Chapter 29. Small Islands

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Executive Summary

Current and future climate-related drivers of risk for small islands during the 21st century include sea-level rise, tropical and extra-tropical cyclones, increasing air and sea surface temperatures, and changing rainfall patterns (*high confidence, robust evidence, high agreement*) [WGI 14, Table 29-1]. Current impacts associated with these changes confirm findings reported on small islands from the AR4 and previous IPCC assessments. The future risks associated with these drivers include loss of adaptive capacity [29.6.2.1, 29.6.2.3] and ecosystem services critical to lives and livelihoods in small islands [29.3.1, 29.3.2, 29.3.3].

Sea-level rise poses one of the most widely recognized climate change threats to low-lying coastal areas on islands and atolls (*high confidence, robust evidence and high agreement*) [29.3.1]. It is *virtually certain* that global mean sea-level rise rates are accelerating [WGI 13.2.2.1]. Projected increases to the year 2100 (RCP 4.5: 0.35m to 0.70m, WGI 13.5.1, Table 29-1) superimposed on extreme sea-level events (e.g. swell waves, storm surges, ENSO) present severe sea-flood and erosion risks for low-lying coastal areas and atoll islands (*high confidence*). Likewise, there is *high confidence* that wave over-wash of sea water will degrade fresh ground water resources [29.3.2] and that sea surface temperature rise will result in increased coral bleaching and reef degradation [29.3.1.2]. Given the dependence of island communities on coral reef ecosystems for a range of services including coastal protection, subsistence fisheries and tourism, there is *high confidence* that coral reef ecosystem degradation will negatively impact island communities and livelihoods.

Given the inherent physical characteristics of small islands, the AR5 reconfirms the high level of vulnerability of small islands to multiple stressors, both climate and non-climate (*high confidence, robust evidence, high agreement*). However, the distinction between *observed* and *projected* impacts of climate change is often not clear in the literature on small islands (*high agreement)* [29.3]. There is evidence that this challenge can be partly overcome through improvements in baseline monitoring of island systems and downscaling of climate-model projections, which would heighten confidence in assessing recent and projected impacts [WGI 9.6, 29.3, 29.4, 29.9].

Small islands do not have uniform climate change risk profiles (*high confidence*). Rather their high diversity in both physical and human attributes and their response to climate-related drivers means that climate change impacts, vulnerability and adaptation will be variable from one island region to another and between countries in the same region [Fig 29.1; Table 29.3]. In the past, this diversity in potential response has not always been adequately integrated in adaptation planning.

There is increasing recognition of the risks to small islands from climate-related processes originating well beyond the borders of an individual nation or island. Such trans-boundary processes already have a negative impact on small islands (*high confidence, robust evidence, medium agreement)*. These include: airborne dust from the Sahara and Asia, distant-source ocean swells from mid- high latitudes, invasive plant and animal species and the spread of aquatic pathogens. For island communities the risks associated with existing and future invasive species and human health challenges are projected to increase in a changing climate [29.5.4].

Adaptation to climate change generates larger benefit to small islands when delivered in conjunction with other development activities, such as disaster risk reduction and community based approaches to development *(medium confidence*) [29.6.4]. Addressing the critical social, economic and environmental issues of the day, raising awareness and communicating future risks to local communities [29.6.3] 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 always trade-offs, but can be regarded as complementary components in the response to climate change (*medium confidence).* Examples of adaptation-mitigation inter-linkages in small islands include energy supply and use, tourism infrastructure and activities, and functions and services associated with coastal wetlands. The alignment of these sectors for potential emission reductions together with adaptation, offer co-benefits and opportunities in some 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 there is *low confidence* in the success of wholesale transfer of adaptation and mitigation options when the local lenses through which they are viewed differ from one island state to the next, given the diverse cultural, socio-economic, ecological and political values [29.6.2, 29.8].

