity (Nicholls and Cazenave, 2010).

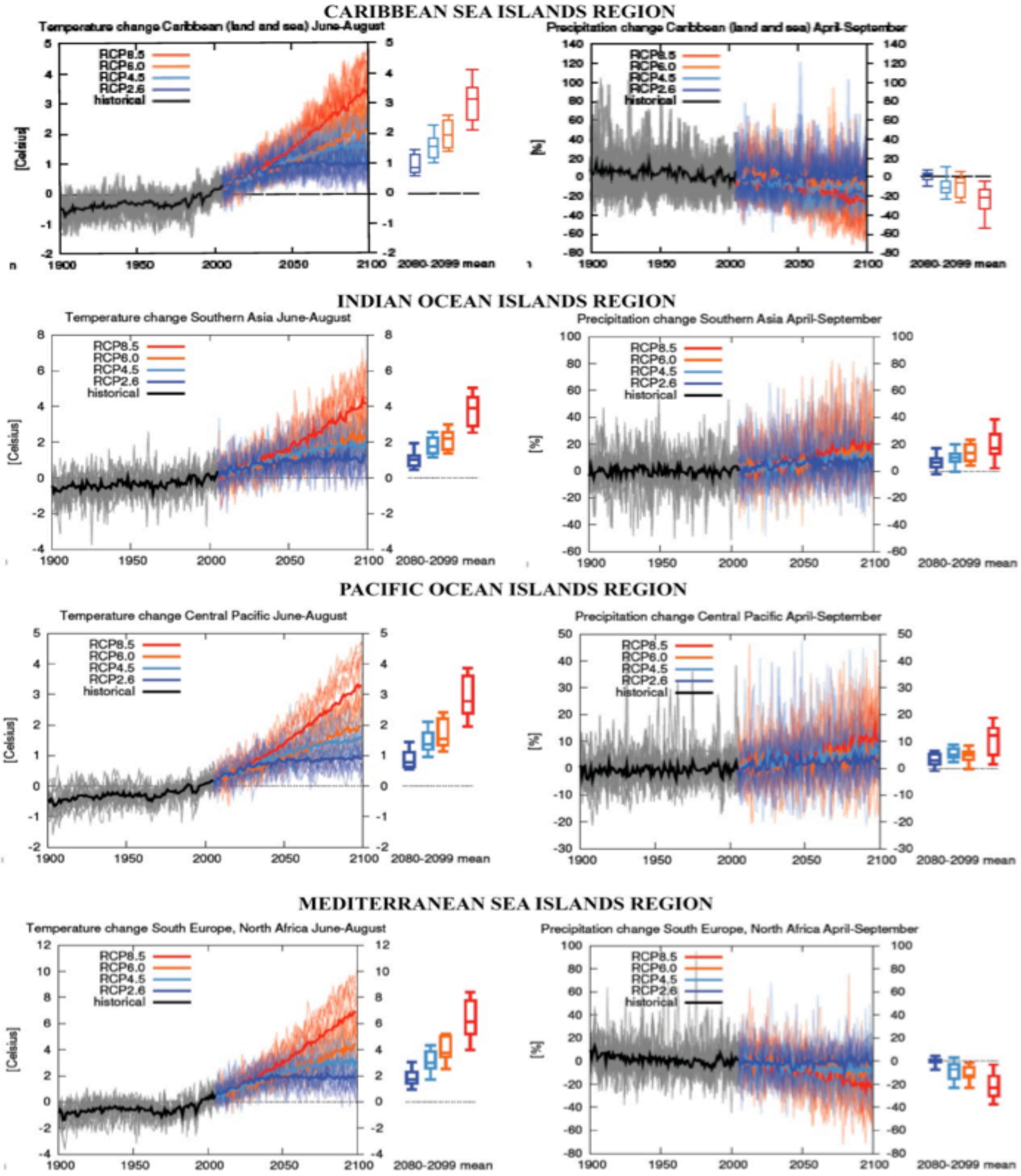

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Figure 29-2: RCP Scenario projections to the year 2100 for the four main small island regions (Adapted from AR5 WG1, Annex 1).

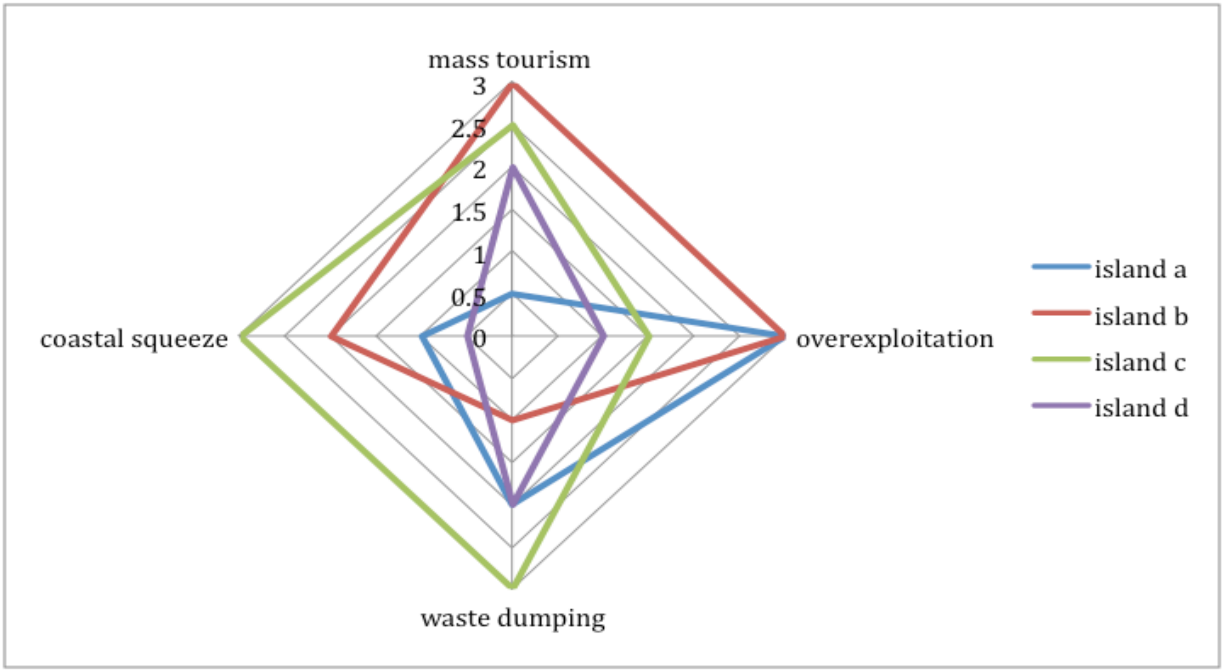

Figure 29-3: Multiple pressures on islands exacerbating island vulnerability to climate change.