Chapter 29. Small Islands

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Executive Summary

The distinction between *observed* and *projected* impacts of climate change is often not clear in the literature on small islands (*high agreement*). 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 climate change impacts on small islands is not specific about the scenario (s) used, partly because of the difficulty in moving from global-scale scenarios and models to the scale of small islands. [29.4] Consequently, there is *low confidence* in the magnitude of projected impacts in some sectors and systems of small islands. However, there is evidence that this challenge can be partly overcome with continued improvements in downscaling, as is demonstrated by the use of downscaled SRES scenarios in a comprehensive assessment of the vulnerability of fisheries in 22 Pacific island countries. As these and other studies are duplicated elsewhere, confidence in projected impacts of climate change on small islands will increase. [29.3, 29.4.2]

Many impacts on small islands are generated from processes well beyond the borders of an individual nation or island and generally they have negative effects (*high confidence, robust evidence*). Trans-boundary impacts on small islands may originate in distant regions including continental countries and high latitudes. Examples of the former include airborne dust from the Sahara and Asia reaching small islands far down-drift from the desert source, and examples of the latter include large ocean swells generated by extra tropical cyclones and high latitude low pressure systems. [29.5.1, 29.5.2] Other trans-boundary impacts result from invasive plant and animal species that reach the warmth of tropical 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. [29.3.3.2, 29.5.3, 29.5.5]

For most small islands climate change is just one of a series of multiple stresses that must be coped with, and often it is not the most important one *(medium agreement, medium confidence*). 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. [29.3.3] 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. [29.6.1, 29.6.2.3, Figure 29-5]

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: energy supply and use, tourism infrastructure and activities, and coastal wetlands. The alignment of these sectors for potential emission reductions together with adaptation needs offers co-benefits and opportunities in small islands. [29.7.2, 29.8] Lessons learned from adaptation and mitigation experiences in one island may offer some guidance to other small island states, though we have *low confidence* in the wholesale transfer of adaptation and mitigation options when the lenses through which they are viewed differ from one island state to the next, based on cultural, socio-economic, ecological and political values. [29.6.2, 29.8]

Assistance from the international community is vital for supporting adaptation and mitigation programs in small islands, though there is increasing concern that some types of interventions may be maladaptive (*medium evidence*). Caution is needed to ensure that donors are not driving the climate change agenda in small islands, as there is a risk that donor-driven adaptation and mitigation aid may not address the critical challenges confronting island governments and communities, and may not be aligned with the sustainable development goals of small islands (*high agreement*). This may lead to inadequate adaptation or a waste of scarce resources and may unintentionally cause enhanced vulnerability by supporting inappropriate adaptation strategies that are externally derived, rather than optimizing the benefits of local practices that have proven to be efficacious through time. [29.8, Box 29-1, 29.6.2.3, 29.6.3]

Island vulnerability to climate change may be related to the experience and perceptions of islanders to both climate and non-climate stressors (*medium agreement*). Islands and islanders are recognized for their long experience of adapting to a range of hazards including extreme weather-climate- and ocean-related events and for their resilience in coping with such hazards. 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. [29.3.3.1, 29.6.1, 29.6.2]

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 the relationship 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 projected for 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 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 raised again and assessed in the light of recent findings in the present chapter.

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, the literature also critiques some aspects of climate change policy, notably in relation to development and security of small islands, and suggests that adaptations for the future are being placed above critical development 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.

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.

[INSERT FIGURE 29-1 HERE
Figure 29-1: This schematic describes common tropical island typology from young high volcanic islands (left) through to atolls (submerged volcanics) on the far right. This simple overview highlights important components such as elevation and differing land and marine resources as well as the presence of coral reefs. On both high and low islands coastal settlement patterns predominate. Elevated limestone islands and islands comprised of 'continental' rocks are not included in this figure, but see Table 29-3.]

29.3.1. Observed Impacts on Island Coasts and Marine Biophysical Systems

29.3.1.1.Sea Level Rise, Inundation, and Shoreline Change on Small Islands

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 small islands where the majority of human communities and infrastructure are located in coastal zones with limited relocation opportunities especially on atoll islands (Woodroffe, 2008) (Figure 29-1). 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; Church and White, 2011) (See Chapter 13, Working Group 1). Rates of sea-level rise are however not uniform across the globe and large regional differences have been detected including in the south Indian Ocean and tropical Pacific, where rates have been significantly higher than the global average (Meyssignac *et al.,* 2012). In the tropical western Pacific where a large number of small island communities exist, rates up to four times the global average (approximately 12 mm yr $^{-1}$) have been reported between 1993 and 2009 and are generally thought to describe transient rates associated with natural cyclic climate phenomena such as ENSO (El Niño-Southern Oscillation) (Cazenave and Remy, 2011; Becker *et al.*, 2012). Large interannual variability in sea level has also been demonstrated from the Indian Ocean (e.g Chagos Archipelago, Dunne *et.al.,* 2012) whilst in the Caribbean Palanisamy et al. (2012) found that over the last 60 years the mean rates of sea-level rise in the Caribbean region were similar to the global average ~ 1.8mm yr^{-1}.

There are few long-term sea level change trends for individual small island locations and the situation is hampered in many sites by the absence of adequate monitoring regimes. Furthermore, sea flooding and inundation is frequently associated with sea level extremes caused by transient phenomena, e.g.; surge, storm wave and routine lunar (tidal) cycles (Vassie *et al.,* 2004; Zahibo *et al.*, 2007; Komar and Allan, 2008; Haigh *et al.*, 2011). For example, high spring tide floods at Fongafale Island, Funafuti Atoll, Tuvalu, have been well publicized and study has shown that areas of the central portion of Fongafale are already below sea-level at high spring tide (Yamano *et al.,* 2007). Rates of relative sea level rise at Funafuti between 1950 – 2009 has been approximately three times higher than the global average (Becker *et al.,* 2012) and saline flooding of internal low-lying areas occurs regularly and is expected to become more frequent and extensive over time (Yamano *et al.,* 2007).

Documented cases of coastal inundation and erosion often cite extenuating circumstances such as vertical subsidence, engineering works, development activities or beach mining. Three examples can be cited. First, on the Torres Islands, Vanuatu communities have been displaced due to increasing inundation of low-lying settlement areas due to a combination of tectonic subsidence and sea-level rise (Ballu *et al.,* 2011). Second, on Anjouan Island, Comores in the Indian Ocean, Sinane et al. (2010) found beach aggregate mining was a major contributing factor influencing rapid beach erosion. Third, the intrinsic exposure of rapidly expanding settlements and agriculture in the low-lying flood prone Rewa Delta, Fiji is shown by Lata and Nunn (2012) to place populations in increasingly severe conditions of vulnerability to flooding and marine inundation.

Since the AR4 several studies have documented changes in island shorelines over the last few decades. Historical shoreline position change over 20 – 60 years on 27 central Pacific atoll islands showed that total land area remained relatively stable in 43 per cent of islands, whilst another 43 per cent had increased in area; and the rest showed a net reduction in land area (Webb and Kench, 2010). Dynamic responses were also found in a four year study of 17 relatively pristine islands on two other central Pacific atolls in Kiribati by Raney (2011) who concluded that sea-level rise was not likely to be the main influencing factor in these shoreline changes. On uninhabited Raine Island on the Great Barrier Reef, Dawson and Smithers (2010) also found that shoreline processes were dynamic but that island area and volume increased 6 per cent and 4 per cent, respectively between 1967 and 2007. Overall, these and other studies conclude that normal seasonal erosion and accretion processes appear to predominate over any long-term morphological trend or signal.

In many locations 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) and mask attribution. A study of Majuro atoll (Marshall Islands) found that erosion was widespread but attribution to factors like sea level rise were masked by pervasive anthropogenic impacts to the coastal system (Ford, 2012). Similarly a study of three islands in the Rosario Archipelago (Colombia) reported shoreline retreat over a 50-55 year span and found Grande, Rosario, and Tesoro Islands had lost 6.7, 8.2 and 48.7 per cent of their land area respectively. Erosion was largely attributed to management issues on densely settled Grande Island, whilst sea level increase and persistent northeast winds enhanced erosion on uninhabited Rosario, and Tesoro (Restrepo *et al.,* 2012). Likewise, Cambers (2009) reported average beach erosion rates of 0.5 m yr $^{-1}$ in eight Caribbean islands from 1985-2000 and whilst the study could not quantify the extent of attribution it did highlight that greater erosion rates were positively correlated with the number of hurricane events. Alternately, Etienne and Terry (2012) found the net shoreline impacts of a category 4 cyclone which passed within 30 km of Taveuni Island (Fiji) nourished shorelines with fresh coralline sediments despite localized storm damage. These studies contribute to improved understanding of island shoreline processes and change since AR4 though the vulnerability of small island shores and low-lying areas to increasing inundation and erosion in response to sea level rise and other potential climate change stressors provided in AR4, remains unchanged.

29.3.1.2. Coastal Ecosystem Change on Small Islands: Coral Reefs and Coastal Wetlands

Coral reefs are an important resource in small tropical islands and the culture and wellbeing of island communities is linked to their on-going function and productivity. They play a significant role in supplying sediment to island shores and in mediating wave energy this reducing potential at-shore erosion. They also provide habitat for a host of marine species upon which many island communities are dependent for subsistence diets as well as underpinning beach and reef-based touristic economic activity (Bell *et al.,* 2011; Perch-Nielsen, 2010). The documented sensitivity of coral reef ecosystems to climate change is summarized elsewhere (see Box CC-CR).

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 regional reef decline (De’ath *et al*., 2009; Tanzil *et al.,* 2009; Cantin *et al.,* 2010). Unprecedented bleaching events in small islands have been recorded iin the remote Phoenix Group (Kiribati) where 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 and temperature-induced coral bleaching was also recorded in isolated and unpopulated Palmyra Atoll during the 2009 ENSO event (Williams *et al*., 2010). In 2005 extensive bleaching was recorded 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). Studies of the severe 1998 El Niño bleaching event in the tropical Indian Ocean showed reefs in the Maldives, Seychelles and Chagos Islands were among the most impacted (Cinner *et al.,* 2012; Tkachenko, 2012). 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 in small islands is well documented and the synergistic effect of increasing ocean acidification can be considered a threat to the long-term persistence of island coral reef ecosystems (see Box CC-OA).

Island reefs have limited defences against thermal stress and acidification. However studies such as Cinner et al. (2012) and Tkachenko (2012) highlight that whilst recovery from bleaching is variable, some reefs show greater resilience that has important implications for reef protection and management regimes. Additionally, there is evidence that coral reef resilience is enhanced in the absence of other environmental stresses such as declining water quality. In Belize chronologies of growth rates in massive corals *Montastraea faveolata* over the past 75–150 years show that the bleaching event in 1998 was unprecedented but that the severity of the response also appeared to stem from reduced thermal tolerance resulting from the direct effect 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 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*., 2010). Coral recovery following the 2004 bleaching event in the central Pacific atolls Tarawa and Abaiang (Kiribati) was also noted to likely be improved in the absence of direct human impacts (Donner *et al.,* 2010).

The loss of coral reef habitat has dire implications to coastal fisheries (Pratchett *et al.,* 2009) in small islands where reef based subsistence and tourism activities are often critical to the wellbeing and economies of islands (Bell *et al.,* 2011). In Kimbe Bay, Papua New Guinea 65% of coastal fish are dependent on living reefs at some stage in their life cycles and that there is a decline in fish 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). In reefs where bleaching has not been an 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 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).