The ability of small islands to undertake adaptation and mitigation programs, and their effectiveness, can be substantially strengthened through appropriate assistance from the international community (*medium confidence*). However, caution is needed to ensure such assistance is not driving the climate change agenda in small islands, as there is a risk that critical challenges confronting island governments and communities may not be addressed . Opportunities for effective adaptation can be found by, for example, empowering communities and optimizing the benefits of local practices that have proven to be efficacious through time, and working synergistically to progress development agendas [29.8, 29.6.2.3, 29.6.3].

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 is threatened by rising sea levels associated with global warming. Whilst such 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 may be reduced through effective adaptation measures.

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). 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). 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 with several small island nations being included in the group of ten countries with the highest relative impact projected for 2100 (Anthoff *et al*., 2010).

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). 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). 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). 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).

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 islands and 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 critical present-day development and security needs of small islands [29.3.3.1] as well as the possibility that some proposed adaptation measures may prove to be maladaptive [29.8]. Fourth, many initiatives have been identified in recent times that will reduce vulnerability and enhance resilience of small islands to on-going global change including improving risk knowledge and island resource management while also strengthening socio-economic systems and livelihoods (Hay, 2013).

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 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, frequency, temporal and spatial extent of the event, as well as on the bio-physical nature of the island (Figure 29.1) and its social, economic and political setting.

[INSERT FIGURE 29-1 HERE
Figure 29-1: Representative tropical island typologies. From top-left: a young, active volcanic island (with altitudinal zonation) and limited living perimeter reefs (purple zone at outer reef edge), through to an atoll (centre bottom) and raised limestone island (bottom right) dominated by ancient reef deposits (brown + white fleck). Atolls have limited, low-lying land areas but well developed reef/lagoon systems. Islands composed 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 is located in coastal zones with limited on-island relocation opportunities especially on atoll islands (Woodroffe, 2008) (Figure 29-1). Over much of the 20th Century, global mean sea level rose at a rate between 1.3 to 1.7 mm yr^{-1} and since 1993, at a rate between 2.8 to 3.6 mm yr^{-1} (WGI, Table 13.1) and acceleration is detected in longer records since 1870 (Merrifield *et al.*, 2009; Church and White, 2011; WGI, 13.2.2.1). Rates of sea-level rise are however not uniform across the globe and large regional differences have been detected including in the Indian Ocean and tropical Pacific, where in some parts rates have been significantly higher than the global average (Meyssignac *et al.*, 2012) (refer also to 5.3.2.2). 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. These are generally thought to describe short-term variations associated with natural cyclic climate phenomena such as ENSO (El Niño-Southern Oscillation) which has a strong modulating effect on sea level variability with lower/higher-than-average sea level during El Nino/La Nina events of the order of ±20-30 cm (Becker *et al.*, 2012; Cazenave and Remy, 2011). Large interannual variability in sea level has also been demonstrated from the Indian Ocean (e.g. Chagos Archipelago, Dunne *et al.*, 2012) whilst Palanisamy *et al*. (2012) found that over the last 60 years the mean rate of sea-level rise in the Caribbean region was similar to the global average ~ 1.8mm yr^{-1}.

There are few long-term sea-level records available for individual small island locations. Reported sea flooding and inundation is often associated with transient phenomena, such as storm waves and surges, deep ocean swell and predicted astronomical 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 areas of the central portion of Fongafale are already below high spring tide level. However, rates of relative sea-level rise at Funafuti between 1950 – 2009 have 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 additional circumstances such as vertical subsidence, engineering works, development activities or beach mining as the causal process. Four 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. Fourth, Hoeke *et al*. (2013) describe a 2008 widespread inundation event that displaced some 63,000 people in Papua New Guinea and Solomon Islands alone. That event was primarily caused by remotely generated swell waves, and the severity of flooding was greatly increased by anomalously high regional sea levels linked with ENSO and on-going sea-level rise. Such examples serve to highlight that extreme events superimposed on a rising sea-level baseline are the main drivers that threaten the habitability of low-lying islands as sea levels continue to rise.

Since the AR4 a number of empirical studies have documented historical changes in island shorelines. 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 Rankey (2011) who concluded that sea-level rise was not likely to be the main influencing factor in these shoreline changes. Similarly in French Polynesia Yates *et al*. (2013) showed mixed shoreline change patterns over the last 40 – 50 years with examples of both erosion and accretion in the 47 atoll islands assessed. Sea-level rise did not appear to be the primary control on shoreline processes on these islands. 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 studies of observed shoreline change on reef islands conclude that for rates of change experienced over recent decades normal seasonal erosion and accretion processes appear to predominate over any long-term morphological trend or signal at this time. Ford's (2013) investigation of Wotje Atoll, Marshall Islands also found shoreline variability between 1945 and 2010 but that overall accretion had been more prevalent than erosion up until 2004. From 2004 to the present 17 out of 18 islands became net erosive, potentially corresponding to the high sea levels in the region over the last 10 years. On the high tropical islands of Kauai and Maui, Hawaii, Romine and Fletcher (2013) found shoreline change was highly variable over the last century but that recently chronic erosion predominated with over 70% of beaches now being erosive. Finally, it is important to note the majority of these studies warn that: (1) past changes cannot be simply extrapolated to determine future shoreline responses; and (2) rising sea level will incrementally increase the rate and extent of erosion in the future.

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 to sea-level rise. A study of Majuro atoll (Marshall Islands) found that erosion was widespread but attribution to sea-level rise was obscured by pervasive anthropogenic impacts to the coastal system (Ford, 2012) (see also 5.4.4). Similarly a study of three islands in the Rosario Archipelago (Colombia) reported shoreline retreat over a 50-55 year period 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 poor management on densely settled Grande Island, whilst sea-level rise 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. Whilst the study could not quantify the extent of attribution it noted that greater erosion rates were positively correlated with the number of hurricane events. Alternately, Etienne and Terry (2012) found a Category 4 tropical cyclone that passed within 30 km of Taveuni Island (Fiji) nourished shorelines with fresh coralline sediments despite localized storm damage. Whilst these studies contribute to improved understanding of island shoreline processes and change since AR4, the warning of increased vulnerability of small island shores and low-lying areas to inundation and erosion in response to sea-level rise and other potential climate change stressors is not diminished.

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 wellbeing of many island communities is linked to their on-going function and productivity. Reefs play a significant role in supplying sediment to island shores and in dissipating wave energy thus reducing the potential foreshore erosion. They also provide habitat for a host of marine species upon which many island communities are dependent for subsistence foods as well as underpinning beach and reef-based tourism and economic activity (Bell *et al.*, 2011; Perch-Nielsen, 2010). The documented sensitivity of coral reef ecosystems to climate change is summarised elsewhere (see Chap 5, Box CC-CR).

Increased coral bleaching and reduced reef calcification rates due to thermal stress and increasing CO_2 concentration are expected to affect the functioning and viability of living reef systems (Hoegh-Guldberg *et al.*, 2007; Eakin *et al.*, 2009). Some studies already implicate thermal stress in reduced coral calcification rates (Tanzil *et al*., 2009) and regional declines in calcification of corals that form reef framework (De'ath *et al*., 2009; Cantin *et al*., 2010). Unprecedented bleaching events have been recorded in the remote Phoenix Islands (Kiribati) with nearly 100 per cent coral mortality in the lagoon 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 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 per cent 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 per cent of corals impacted (Oxenford *et al.*, 2008). Globally, the incidence and implications of temperature-related coral bleaching in small islands is well documented and combined with the effects of increasing ocean acidification these stressors could threaten the function and persistence of island coral reef ecosystems (see Chap 5, Box CC-OA).