Like coral reefs, mangroves and sea grass environments provide a range of ecosystem goods and services (Polidoro *et al*., 2010 and Waycott *et al*., 2009) and both habitats play a significant role in the wellbeing of small island communities. 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. Elsewhere in the Caribbean and tropical Pacific observations vary in regards to the potential for sedimentation rates in mangroves forests to keep pace with sea-level rise (McKee *et al.,* 2007; Krauss *et al.,* 2003). In Kosrae and Pohnpei Islands (Federated States of Micronesia), Krauss *et al.,* (2010) found significant variability in mangrove average soil elevation changes due to deposition 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 sediment inputs. However, Rankey's (2011) study of shoreline change in atolls in Kiribati also noted natural seaward migration (up to 40m) of some mangrove areas between 1969 and 2009 suggesting 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) though in small islands accommodation space is seldom extensive as illustrated by Martinique in the Caribbean (Schleupner, 2008).

The response of sea grass to climate change stress is also likely to be complex, regionally variable and manifest in quite different ways. 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). 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 shallow waters on Hawaii's Molokai Island's fringing reefs, with negative implications to photosynthetic species such as seagrass. 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 seagrass 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 Systems: Island Biodiversity and Water Resources

Climate change impacts on terrestrial biodiversity on islands, frequently interacting with several other drivers (Blackburn *et al*., 2004; Didham *et al*., 2005), fall into three general categories namely: (a) ecosystem and species horizontal shifts and range decline; (b) altitudinal species range shifts and decline mainly due to temperature increase on high islands; and (c) exotic and pest species range increase and invasions mainly due to temperature increase in high latitude islands. Due to the limited area and isolated nature of most islands, these effects are generally magnified compared to continental areas and may cause species loss especially in tropical islands high in endemics. For example, decline in the long-term persistence of freshwater-dependent ecosystems within two low-lying Caribbean carbonate islands in the Bahamas have been attributed to 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 negatively impacts vegetation formerly reliant on deeper freshwater reserves. Sea level rise has been observed to threaten the long-term persistence of freshwater-dependent ecosystems within low-lying islands in the Florida Keys in the northern end of the Caribbean (Goodman *et al*., 2012). 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.

Whilst there are many studies that report observations associated with temperature increases in mid- and high-latitude islands, such as the Falkland Islands and Marion Islands in the south Atlantic and south Indian ocean respectively (Bokhorst *et al*., 2007; 2008; (Le Roux *et al*., 2005) and Svalbard in the Arctic (Webb *et al*., 1998) there are few equivalent studies in tropical small islands. One exception is a recent study of the tropical bird species the Mauritius kestrel that indicates changing rainfall conditions in the island of Mauritius over the last 50 years has 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).

Increasing global temperatures also lead to altitudinal species range shifts and contractions within high islands with an upward creep of the tree line and associated faunal species (Benning *et al*., 2002). Comparative vegetation distribution and composition studies in sub-Antarctic Marion Island, found an altitudinal shift of 3.4 m per year for plant species (Parolo and Rossi 2008). Comparative effects also occur in the tropics such as the Hawaii Volcano National Park where comparison of sample plots over a 40 year period from 1966-67 to 2008 show climate change attributed adaptation of fire adapted grasses upward in elevation (Angelo and Daehler, 2012). 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). 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).

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 harvesting is also an important contribution to freshwater access and alternatives like desalination have mixed success in small island settings due to operational costs (White and Falkland, 2010).

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). In the Caribbean where there is considerable variation in the types of freshwater supplies utilised concern over the status of freshwater availability has been expressed for at least the past 30 years (Cashman *et al.*, 2010). There have also been economic and management failures in the water sector not only in the Caribbean (Mycoo, 2007) but also in small islands in the Indian (Payet and Agricole, 2006) and Pacific oceans (Moglia *et al.,* 2008a; 2008b; White *et al.,* 2007) .

These issues also occur on a background of decreasing rainfall and increasing temperature. Rainfall records averaged over the Caribbean region for 100 years (1900-2000) show a consistent 0.18 mm/year reduction in rainfall, a trend that is projected to continue (Jury and Winter, 2010), In contrast, analysis of rainfall data over the past 100years from the Seychelles has shown substantial variability related to ENSO though an increase in average rainfall from 1959 to 1997 and an increase in temperature of ~ 0.25 °C per decade has occurred (Payet and Agricole, 2006). Detection of long-term statistical change in precipitation is one prerequisite to understanding the impacts of climate change in small island hydrology and water resources.

Much recent literature has focussed on saline (sea-water) intrusion into fresh groundwater reserves on atoll islands which is frequently attributed to incremental sea-level rise though 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 atoll 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 pond at the surface. This phenomenon already occurs in very low-lying central areas of Fongafale Island, Tuvalu, and during extreme high ‘king’ tides large areas of the inner part of the island become inundated with brackish waters (Yamano *et al.*, 2007; Locke, 2009).

29.3.3. Observed Impacts on Human Systems of Small Islands

29.3.3.1. Observed Impacts on Island Settlements and Tourism

Whilst traditional settlements on high islands were often located inland, the move to coastal locations was encouraged by colonial and religious authorities and more recently through the development of tourism. Now the majority of settlements, infrastructure and development is located on low-lands along the coastal fringe of small islands. In the case of atoll islands, all development and settlement 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 (Walsh *et al.*, 2012). Population drift from outer islands or from inland, together with rapid population growth in main centers and 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 place communities and infrastructure in positions of increased risk (Schleupner, 2008; Yamano *et al.*, 2007).

Many of the environmental issues that the media raise relating to Tuvalu, the Marshall Islands and Maldives are in fact only relevant 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 rather to the southern part 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 concern. They argue that these problems require immediate resolution if the vulnerability of the South Tarawa community to the 'real and alarming threat' of climate change is to be managed effectively (Storey and Hunter, 2010).

On Majuro atoll, rapid urban development and the abandonment of traditional settlement patterns has resulted in movement from less vulnerable to more vulnerable locations on the island (Spennemann, 1996). Likewise, geophysical studes 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.

The issue of 'coastal squeeze' remains a concern for many small islands 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). 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.

Tourism is an important sector on many small islands. Linkages between weather, climate and tourism in small islands have been assessed on several occasions, including in IPCC assessments. There is currently no evidence that observed climatic changes in small island destinations or source markets have altered patterns of demand for tourism to small islands (Scott *et al.,* 2012a). There is also no systematic analysis of how recent extreme storm events have impacted tourism operations (costs of evacuations, damages, recovery interruption, insurance) in small islands (UNWTO, 2010).

Climate can also impact directly on environmental resources that are major tourism attractions in small islands. Beach erosion is widespread and has been found to negatively impact destination attractiveness and accommodation prices (Houston 2002, Cowell *et al.,* 2006, Buzinde *et al.,* 2010a, 2010b, Hamilton 2007). Erosion caused by Hurricane *Wilma* in 2005 at renowned coastal tourism destinations in Mexico is indicated of these impacts. Tourist perceptions of the beach erosion and restoration ranged from aesthetically unpleasant and feeling deceived by marketing of extensive beaches to focusing on new recreational opportunities provided by the erosion control structures in the water (Buzinde *et al.*, 2010a, 2010b). Visitation at Cancun declined roughly 50% in the year following the erosion, but as beach restoration continued, arrivals recovered to pre-erosion levels in 2007 (Scott *et al.,* 2012b). It is unclear whether the extent of this recovery would have occurred without the extensive investment in beach restoration.

Higher surface water temperatures continue to cause coral bleaching near many small islands. Severe bleaching caused several marine parks and dive sites in Southeast Asia and the Indian Ocean to close during 2010, in an attempt to try and reduce further damage (Sarnsamak, 2011). Studies reveal dive tourists are well aware of coral bleaching, particularly the experienced diver segment (Cesar, 2000; Westmacott *et al.,* 2000, Ngazy *et al.,* 2005, Gössling *et al.,* 2008, Kragt *et al.,* 2009, Klint *et al.,* 2012a, 2012b, Klinthong 2012), and therefore more acute impacts occur among tourism operators and resorts that cater to these markets. No information is available on how changes in marine ecology are influencing the sport fishing industry of small islands (Scott *et al.,* 2012b).
The availability of freshwater is limited on many small islands, and changes in the availability or quality during drought events linked to climate change have adverse impacts on tourism operations (Gössling *et al.,* 2012, UNWTO 2012). One aspect of this that cruise ships may cease coming to an island where there is not sufficient freshwater to restock their supplies. Tourism is a seasonally significant water user in many island destinations and in times of drought, concerns over limited supply for residents and other economic activities become heightened (Tapper *et al.,* 2011, Gössling *et al.,* 2012). As a consequence, some islands are investing in coral reef restoration,

beach rehabilitation, water demand management and desalination plants in attempts to reverse the negative publicity arising from those observed impacts. There is no analysis of how widespread these investments are or their capability to cope effectively with future climate change. The tourism industry and investors are also beginning to consider the climate risk of tourism operations (Scott *et al.,* 2012b).

29.3.3.2. Observed Impacts on Human Health of Island Populations

Globally, the effects of climate change on human health will be both direct and indirect, and are expected to exacerbate existing health risks, especially in the most vulnerable communities where the burden of disease is already high (refer to Chapter 11.3, 11.5 and 11.6.1, this volume).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 (Barnett and Campbell, 2010; Cashman *et al.,*2010; Pulwarty *et al.,* 2010; McMichael and Lindgren, 2011). 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. The Caribbean has been identified 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-Stock *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) that are likely to be enhanced with increases in ambient temperature and changes in precipitation, vegetation and water availability as a consequence of climate change (Russell, 2009).

In Pacific islands the incidence of diseases such as malaria and dengue fever has been increasing, especially endemic dengue in Samoa, Tonga and Kiribati (Russell, 2009). While studies conducted so far in the Pacific have only established a direct link between malaria, dengue and climate variability, these and other health risks including from cholera, are projected to increase as a consequence of climate change (Russell, 2009; refer also to Chapter 11.2.4 and 11.2.5 this volume, for detailed discussion on the link between climate change and projected increases in the outbreak of dengue and cholera). Dengue incidence is also a major health concern in other small island countries, including Trinidad and Tobago, Singapore, Cape Verde, Comoros and Mauritius (Chadee *et al*, 2007; Chadee 2009; Koh *et al.,* 2008; Van Kleef *et al.,* 2010; Teles, 2011). In the specific cases of Trinidad and Tobago, the outbreaks have been significantly correlated with rainfall and temperature, respectively (Chadee *et al.,* 2007; Chadee 2009; Koh *et al.,* 2008).

Previous IPCC assessments have consistently shown that human health on islands can be seriously compromised by lack of access to adequate, safe, fresh water and adequate nutrition (Nurse *et al*., 2001; Mimura *et al*., 2007). Lovell (2011) notes that in the Pacific many of the anticipated health effects of climate change are expected to be indirect, connected to the increased stress and declining well-being that comes with property damage, loss of economic livelihood and threatened communities. There is also a growing concern in island communities in the Caribbean, Pacific and Indian Ocean, that fresh water scarcity, more intense droughts and storms could lead to a deterioration in standards of sanitation and hygiene (Cashman *et al*., 2010; McMichael and Lindgren, 2011). In such circumstances, increased exposure to a range of health risks including communicable diseases would be a distinct possibility.

Ciguatera fish poisoning (CFP) occurs in tropical regions and is the most common non-bacterial food-borne illness associated with consumption of fish. 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 in the island regions of the Caribbean (Morrison *et al.,* 2008; Tester *et al.,* 2010), Pacific (Llewellyn, 2010; Rongo and van Woesik, 2011; Chan et al, 2011) and the Mediterranean *(Aligizaki and Nikolaidis, 2008; refer also to section 29.5.4)*. One of the objectives of the Caribbean study was to characterize the relationships between sea surface temperatures (SSTs) and CFP incidence rates. 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 (Hay *et al.,* 2009; Martens *et al.*, 1999; Parham and Michael, 2010; Pascual *et al.*, 2006). While the present incidence of malaria on small islands is not reported to be high, favourable environmental and social circumstances for the spread of the disease are present in some island regions, and are expected to be enhanced under projected changes in climate in Papua New Guinea, Guyana, Suriname and French Guyana (Michon *et al.,* 2007**;** Rawlins *et al.,* 2008; Figueroa, 2008), 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.

29.3.3.3. Observed Impacts of Climate Change on Relocation and Migration

Empirical evidence of human migration as a response to climate change is scarce for small islands – in terms of a lack of studies showing the direct impacts of climate change on human settlements, and how these impacts lead to changes in migration and resettlement attitudes and behaviours. Several authors highlight this lack of empirical studies of the effect of climate drivers such as sea level rise, on island migration (Lilleor and Van den Broeck, 2011: s78, Mortreux and Barnett, 2009). Further there is no evidence of any government policy that allows for climate 'refugees' from islands to be accepted into another country (Bedford and Bedford, 2010). This surprising finding contrasts with the early desk-based estimates of migration under climate change such as the work of Myers (2002). These early studies have been criticised as they fail to acknowledge: the reality of climate impacts on islands, the capacity of islands and islanders to adapt, or the actual drivers of migration (Barnett and O'Neill, 2012).

The majority of studies on island migration reveal that the key drivers are economic or cultural and not climatic. For example when looking at historical process of migration within the Mediterranean it appears that rising levels of income, coupled with a decreased dependence on subsistence agriculture has left the Mediterranean less vulnerable to all environmental stressors, resulting in a reduced need for mobility to cope with environmental or climatic change (de Haas, 2011). Studies from the Pacific have also shown that culture, lifestyle and a connection to place are more significant drivers of migration than climate (Mortreux and Barnett, 2009, Barnett and Webber, 2010). For example a Pacific Access Category of migration has been agreed between New Zealand and Tuvalu that permits 75 Tuvaluans to migrate to New Zealand every year (Kravchenko, 2008). Instead of enabling climate driven migration, this agreement is designed to facilitate economic and social migration as part of the Pacific island lifestyle (Shen and Gemenne, 2011). Thus, there is no evidence *yet* that reveals that migration from islands is being driven by climate change.

Nonetheless there is recognition that environmental change affects land use and land rights, which in turn are drivers of migration (Bedford and Bedford, 2010). In a survey of 86 case studies of community relocations in Pacific islands, Campbell et al. (2005) found that environmental variability and natural hazards accounted for 37 communities relocating. In the Pacific, where land rights are a source of conflict, climate change could increase levels of stress associated with land rights, and impact on migration (Campbell, 2010; Weir and Virani, 2011).

While there is not yet a climate fingerprint on migration and resettlement patterns in small islands, it is clear that there is the potential for human movement as a response to climate change. To better understand the impact of climate change on migration there is an urgent need for robust methods to identify and measure the effects of the drivers of migration on migration and resettlement.

29.3.3.4. Observed Impacts on Island Economies

The economic and environmental vulnerabilities of small islands states are well documented (Briguglio *et al.,* 2009, Bishop, 2012). Such vulnerabilities, which render the states at risk of being harmed by economic and environmental conditions, stem from intrinsic features of these states, and are not governance induced (although poor governance in this regard may aggravate the harm).

Economic vulnerability is the result of a high degree of exposure to economic conditions often outside the control of small island states, exacerbated by dependence on a narrow range of exports and a high degree of dependence on strategic imports, such as food and fuel (Briguglio *et al.,* 2009). This leads to economic volatility, a condition that is harmful for the economy of the islands (Guillaumont, 2010).

There are other economic downsides associated with small size and insularity. Small size leads to high overhead cost per capita, particularly in infrastructural outlays. This is of major relevance to climate change adaptation as this often requires upgrades and redesign of island infrastructure. Insularity leads to high cost of transport per unit, associated with purchases of raw materials and industrial supplies in small quantities, as well as high cost of storing and warehousing to ensure adequate supply of production inputs and consumer goods. These disadvantages are associated with the inability of small islands to reap the benefits of economies of scale resulting in a high cost of doing business in small islands (Winters and Martins, 2004).

The environmental vulnerability of small island states stems from various intrinsic features, including the high ratio of coastline to land mass, rendering these states highly exposed to ocean borne hazards and to sea-level rise (Barnett and Campbell, 2010, Nicholls and Cazenave, 2010). Small island states are also highly prone to natural disasters (Peduzzi *et al.,* 2009; Turvey, 2007). Other environmental problems associated with small territory size relate to the high population densities of many small island states, which leads to a high per capita cost of waste management, traffic congestion, relatively high degree of biodiversity loss, heavy strain on water resources and other environmental harm associated with population pressure.

These economic and environmental problems are exacerbated by climate change, particularly because government funds have to be diverted from the normal budget outlays to cover additional expenditures associated with mitigation and adaptation to climate change. In addition, a large proportion of economic activity of many small island states, particularly those associated with tourism and fisheries, are located right on the coastline and these are likely to be affected by sea-level rise and extreme weather events.

29.3.4. Detection and Attribution of Observed Impacts of Climate Change on Small Islands

While exceptional vulnerability of many small islands to future climate change is widely accepted, the foregoing analysis indicates that scientific literature on observed impacts is quite limited. Detection of past and recent climate change impacts is challenging due to the presence of other anthropogenic drivers, especially in the constrained environments of small islands. Attribution is further challenged by the strong influence of natural climate variability compared to incremental change of climate drivers. Notwithstanding these limitations we have prepared a summary of the relationship between detection and attribution to climate change of several of the phenomena described in the above sections. Figure 29-2 reflects our degree of confidence in the linkage between observed changes in several components of the coastal, terrestrial and human systems of small islands and the drivers of climate change.

[INSERT FIGURE 29-2 HERE
Figure 29-2: Based on available literature discussed in this chapter, the diagram shows a comparison of the degree of confidence in the detection of tropical small island impacts (horizontal axis) with the degree of confidence in attribution to climate change drivers (vertical axis). For example; the blue symbol No. 2 (Coastal Systems), indicates there is very high confidence in both the detection of "sea-level rise consistent with global means" and its attribution to climate change drivers; whereas the yellow symbol No. 17 (Human Systems) indicates whilst detection of "casualties and damage during extreme events" is very high, at this time there is low confidence in the attribution to climate change drivers. It is important to note that low confidence in attribution frequently arises due to the very limited research available for small island environments.]

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 (GCMs) used in the SRES scenarios 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 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 GCM data and observations. In most small islands long-term quality-controlled climate data is generally sparse, so that in widely dispersed islands such as in the Pacific, observational records are usually supplemented with satellite observations combined with computer models (Australian Bureau of Meteorology and CSIRO, 2011a; Keener *et al*., 2012). 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, 2010). Even so, most projected changes in climate for the Caribbean, Pacific, Indian Ocean and Mediterranean islands, generally apply to the region as a whole and this may f be adequate to determine general trends in regions where islands are close together.

29.4.1. Non-Formal Scenario-Based Projected Impacts

Scenarios are often constructed by using a qualitative climate projections approach based on expected changes in some physical climate signal from literature review rather than direct modelling. Sometimes this is proposed as a 'what if' question which is then quantified using a numerical method. For example, in the Caribbean, sea level projections superimposed on topographic maps have been used to estimate that 49-60% of resort properties would be damaged with a one metre sea-level rise, potentially transforming the competitive position and sustainability of coastal tourism destinations in the region (Scott *et al.,* 2012c). Another example of qualitative modelling from the Pacific is a case study from Nauru which uses local data and knowledge of climate to assess the GCM projections. It suggests that Nauru should plan for continued ENSO variability in the future with dry years during La Niña and an overall increase in mean rainfall and extreme rainfall events. Climate adaptation concerns which arise include water security and potential changes in extreme wet events which affect infrastructure and human health (Brown *et al., submitted*).

29.4.2. Projected Impacts for Islands based on Existing SRES Scenarios

Another approach to scenario development is to use the SRES projections more directly. The broad synthesis in the AR4 of climate scenario projections and impacts on small island regions (e.g. Mimura *et al*., 2007) remains valid (see new RCP Projections in Figure 29-3). 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 (see also AR5 WG 1, 14.7.4) and a 3-5% increase in the Indian and Pacific Oceans small island regions. There are important spatial differences however as for example among the more dispersed Pacific islands where the more equatorial regions are likely to get wetter and the sub-tropical high pressure belts drier as reported by AR5 WG I, however, in regions directly affected by the SPCZ and western portion of the ITCZ, the rainfall outlook is uncertain (AR5 WG 1, 14.7.13). The Mediterranean islands also have differences from the tropical small island pattern. Throughout the Mediterranean region, the length, frequency, and/or intensity of warm spells or heat waves are very likely to increase to the year 2100 (AR5 WG 1, 14.7.6).

[INSERT TABLE 29-1 HERE
Table 29-1: Small islands regions temperature and precipitation change projections for the SRES A1B scenario over the period 2080-2099 compared to 1980-1999. 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 WGI AR4 Table 11.1).

In the main regions in which most tropical or sub-tropical small island states are located, there are few independent peer reviewed scientific publications providing downscaled climate data projections, and virtually none illustrating the experience gained from their use for policy making. 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 (see Chapter *6.2.2.4.4.*). 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 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 locally 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.,* 2011, Taylor *et al.,* 2013). 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 high emissions scenario (Maunsell Australia Pty Ltd., 2009). Future climate change projections for the two islands for 2070 include a 1.8°C increase in air temperature by 2070, probable drier dry seasons and wet seasons, a 40 cm rise in sea level and a decrease in intense tropical cyclones.

In the western tropical Pacific, extensive climate projections have been made for 15 small islands based on downscaling from an ensemble of 15 GCMs (Australian Bureau of Meteorology and CSIRO, 2011b). The temperature projections in this region dominated by oceans seem less than those seen globally ranging from +1.5 to 2.0 °C for the B1 low emissions scenario to +2.5 to 3.0 °C for the A2 high emissions scenario by the year 2090 relative to a 20 year period centred on 1990. Notably there is a expected trend of increasing rainfall as indicated by a projected increase in 20 year extreme rainfall events to an average of seven times per year, by 2090 under the A2 (high emissions) scenario (Australian Bureau of Meteorology and CSIRO, 2011b). In the tropical Pacific Ocean, another 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: Preliminary projected percentage changes in tuna catches relative to the 20 year average (1980-2000) and estimated percentage change to government revenue resulting from projected changes in the catch of skipjack tuna in 2030 and 2100 (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, Bell *et al.*, 2013).

In the Mediterranean islands of Mallorca, Corsica, Sardinia, Crete and Lesvos, Gritti et al. (2006) simulated the terrestrial 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) 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.

29.4.3. RCP Projections and Implications for Small Islands

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 in an ongoing process are matched to a global socio-economic scenario storyline (SSP) such that each RCP can respond to more than one SSP. Scientists have strongly cautioned against the specification of detailed sub-global conditions and local trends 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 29-3 adapted from Annex I WGI AR5. Highlighted in Figure 29-3 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 29-3 HERE
Figure 29-3: 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) advocated that the Global Mean Surface Temperature (GMST) increase should be limited to ‘well below’ 1.5ºC above pre-industrial levels (Hare *et al.,* 2011; Riedy and McGregor, 2011). Inspection of column 1 in Figure 29-3 suggests that for Caribbean, Indian Ocean and Pacific SIDS in the tropics, that is only plausible under RCP 2.6 that 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 29-3 suggest a probable 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 may experience a decrease in mean rainfall while the Indian and Pacific Ocean SIDS may experience increased rainfall. These trends accelerate moderately for RCP 6.0 and steeply for RCP 8.5.

29.5. Inter- and Intra-Regional Trans-Boundary Impacts on Small Islands

Many impacts on small islands are generated by processes originating in another region or continent well beyond the borders of an individual archipelagic nation or small island. These are inter-regional trans-boundary impacts. Intra-regional trans-boundary impacts originate from a within-region source (e.g. within the Caribbean). Some trans-boundary 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 trans-boundary 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. Large Ocean Waves from Distant Sources

Unusually large deep ocean swells, generated from far distant sources in the mid- and high-latitudes by Extra-Tropical Cyclones (ETC) 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. While significant wave height has been observed to increase in some regions, current model simulations project enhanced wave heights only in the Southern Ocean and the tropical South Pacific, and decreases in all other ocean basins (See AR5-WG1, 13.7.3.2). This may however be related to the challenge of downscaling 'future wind states from coarse resolution climate models into regional and global wave model projections' (AR5-WG1, 13.7.3).

Swell events of similar origin and characteristics also occur in the Pacific the best documented being in the Hawaiian island where there is evidence of damage to coral growth by swell from the north Pacific, especially during years with a strong El Nino signal (Fletcher *et al*., 2008). Hoeke et al. (submitted) describe inundation from mid-high latitude north and south Pacific waves respectively at Majuro (Marshall Islands) in November and December 1979 and along the Coral Coast (Fiji) in May 2011. They also describe in detail an inundation event in December 2008 that was widespread throughout the western and central Pacific and resulted in waves surging across low-lying islands causing severe damage to housing and infrastructure and key natural resources that affected about 100,00 people across the region. The proximate cause of this event was swell generated in mid-latitudes of the north Pacific Ocean, more than 4000 km from the furthest affected island (Hoeke *et al.,* submitted).

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 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). From the perspective of those islands that suffer damage from this coastal hazard on an annual basis, this is an area that warrants further investigation.

Deep ocean swell waves and elevated sea-levels resulting from ETCs are examples of *inter-regional* trans-boundary processes; locally generated Tropical Cyclones (TCs) provide examples of *intra-regional* trans-boundary processes. Whilst hurricane force winds, heavy rainfall and turbulent seas associated with TCs can cause massive damage to both land and coastal systems in tropical small islands, the impacts of sea waves and inundation associated with far distant ETCs are limited to the coastal margins. Nevertheless both storm types result in a range of impacts covering island morphology, natural and ecological systems, island economies, settlements and human well-being (see Figure 29-4).

[INSERT FIGURE 29-4 HERE
Figure 29-4: Tropical and extra-tropical cyclone impacts on the coasts of small islands: a. Example of tropical cyclone impacts on small island coasts with reference; b. Example of extra-tropical cyclone (mid-high-latitude lows) impacts on small island coasts with reference.

1a. Society Islands, French Polynesia, February 2010 (Etienne, 2012); 1b. Maldives, April 1987 (Harangozo, 1992); 2a.Taveuni (Fiji) March 2010 (Etienne and Terry, 2012); 2b. Funafuti atoll, Tuvalu, October 1972 (Baines *et al.*,1974); 3a. Society and Autrales Islands, French Polynesia, February 2010 (Etienne, 2012); 3b.Maldives, April 1987 (Harangozo, 1992); 4a. Viti Levu, Fiji, March 1997 (Terry, *et al.,* 2002); 5a.Society Islands, French Polynesia, February 2010 (Etienne, 2012); 6a. Curacao, Bonaire, Netherlands Antilles, November 1999 (Scheffers and

Scheffers, 2006); Hawaiian Islands (Fletcher *et al.,*, 2008); 8a. Marshall Islands, June 1905 (Spennemann, 1996); 9a. Pukapuka atoll, Cook Islands 2005 (Terry and Falkland, 2010); 9b. Solomon Islands, December 2008 (Hoeke, submitted); 10a. Vanuatu 2004 (Richmond and Savacool, 2012); 10b. Chuck, Pohnpei, Kosrae, Federated States of Micronesia, December 2008 (Hoeke, submitted); 11a. 12a. 13a. Tuamotu Islands, French Polynesia, 1982-83 (Dupon, 1987); 15a. Tubuai (Australes Islands) February 2010 (Etienne, 2012); 15b. Majuro, Marshall Islands, November 1979 (Hoeke, submitted); 16a. Vanuata February 2004 (Richmond and Savacool, 2012);16b. Coral Coast, Viti Levu, Fiji, May 2011 (Hoeke, submitted); 17a. Bora Bora,Raiatea, Maupiti, Tahaa, Hahine (Society Islands) February 2010 (Etienne, 2012);17b. Majuro, Kwajalein, Arno Marshall Islands,December 2008 (Hoeke, submitted); 18a. Vanuatu, February 2004 (Richmond and Savacool, 2012); 18b. Bismark Archiplago, Papua New Guinea, December 2008 (Hoeke, submitted); 19a. Tuamotu (French Polynesia) 1982-83 (Dupon, 1987).]

29.5.2. Trans-Continental Dust Clouds and their Impact

The transport of airborne 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 carry pollen, microbes, insects, bacteria, fungal spores and various chemicals (Prospero *et al*., 2005; Middleton *et al*., 2008; Monteil, 2008). During major events, dust concentrations can exceed 100 $\mu g\ m^{-3}$ (Prospero, 2006; Griffin, 2007). 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 change effects over large areas, including the eastern Caribbean and the Mediterranean (Prospero and Lamb, 2003). 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 also 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 problems 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.

29.5.3. 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*., 2009; 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 Hawaiian islands; and by Christenhusz and Toivonen (2008) who showed 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 and return to species richness. . This has been demonstrated in Mauritius by Baider and Florens, 2011) where some forested areas were weeded of alien plants and after a decade the forest had recovered close to its initial condition,. 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. Recent research has shown that the invasion of the Caribbean Sea by the Indo-Pacific lionfish (*Pterois volitans*), a highly efficient and successful predator, is a major contributor to observed increases in algal dominance in coral and sponge communities in the Bahamas and elsewhere in the region. The consequential damage to these ecosystems has been attributed to a significant decline in herbivores due to predation by lionfish (Schofield, 2010; Albins and Hixon, 2008; Lesser and Slattery, 2011; Green *et al.,* 2011). While there is no evidence that the lionfish invasion is climate-related, the concern is that when combined with pre-existing stress factors the natural resilience of Caribbean reef communities would decrease (Albins and Hixon, 2011; Green *et al*., 2012), making them more susceptible to climate change effects such as bleaching. 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).

29.5.4. 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;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; Brandt and McManus, 2009; Miller *et al*., 2009; Weil and Croquer, 2009; McClanahan *et al*,, 2009; Weil and Rogers, 2011).

29.5.5. Trans-Boundary 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, that 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

For most islands, there is limited empirical evidence of changes in risk associated with climate change, largely due to: poor regional projections e.g. of sea level rise (Willis and Church, 2012), and a lack of long term baseline monitoring of changes in climatic risk (Voccia, 2012), such as risk of saline intrusion, risk of invasive species, risk of biodiversity loss, risk of large ocean waves, or risk of sea-level rise. Island adaptation studies therefore rely on analogues of responses to past and present weather extremes and climatic change, or assumed impacts of climate change based on island type, see Table 29-3. Until climate risks are better identified for islands, our ability to identify effective adaptations remains constrained.

[INSERT TABLE 29-3 HERE
Table 29-3. Type of island in the Pacific region and implications for hydro-meteorological hazards.]

29.6.1. Addressing Current Vulnerabilities and Adaptation Gaps on Small Islands

There is medium evidence of generic vulnerability of small islands to climate change, with some disagreement about the costs of adapting in small islands, and ultimately the potential need for migration from small islands (Nicholls *et al.,* 2011, Gemenne, 2011, Biermann and Boas, 2010, Voccia 2012). Islands are heterogeneous in geomorphology, culture, ecosystems, populations and hence also in their vulnerability to climate change (Wheeler, 2011). 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).

Generic indices of national level vulnerability continue to emerge (Cardona, 2007) with a minority focused on small islands (e.g. Blancard and Hoarau, 2013). Many indicators suffer from lack of data, for example, Peduzzi et al. (2009) note that 18 small island states in the Pacific, Caribbean and Indian oceans are not included in their Disaster Risk Index due to lack of data. Other generic indices use indicators that are not relevant in all islands (Barnett and Campbell, 2010), or use data of limited quality for islands, such as sea level rise (as used in Wheeler, 2010). Park et al. (2012) attempt to produce relevant indicators of climate vulnerability and adaptive capacity for the Pacific Islands by adopting a three-stage participatory approach linking scientific knowledge with local visions of vulnerability. Their study concludes that all Pacific Island nations will be vulnerable to climate change in the next 40 years.

Following Smit et al. (2000), Brooks et al. (2005), and Yamano et al. (2007), Barnett and Campbell (2010) reinforce the point that island vulnerability to climate change is often a function of four key stressors: socio-economic, geo-physical, and socio-ecological vulnerabilities, as well as the climate stressor. Socio-economic vulnerabilities are related to on-going challenges of managing urbanisation, pollution and sanitation, both in small island states and non-sovereign islands as highlighted by Storey and Hunter (2010) in Kiribati, López-Marrero and Yarnal (2010) in Puerto Rico, and in Mayotte (France) (Le Masson and Kelman, 2011). Geo-physical characteristics of islands are varied, some low-lying atolls, some oceanic, some volcanic islands (see Table 29-3; Figure 29-1), each of which creates different 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 (described in Sax and Gaines, 2008), overexploitation, pollution, human encroachment and disease can harm biodiversity (Caujape-Castells *et al*., 2010; Kingsford *et al.,* 2009), and reduce the ability of socio-ecological systems to bounce back after shocks. To understand climate vulnerability on islands, the impact of each of these non-climate stresses needs to be first understood and then integrated into climate vulnerability assessments (Rasmussen *et al*., 2011). For example, with individual ecosystems, such as 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). Evidence is starting to emerge that shows the same applies at the island scale. In Majuro (Marshall Islands), 34-37 years of aerial photography indicates that rural areas have experienced lower rates of erosion than urban areas (Ford, 2012). This could suggest that either the eroding urban coastal areas were initially more exposed, or that human activity in coastal areas and interventions in coastal ecosystems are exacerbating erosion associated with sea level rise. Additional empirical evidence is needed to confirm which explanation is accurate. In short, all aspects of vulnerability and climate risk assessment remain under-researched in islands; for most islands it is not possible to answer the key vulnerability questions unequivocally, i.e. who is at risk of what, where, and when?

29.6.2. Practical Experiences of Adaptation on Small Islands

Islands are often assumed to be generically vulnerable to climate change (Parks and Roberts, 2006, Myers, 2002). Yet 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 hydro-meteorological hazards (Barnett, 2001). Their resilience appears to come from both a belief in their own capacity (Kuruppu and Liverman, 2011; Adger and Brown, 2009), and a familiarity with their environment and understanding of what is needed to adapt (Tompkins et al., 2009; Le Masson and Kelman, 2011). For example, compared to communities in the larger countries of Madagascar, Tanzania and Kenya, the Indian Ocean islands – the Seychelles and Mauritius – were found to have comparatively high adaptive capacity (Cinner *et al.,* 2012). Adaptive capacity was assessed as: capacity to anticipate change and prepare strategies, self-awareness of human impact on environment; willingness to change occupation; livelihood diversity; social capital; material assets; access to technology and infrastructure. These studies all point to the importance of self-belief as well as culturally communicated knowledge of current risks and how to respond to them.

There are many ways in which climate adaptation can be undertaken: reducing socio-economic vulnerabilities, building adaptive capacity, enhancing disaster risk reduction, or building longer term climate resilience (e.g. see McGray *et al*., 2007, Eakin *et al.,* 2009). Figure 29-5 highlights the potential benefits and risks associated with the various options. Not all adaptations will be equally appropriate in all contexts. Understanding the baseline conditions and stresses (both climate and other) are important in understanding which climate change adaptation option will generate the greatest benefits. On small islands where resources are often limited, recognising the starting point for action is critical to maximising the benefits from adaptation. The following section considers the benefits of pursuing the various options.

[INSERT FIGURE 29-5 HERE
Figure 29-5. Potential benefits and risks associated with alternative climate change adaptation actions or policies.]

29.6.2.1. Building Adaptive Capacity on Small Islands

Capacity to adapt to current risks on islands may be correlated to ability to adapt to future climate change, but there is limited evidence for this (such as Lefale, 2010). Consequently, this section can only assess evidence of adaptive capacity that: reduces vulnerability to existing stressors, enables adaptation to current stresses, or supports current disaster risk management, much of this relates to traditional practices.

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). Two discrete studies from the Solomon Islands highlight the importance of traditional patterns of social organization within communities to support food security under social and environmental change (Reenberg *et al.,* 2008, Mertz *et al.,* 2010). In both studies 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. Evidence is inconclusive on the local capacity to observe long-term climate change. In the Solomon Islands, Lauer and Aswani (2010) found mixed ability to detect change in spatial cover of seagrass meadows. In Jamaica, Gamble et al. (2010) reported a high level of agreement between farmers' perception of increasing drought incidence and statistical analysis of precipitation and vegetation data for the area. In this case farmers perceptions clearly validated the observational data and vice versa. Despite some claims that the vulnerability of indigenous groups in small islands may be best tackled by combining indigenous and Western knowledge in a culturally compatible and sustainable manner (Mercer *et al.,* 2007), given the small number of studies in this area, there is not sufficient evidence to determine the benefits and limits to the use of traditional knowledge in building adaptive capacity to climate change on small islands.

There is a growing literature, but a lack of agreement on the role of traditional technologies and skills for climate adaptation. In coastal Samoa participatory village consultation and capacity building that take into account traditional practices, can be vital to the success of adaptation initiatives in island communities (Daly, 2010). Campbell (2009) identified that traditional disaster reduction measures used in Pacific islands focussed around maintaining food security, building community cooperation, and protecting settlements and inhabitants. Examples of actions to maintain food security include: the production and storage of food surpluses – such as yam and breadfruit buried in leaf-lined pits to ferment; high levels of agricultural diversity to minimise specific damage to any one crop; and the growth of robust famine crops – unused in times of plenty which could be used in emergencies (Campbell, 2009). Nonetheless there are physical and cultural limits to the ability to store surplus production on atoll islands. On Rongelap in the Marshall Islands, surpluses are avoided, or are redistributed to support community bonds (Bridges and McClatchey, 2009). Further, traditional approaches that Pacific island communities have used for survival for millennia (such as building elevated settlements and resilient structures; and working collectively), have been abandoned or forgotten due to processes of globalisation, colonialism and development (Campbell, 2009).

Traditional construction methods have long been identified across the Pacific as a means of adapting to tropical cyclones and floods. In the Solomon Islands traditional practices include: 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' 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). In parallel, Campbell (2009) documents the characteristics of traditional building styles (in Fiji, Samoa and Tonga) where relatively steep hipped roofs, well bound connections and joints, and airtight spaces with few windows or doors offer some degree of wind resistance. Traditional building measures can also reduce damages associated with earthquakes – as evidenced in Haiti (Audefroy, 2011). By reducing damage caused by other stresses (such as earthquakes), adaptive capacity is more likely to be maintained. The quality of home construction is critical to its wind-resistance. If inadequately detailed, home construction will fail irrespective of method. While some traditional measures could be challenged as potentially risky – for example using palm leaves, rather than metal roofs as a preparation for tropical cyclone impacts – the documentation of traditional approaches, with an evaluation of their effectiveness remains urgently needed.

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). In Reunion and Mayotte, population growth, and consequent rises in land and house prices have lead low-income families moving closer to hazardous slopes that are prone to landslides and river-banks which are prone to flooding (Le Masson and Kelman, 2011). Traditional belief systems can also limit adaptive capacity, for example in two Fijian villages, approximately half of survey respondents identified divine will as the cause of climate change (Lata and Nunn, 2012). These findings reinforce earlier studies in Tuvalu (Mortreux and Barnett, 2009), and more widely across the Pacific (Barnett and Campbell, 2010). 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 research is also needed to identify its limits, such as in the context of rapid socio-ecological change, or the impact of belief systems on adaptive capacity.

There remains limited evidence 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. More detailed studies on small islands in the central and western Indian Ocean, the Mediterranean and the central and eastern Atlantic would improve understanding in this area.

29.6.2.2.Addressing Risks on Small Islands

Many of the future climate risks on small islands remain unknown due to: the lack of effective downscaling methods for small islands, the lack of baseline data to ground-truth model results, and the lack of model skill in projecting the climatic variables that matter to small islands, notably: tropical cyclone frequency and intensity, wind speed and direction, precipitation, sea level, ocean temperature and ocean acidification (Brown *et al.,* submitted). Therefore much of the research on climate risks on islands depicts either current hydro-meteorological risks and responses, or risk management for hypothesised risks. In terms of present disaster risks, reflected by global disaster statistics, islands rarely appear to be in the 'worst affected' category - this is due to their small size and population. Yet, when the relative impact of current natural hazards are considered, in terms of percentage of the population exposed or in terms of losses as a percentage of GDP, then islands appear to suffer disproportionately (see Table 29-4).

[INSERT TABLE 29-4 HERE
Table 29-4: Top ten countries in the Asia-Pacific region based on absolute and relative physical exposure to storms and impact on GDP (between 1998 and 2009).]

Much of the climate risks literature recognises the relatively severe impacts of current natural hazards on islands, and identifies a range of approaches for managing this risk. Again, it is worth highlighting that most of this literature considers present day risk as an analogue for future risk; yet there is little evidence of a correlation between the effectiveness of current and future risk management under climate change. Given this constraint, much of the work on addressing risk focuses on either risk transfer, risk spreading or risk avoidance. Risk transfer is often 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.

Risk transfer through insurance markets has limited uptake in small islands, as the markets do not function as effectively as they do in larger locations, in part due to a small demand for the insurance products (Heger *et al.*, 2008). In the case of insurance for farmers, researchers found that a lack of demand for insurance products (in their study countries: Grenada, Jamaica, Fiji and Vanuatu) meant an undersupply of customized food insurance products, which in turn contributed to a lack of demand for insurance (Angelucci and Conforti, 2010). Alternatives exist such as index-based schemes which provide pay outs based on the crossing of a physical threshold, e.g. when rainfall drops below a certain level, rather than on drought damage sustained, (Linnerooth-Bayer and Mechler, 2009). The potential for index-based insurance for climate stressors on islands is under-researched. Small island governments also face expensive climate risk insurance. The Caribbean Catastrophe Risk Insurance Facility (CCRIF) pools Caribbean-wide country-level risks into a central, more diversified portfolio – offering lower premiums for participating national governments. CCRIF has been operating since 2007 (CCRIF, 2008). The potential for a similar scheme in the Pacific is being explored (ADB, 2009, Cummins and Mahul, 2009), although there is limited evidence of the long-term effectiveness of index-based or pooled-risk insurance in supporting household level adaptation.

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. In Fiji, after Cyclone *Ami* in 2003, households whose homes were not affected by the cyclone increased their fishing effort 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). In Fiji, Locally Managed Marine Areas – which involve the local community in the management and protection of their local marine environment – have proven to be effective in increasing biodiversity, and in reducing poverty in areas dependent on marine resources (Techera, 2008). By creating a network of protected areas supported by local communities there is medium evidence that risks associated with some forms of climate change can be spread and potentially reduced (Mills *et al*., 2010).

29.6.2.3. Working Collectively to Address Climate Impacts on Small Islands

More attention is being focused on the relevance and application of community-based adaptation (CBA) principles to island communities, to facilitate adaptation planning and implementation (Warrick, 2009; Kelman *et al*., 2011), and to tackle rural poverty in resource dependent communities (Techera, 2008). 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 being promoted as an appropriate strategy for small states, since it is something done 'with' rather than 'to' communities (Warrick, 2009).

Nonetheless externally driven programmes to encourage community-level action have produced some evidence of effective adaptation. Both Limalevu et al. (2010) and Dumaru (2010) describe the outcomes of externally-led pilot community-based adaptation projects (addressing water security and coastal management) implemented in villages across Fiji, notably: 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. Limalevu et al. (2010) recognise that more long term monitoring and evaluation of the effectiveness of community level action is needed.

There is medium evidence that collaboration between a variety of stakeholders can benefit communities through the introduction of technical expertise to avoid simple mistakes that can dampen the effectiveness of adaptation actions. Evidence from the Eastern Caribbean suggests that adaptations taken by individual households to reduce landslide risk – building simple retaining walls – can be ineffective compared to community level responses (Anderson et al., 2011). They argue better hillside drainage through construction of networks of drains to capture surface runoff, household roof-water and grey water, with community support to construct the networks, with input from engineers can significantly reduce landslide risk . 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. In the case of community based disaster risk reduction (CBDRR), Pelling (2011) notes that buy-in from local and municipal governments are needed, as well as strong pre-existing relationships founded on routine daily activities, to make CBDRR effective. In both the Solomon Islands and the Cayman Islands there is reasonable agreement that the factors that underpin resilience to hazards resonates with earlier work on successful governance of the commons, that is: community cohesion; effective leadership; and, community buy-in to collective action (Schwarz *et al.,* 2011, Tompkins *et al*., 2008). Where community organisations are operating in isolation, or where there is limited coordination and collaboration community vulnerability is likely to increase (Ferdinand *et al*., 2012). Strong local networks, and trusting relationships between communities and government appear to be key elements in adaptation, in terms of maintaining sustainable agriculture and in disaster risk management.

All of these studies reinforce the earlier work of Barnett (2001), providing robust evidence that supporting community-led approaches to disaster risk reduction and hazard management may contribute to greater community engagement with anticipatory adaptation. However, it is not yet possible to identify the extent to which climate resilience is a coincidental benefit of island lifestyle and cultural, or a purposeful approach, such as the community benefits gained from reciprocity among kinship groups (Campbell, 2009).

29.6.2.4. Addressing Long-Term Climate Impacts and Migration on Small Islands

Small island states have 16% of their land area in low elevation coastal areas (<10m) as opposed to a global average of 2%, and the largest proportion of low elevation coastal urban land area: 13% (along with Australia and New Zealand), in contrast to the global average of 8% (McGranahan *et al.,* 2007). Figures like these lead many to suggest that small islands could be overwhelmed by rising seas associated with sea level rise (Loughry and McAdam, 2008, Yamamoto and Esteban, 2010, Gordon-Clark, 2012, Berringer, 2012, Dema, 2012, Lazrus, 2012, Laczko and Aghazarm, 2009). Yet there remains limited evidence as to which regions (Caribbean, Pacific, Indian Ocean) will experience the largest sea level rise (Willis and Church, 2012), which islands will experience the worst climate impacts, or which, if any, islands might disappear completely. Nicholls et al. (2011) have modeled impacts of 4°C warming, producing a 0.5 to 2.0m sea level rise, to assess the impacts on land loss and on migration. With no adaptation occurring, they estimate that this could produce displacement of between 1.2 and 2.2 million people from the Caribbean, Indian Ocean and Pacific Ocean. More research is needed to produce robust agreement on the impact of sea level rise on small islands, and on the range of adaptation strategies that could be appropriate under those scenarios. Some authors highlight that the image of small islands as ‘canaries in the coal mine’ is a western discourse that could potentially hinder adaptation in islands (Farbotko and Lazrus, 2012). Research into the possible un-inhabitability of islands has to be undertaken sensitively to avoid short-term risks (i.e. to avoid depopulation and ultimately island abandonment) associated with a loss of confidence in an islands’ future (McNamara and Gibson, 2009, McLeman, 2011).

Relocation and displacement are frequently cited as outcomes of sea level rise and consequent land loss on islands (Byravan and Rajan, 2006, Biermann and Boas, 2008, Kolmannskog and Trebbi, 2010). Recent examples of environmental stress driven relocation and displacement provide contemporary analogues of climate-induced migration. Evidence of post-natural disaster migration has been documented in the Caribbean in relation to hurricanes (McLeman and Hunter, 2010), and in the Carteret Islands, Papua New Guinea – where during exceptionally high inundation event in 2008 (see 29.5.1.1) islanders sought refuge on neighbouring Bougainville island (Jarvis, 2010). Drawing any strong conclusions from this literature is challenging as there is little understanding of how to measure the effect of the environmental signal in migration patterns (Afifi *et al*., 2013, Krishnamurthy, 2012). While the example of the Carteret Islands cannot be described as evidence of adaptation to climate change, it suggests that under some scenarios entire island communities may need to relocate in the future (Gemenne, 2011). In reality, financial and legal barriers are likely to inhibit significant levels of international environmentally induced migration in the Pacific (Barnett and Chamberlain, 2010) (see also Box 29-1). In the event of entire island relocation, 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). The potential migration options open to islands are presented in Table 29-5.

[INSERT TABLE 29-5 HERE
Table 29-5: Climate migration options in the Pacific.]

Climate stress is occurring at the same time as the growth in rural to urban migration. The latter is leading to squatter settlements that strain urban infrastructure – notably: sewerage, waste management, transport and electricity (Jones, 2005, Connell and Lea, 2002). Urban squatters often live in highly exposed locations, lacking basic amenities, leaving them highly vulnerable to climate risks (Baker, 2012). There is however limited evidence of the impact of climate change on the growing number of urban migrants in islands.

29.6.3. Barriers and Limits to Adaptation in Small Island Settings

Since publication of the IPCC SAR in 1996, significant barriers to climate change adaptation strategies in island settings have been discussed in considerable detail. Barriers include inadequate access to financial, technological and human resources, issues related to cultural and social acceptability of measures, constraints imposed by the existing political and legal framework, the emphasis on island development as opposed to sustainability, and a tendency to focus on addressing short term climate variability rather than long term climate change, and community preferences for “hard” adaptation measures (seawalls i.e.) instead of “soft” devices (Sovacool 2012). Heger et al.

(2008) recognise that more diversified economies have more robust responses to climate stress, yet most small islands lack economies of scale in production, thus specialising in niche markets and developing monocultures (e.g. sugar or bananas). Non-sovereign island states face additional exogenous barriers to adaptation. For example, islands like Réunion and Mayotte experience French provision of social services, but not the French level of building codes and land use planning (Le Masson and Kelman, 2011). 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. Exogenous factors, such as the comparatively few assessments of social vulnerability to climate change, adaptation potential or resilience for island communities (Barnett, 2010) limit current understanding and action. In part this is due to the particularities of islands – both their heterogeneity and their difference from mainland locations – as well as the limitations of climate models in delivering robust science for small islands. It remains the case that thirteen years after Nurse et al. (2001) noted that downscaled global climate models do not provide a complete or necessarily accurate picture of climate vulnerabilities on islands, there is still little climate impacts research that reflects local concerns and contexts (Barnett *et al.,* 2008).

While lack of access to adequate financial, technological 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 important in constraining adaptation. Translating the word 'climate' into Marshallese implies cosmos, nature and culture as well as weather and climate (Rudiak-Gould, 2012), such cultural misunderstandings can create both barriers to action and novel ways of engaging with climate change. The lack of local support (due to encroachment on traditional lands) for the development of new infiltration galleries to augment freshwater supply on Tarawa atoll, Kiribati, highlights the importance of social acceptability (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 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). Even where the threat has been identified, it is often not considered an urgent issue, or a local priority, as exemplified in Malta (Akerlof *et al.,* 2010), and Funafuti, Tuvalu (Mortreux and Barnett, 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 in both Fiji and Kiribati 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 (Kuruppu, 2009, 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. Various mechanisms through which development agencies as well as donor and recipient countries can seek to capitalize on the opportunities to mainstream are beginning to emerge (see for example Klein *et al.,* 2007; Mertz *et al.,* 2009). Agarwala and van Aalst (2008) provide examples from Fiji and elsewhere, of where synergies (and trade-offs) can be found in integrating adaptation to climate change into development cooperation activities, notably: disaster risk reduction, community-based approaches to development, and building adaptive capacity. Boyd et al. (2009) urge for more rapid integration of adaptation into development planning, to ensure that adaptation is not side-lined, or treated separately from sectoral policies. Although there are synergies and benefits to be derived from the integration of climate change and development policies, care is needed to avoid institutional overlaps, and differences in language and approach – which can give rise to conflict (Schipper and Pelling, 2006). 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 be highly impacted by climate change (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 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 and economic structures (see Table 29-3, Figure 29-1). 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. The geography and location of islands affect their 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, resources endowment, technology and knowledge (see 29.6.2).

The costs of adaptation in small islands are likely to be relatively large, mostly due to the problem of overhead cost indivisibilities (see 29.3.3) and also because of the potentially high climate change impacts. 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.

The potential for mitigation and emissions reductions in islands depends to a large extent on their size and stage of economic development. In the small and less developed islands key 'mitigation' sectors: including energy, transport, industry, built environment, agriculture, forestry, or waste management sectors are likely to be relatively small (Metz *et al.,* 2007, Swart and Raes, 2007). Hence opportunities for emissions reductions are usually quite limited and are mostly associated with electricity generation and utilization of vehicles. More mitigation opportunities should exist in more economically advanced and larger islands that rely on forms of production that utilize fossil fuels, including manufacturing, and where vehicle usage is extensive and electricity driven home appliances, such as air conditioners and water heaters, are extensively used. Table 29-6 presents an indicative assessment of potential areas for mitigation activity on small islands by island 'economy type'.

[INSERT TABLE 29-6 HERE
Table 29-6. Economic structure of small islands and areas of potential emissions reduction.]

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, 2011; Rosenzweig and Wilbanks, 2010, Thornton *et al.,* 2011, Birkmann, 2011). Nicholls et al. (2011) make a similar observation with respect to coastal protection as a response 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. Potential Synergies and Conflicts

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

Small islands have relatively large coastal zones (in comparison to land area) and most development (as well as potential mitigation and adaptation activities) are located in the coastal zone. Coastal ecosystems (coral reefs, sea grasses and mangroves) play an important role in protecting coastal communities from wave erosion, tropical cyclones, storm surges, and even moderate tsunami waves (Cochard *et al*., 2008). Whilst coastal forests including both endemic and exotic species especially mangroves are seen as effective adaptation options ('bioshields' Feagin *et al*..2010) in the coastal zones, they also play an important role in mitigation as carbon sinks (van der Werf *et al*., 2009). Thus, the management and conservation of mangrove forests has the potential to generate synergies between climate change adaptation and mitigation. However, despite this knowledge population, development and agricultural pressures have constrained the expansion of island forest carbon stocks (Fox *et al*., 2010) while Gilman et al. (2008) note that such pressures can also reduce the buffering capacity of coastal vegetation systems.

Renewable energy resources on small islands have only recently 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 undertake research and development of alternatives. Those islands that have introduced renewable energy technologies have often done so with support from international development agencies (Dornan, 2011). Despite thisthere 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): 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 away from fossil fuel dependence has been partly driven by economic motives, notably to avoid oil price volatility and its impact. The development of hydro-power (in Fiji for example) necessitates protection and management of the water catchment zones, and thus could lead 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 could enhance project viability (Dornan, 2009). 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).

Energy prices in small islands are among the highest anywhere in the world, mainly due to their dependence on imported fossil fuel, and limited ability to reap the benefits of economies of scale including bulk buying. Recent studies show that the energy sectors in small 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 seeks to decrease energy dependence in SIDS, while generating financial resources to support low carbon growth and adaptation interventions.

Many small islands rely heavily on the foreign exchange from tourism to expand and develop their economies, including the costs of mitigation and adaptation. Tourism, particularly in small islands, often relies on coastal and terrestrial ecosystems o provide visitor attractions and accommodation space. Much has been made of the relationship between ecosystem services and tourism 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. Gossling and Schumacher (2010) and others who have examined the linkages between greenhouse gas emissions and sustainable tourism argue that the tourism sector (operators and tourists) should pay to promote sustainable tourism, especially where they benefit directly from environmental services sustained by these investments.

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).

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 _____

Notwithstanding the observations of Barnett and O'Neill (2012), there is a concern that early foreclosure of this option might well prove maladaptive, if location-specific circumstances show such action to be efficacious in the longer-term. States contemplating this option may wish to consider early proactive planning, as resettlement of entire communities might prove to be socially, culturally and economically disruptive (Campbell, 2010; McMichael *et al.,* 2012; refer also to 29.3.3.4). The case study of the residents of Nauru who contemplated resettlement in Australia after the collapse of phosphate mining (their only revenue source) in the1950s, provides helpful insight about the complex social, economic and cultural challenges associated with environmentally triggered migration (Tabucanon and Opeskin, 2011). The challenge therefore is to find the middle ground between premature resettlement and objective assessment of other appropriate adaptation choices.

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 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 governments 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. Studies have 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 and trust (Fazey *et al.,* 2008; Lopez Marrero, 2010; van Aalst et al., 2008). 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 Mamanuca 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 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, may prove 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 offer collateral benefits 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 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).

29.9. Research and Data Gaps

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 small islands**. For example, projected changes in climate for the Caribbean, Pacific, Indian Ocean and Mediterranean islands, generally apply to the region as a whole and not to specific countries. However, most socio-economic decisions are taken at smaller scales. There is need for credible simulations of future small island climates and socio-economic conditions at comparable scales
- **Difficulties in detecting and attributing past impacts on small islands to climate change processes.** Further investigation of the observed impacts of weather, climate and ocean events that may be related to climate change is required to clarify the relative role of climate change and non-climate change drivers.
- **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. 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 is 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 in a small island context.

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, there are few studies that have been able to isolate anthropogenically-induced climate change impacts from those associated with natural climate variability and/or human activities. Even in the case of atolls where inundation from sea-flooding, storm surges and shoreline erosion has occurred, sea-level rise specifically linked to climate change has not been definitively identified as a primary cause of these hazards, or of outmigration and resettlement of populations from such areas. This does not mean that small islands are not experiencing the physical and socio-economic impacts of climate change, but rather that the manifestation of any climate change impact is not easily distinguishable from impacts attributable to other possible causes. It also reflects the poor level of empirical monitoring which occurs in small island environments and represents a research gap that needs to be urgently filled if greater confidence in the attribution of climate change stress in both human and physical systems is to be achieved.

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.

FAQ 29.3: Why is the cost of adaptation to climate change so high in small islands?

Adaptation to climate change often involves overhead costs, such as infrastructural changes and upgrades. These generally include ‘lumpy‘ costs and costs that cannot be downscaled in proportion to the size of the population or territory. This disadvantage, termed the ‘indivisibility’ problem, is a major socio-economic issue for many small islands. It can be illustrated by way of example. A seawall, intended as a shore protection measure, 100 m long, suitable for a small island, will cost much more than one-tenth of a seawall 1 km long (that is ten times as much), suitable for a larger territory. This means that the cost of the seawall to the small island will be higher per m than for the larger territory. This reality applies throughout much of a small island economy including the indivisibility of public utilities and services. It also applies to all forms of development and redesign of the infrastructure, aimed at ensuring that it is more resilient to climate change and extreme weather events. The result is a relatively higher adaptation cost per capita in countries with small populations, such as small islands and especially those islands that are geographically isolated, have a poor resource base and high import and transport costs.

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Table 29-1: Small islands regions temperature and precipitation change projections for the SRES A1B scenario over the period 2080-2099 compared to 1980-1999. 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 WGI AR4 Table 11.1).

Small Island Region	**Season (by month)**	**Temperature Change (ºC)** min	median	max	**Precipitation Change (%)** 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: Preliminary projected percentage changes in tuna catches relative to the 20 year average (1980-2000) and estimated percentage change to government revenue resulting from projected changes in the catch of skipjack tuna in 2030 and 2100 (Bell et al., 2011).

SRES Scenario		2035	2100	
		B1/A2	B1	A2
Skipjack tuna	Western fishery	+ 11%	-0.2%	-21%
	Eastern fishery	+37%	+43%	+27%
Bigeye tuna	Western fishery	-2%	-12%	-24%
	Eastern fishery	+3%	-4%	-18%
Skipjack tuna	Total	+19%	+12%	-7%
Bigeye tuna	Total	+0.3%	-9%	-27%
Change to Government Revenue (Percent)	FSM	0.8 to 1.7%	-0.9 to -1.9%	
	Solomon Is	0.01 to 0.16%	-0.03 to0.77%	
	Kiribati	+11 to 18.4%	+7.2 to12.0%	
	Tuvalu	+3.7 to 9.2%	+2.5 to6.2%	

Table 29-3: Type of island in the Pacific region and implications for hydro-meteorological hazards.

Island type and size	**Island elevation, slope, rainfall**	**Implications for hazard**
Continental - Large - High biodiversity - Well developed soils	- High elevations - River flood plains - Orographic rainfall	River flooding more likely to be a problem than in other island types. In PNG high elevations expose areas to frost (extreme during El Nino).
Volcanic High Islands - Relatively small land area - Barrier reefs - Different stages of erosion	- Steep slopes - Less well developed river systems - Orographic rainfall	Because of size few areas are not exposed to tropical cyclones. Streams and rivers subject to flash flooding. Barrier reefs may ameliorate storm surge.
Atolls - Very small land area - Small islets surround a lagoon - Larger islets on windward side - Shore platform on windward side - No or minimal soil	- Very low elevations - Convectional rainfall - No surface (fresh) water - Ghyben Herzberg (freshwater) lens	Exposed to storm surge, 'king' tides and high waves. Narrow resource base. Exposed to fresh water shortages and drought. Water problems may lead to health hazards.
Raised Limestone Islands - Concave inner basin - Narrow coastal plains - No or minimal soil	- Steep outer slopes - Sharp karst topography - No surface water	Depending on height may be exposed to storm surge. Exposed to fresh water shortages and drought. Water problems may lead to health hazards.

Source: Campbell (2009:89)

Table 29-4: Top ten countries in the Asia-Pacific region based on absolute and relative physical exposure to storms and impact on GDP (between 1998 and 2009).

Rank	**Absolute exposure (millions affected)**	**Relative exposure (% of the population)**	**Absolute GDP loss ($billions)**	**Loss (as a % of GDP)**
1	Japan (30.9)	**North Mariana Isls (58.2)**	Japan (1,226.7)	**North Mariana Isl (59.4)**
2	Philippines (12.1)	**Niue (25.4)**	Rep. of Korea (35.6)	**Vanuatu (27.1)**
3	China (11.1)	Japan (24.2)	China (28.5)	**Niue (24.9)**
4	India (10.7)	Philippines (23.6)	Philippines (24.3)	**Fiji (24.1)**
5	Bangladesh (7.5)	**Fiji (23.1)**	Hong Kong (13.3)	**Fiji (16.0)**
6	Rep. of Korea (2.4)	**Samoa (21.4)**	India (8.0)	Japan (23.9)
7	Myanmar (1.2)	**New Caledonia (20.7)**	Bangladesh (3.9)	Philippines (23.9)
8	Viet Nam (0.8)	**Vanuatu (18.3)**	North Mariana Isls (1.5)	**New Caledonia (22.4)**
9	Hong Kong (0.4)	**Tonga (18.1)**	Australia (0.8)	**Samoa (19.2)**
10	Pakistan (0.3)	**Cook Islands (10.5)**	New Caledonia (0.7)	**Tonga (17.4)**

Source: ESCAP and UNISDR (2010) using the EM-DAT database.

Table 29-5: Climate migration options in the Pacific.

	Type of mobility	
	Induced	**Forced**
Migration	**Individuals and families migrate**	**Communities relocate**
Internal		
- Proximate (own lands)	Not likely	Least disruptive
- Proximate (others lands)	Not likely	Land can be problematic
- Distant (mostly urban-rural)	Most likely	Difficult to sustain community
External		
- Regional (other Pacific Island countries)	Possible	Possible to sustain community and lifestyle but land problematic
- International	Most likely	Very unlikely to sustain community and lifestyle

Source: Campbell (2010: 34).

Table 29-6: 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

Island Typology

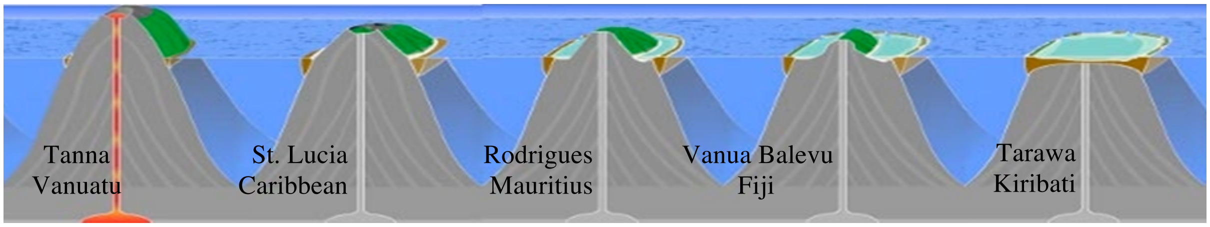


Figure 29-1: This schematic describes common tropical island typology from young high volcanic islands (left) through to atolls (submerged volcanics) on the far right. This simple overview highlights important components such as elevation and differing land and marine resources as well as the presence of coral reefs. On both high and low islands coastal settlement patterns predominate. Elevated limestone islands and islands comprised of 'continental' rocks are not included in this figure, but see Table 29-3.

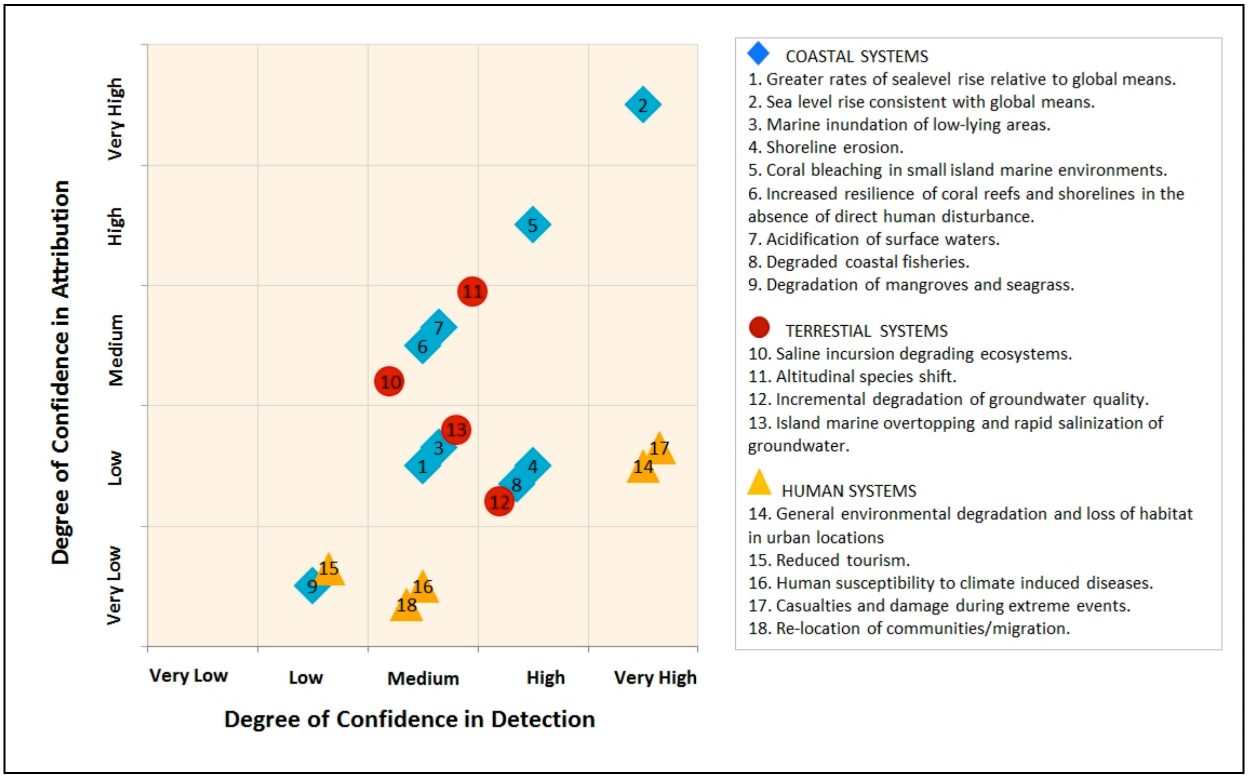


Figure 29-2: Based on available literature discussed in this chapter, the diagram shows a comparison of the degree of confidence in the detection of tropical small island impacts (horizontal axis) with the degree of confidence in attribution to climate change drivers (vertical axis). For example; the blue symbol No. 2 (Coastal Systems), indicates there is very high confidence in both the detection of "sea-level rise consistent with global means" and its attribution to climate change drivers; whereas the yellow symbol No. 17 (Human Systems) indicates whilst detection of "casualties and damage during extreme events" is very high, at this time there is low confidence in the attribution to climate change drivers. It is important to note that low confidence in attribution frequently arises due to the very limited research available for small island environments.

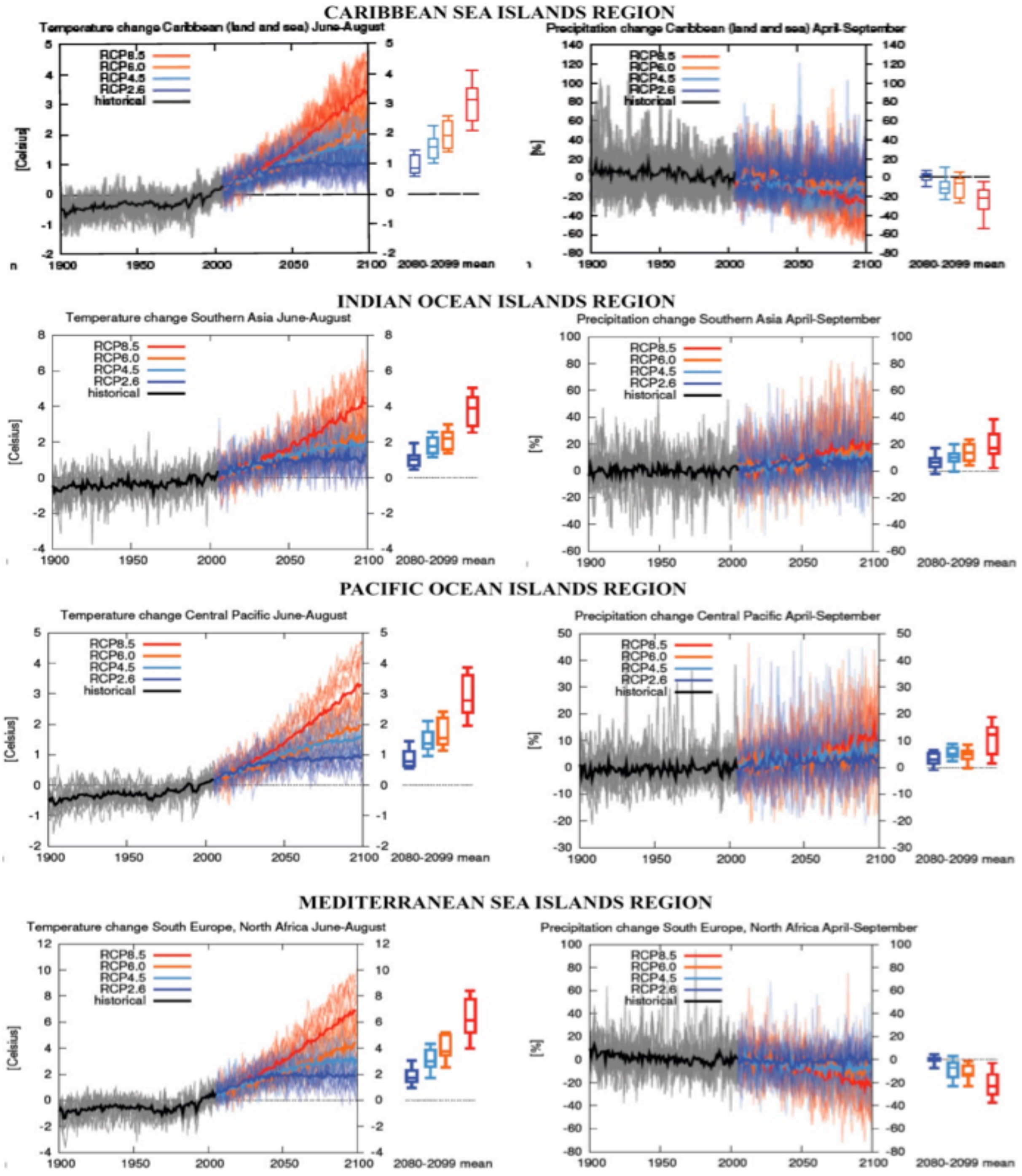


Figure 29-3: RCP Scenario projections to the year 2100 for the four main small island regions (adapted from AR5 WG1, Annex 1).

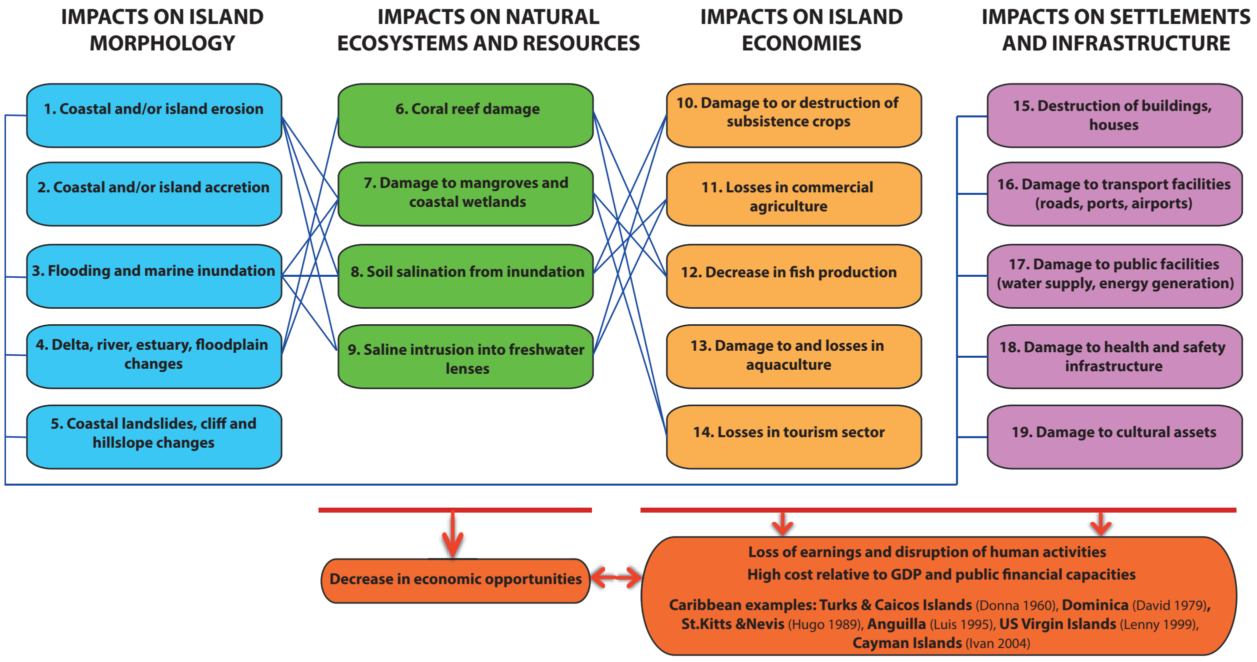
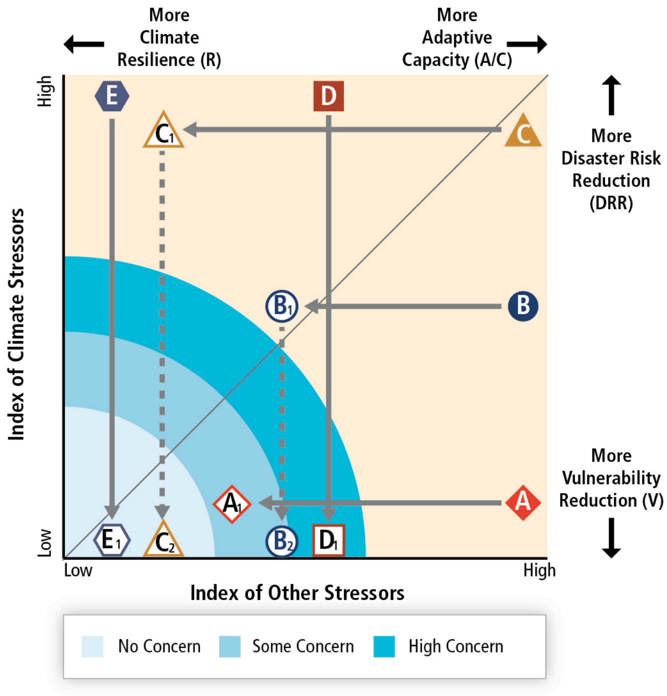


Figure 29-4: Tropical and extra-tropical cyclone impacts on the coasts of small islands: a. Example of tropical cyclone impacts on small island coasts with reference; b. Example of extra-tropical cyclone (mid-high-latitude lows) impacts on small island coasts with reference.

1a. Society Islands, French Polynesia, February 2010 (Etienne, 2012); 1b. Maldives, April 1987 (Harangozo, 1992); 2a.Taveuni (Fiji) March 2010 (Etienne and Terry, 2012); 2b. Funafuti atoll, Tuvalu, October 1972 (Baines *et al.*,1974); 3a. Society and Autrales Islands, French Polynesia, February 2010 (Etienne, 2012); 3b.Maldives, April 1987 (Harangozo, 1992); 4a. Viti Levu, Fiji, March 1997 (Terry, *et al.,* 2002); 5a.Society Islands, French Polynesia, February 2010 (Etienne, 2012); 6a. Curacao, Bonaire, Netherlands Antilles, November 1999 (Scheffers and Scheffers, 2006); Hawaiian Islands (Fletcher *et al.,*, 2008); 8a. Marshall Islands, June 1905 (Spennemann, 1996); 9a. Pukapuka atoll, Cook Islands 2005 (Terry and Falkland, 2010); 9b. Solomon Islands, December 2008 (Hoeke, submitted); 10a. Vanuatu 2004 (Richmond and Savacool, 2012); 10b. Chuck, Pohnpei, Kosrae, Federated States of Micronesia, December 2008 (Hoeke, submitted); 11a. 12a. 13a. Tuamotu Islands, French Polynesia, 1982-83 (Dupon, 1987); 15a. Tubuai (Australes Islands) February 2010 (Etienne, 2012); 15b. Majuro, Marshall Islands, November 1979 (Hoeke, submitted); 16a. Vanuata February 2004 (Richmond and Savacool, 2012);16b. Coral Coast, Viti Levu, Fiji, May 2011 (Hoeke, submitted); 17a. Bora Bora,Raiatea, Maupiti, Tahaa, Hahine (Society Islands) February 2010 (Etienne, 2012);17b. Majuro, Kwajalein, Arno Marshall Islands,December 2008 (Hoeke, submitted); 18a. Vanuatu, February 2004 (Richmond and Savacool, 2012); 18b. Bismark Archiplago, Papua New Guinea, December 2008 (Hoeke, submitted); 19a. Tuamotu (French Polynesia) 1982-83 (Dupon, 1987).



	Policy Focus		Additional Policy Objective	
A	Reducing vulnerability to non-climate stressors	A_1		
B	Reducing vulnerability to non-climate stressors AND disaster risk reduction	B_1	Creating climate resilience	B_2
C	Reducing vulnerability to non-climate stressors AND disaster risk reduction	C_1	Climate resilience	C_2
D	Disaster risk reduction AND climate resilience	D_1		
E	Climate resilience	E_1		

Figure 29-5. Potential benefits and risks associated with alternative climate change adaptation actions or policies.