Island coral 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 than others. There is also some evidence to show 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 suggest that the bleaching event in 1998 was unprecedented and its severity appeared to stem from reduced thermal tolerance related to human coastal development (Carilli *et al*., 2010). Likewise a study over a 40 year period (1960s – 2008) in the Grand Recif of Tulear, Madagascar concluded that severe degradation of the reef was mostly ascribed to direct anthropogenic disturbance, despite an average 1 ^{0}C increase in temperature over this period (Harris *et al*., 2010). Coral recovery following the 2004 bleaching event in the central Pacific atolls of Tarawa and Abaiang (Kiribati) was also noted to be improved in the absence of direct human impacts (Donner *et al.*, 2010) and isolation of bleached reefs was shown by Gilmour *et al*. (2013) to be less inhibiting to reef recovery than direct human disturbance.

The loss of coral reef habitat has detrimental implications for 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 per cent of coastal fish are dependent on living reefs at some stage in their life cycle and that following degradation of the reef fish abundance declined (Jones *et al.*, 2004). Even where coral reef recovery has followed bleaching, reef associated species composition may not recover to its original state (Pratchett *et al.*, 2009; Donner *et al.*, 2010). Sea Surface Temperature (SST) anomaly events can be associated with a lag in the larval supply of coral reef fishes, as reported by Lo-Yat *et al.* (2011) between 1996 and 2000 at Rangiroa Atoll, French Polynesia. Higher temperatures have also been implicated in negatively affecting the 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; Waycott *et al*., 2009) and both habitats play a significant role in the wellbeing of small island communities. Mangroves in particular serve 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 (Waycott *et al.*, 2011). Loss of the seaward edge of mangroves at Hungry Bay, Bermuda has been reported by Ellison (1993) who attributes this process to sea-level rise and the inability of mangroves to tolerate increased water depth 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 an accretion deficit of 4.95 mm y^{-1} to an accretion surplus of 3.28 mm y^{-1} relative to the estimated rate of sea-level rise. Such surpluses are generally reported from high islands where additional sediments can be delivered from terrestrial runoff. However, Rankey (2011) described natural seaward migration (up to 40m) of some mangrove areas between 1969 and 2009 in atolls in Kiribati suggesting sediment accretion can also occur in sediment rich reefal areas and in the absence of terrigenous inputs.

The response of seagrass to climate change is also 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 water depth and sedimentation (Ralph *et al.*, 2007). Ogston and Field (2010) observed that a 20 cm rise in sea-level may double suspended sediment loads and turbidity in shallow waters on fringing reefs of Molokai, Hawaiian Islands, with negative implications to photosynthetic species such as seagrass. Otherwise, temperature stress is most commonly reported as the main expected climate change impact on seagrass (e.g. 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, seagrass shoot mortality and recruitment rates were negatively influenced by higher temperature (Marbá and Duarte, 2010). (See also Chapter 5.4.2.3 for further discussion of impacts on mangrove and sea grass communities).

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 with high numbers of endemic species. For example, in two low-lying islands in the Bahamas, 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 negatively impacting on coastal strand vegetation. Sea-level rise has also been observed to threaten the long-term persistence of freshwater-dependent ecosystems within low-lying islands in the Florida Keys (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 salinisation 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. A recent study of the tropical Mauritius kestrel indicate changing rainfall conditions in Mauritius over the last 50 years have resulted in this species having reduced reproductive success due to a mismatch between the timing of breeding and peak food abundance (Senapathi *et al*., 2011).

Increasing global temperatures may also lead to altitudinal species range shifts and contractions within high islands with an upward creep of the tree line and associated fauna (Benning *et al*., 2002; Krushelnycky *et al*., 2013). A study in the Hawaiian Islands which assessed data from 21 stations over 85 years showed a rapid rise in surface temperatures over the last 30 years with stronger warming in mountain areas (CCSP, 2008). Comparative vegetation distribution and composition studies in sub-Antarctic Marion Island, found an altitudinal shift of 3.4 m yr $^{-1}$ for plant species (Parolo and Rossi, 2008). Comparable effects also occur in the tropics such as in Hawaii Volcano National Park where comparison of sample plots over a 40 year period from 1966-67 to 2008 show fire-adapted grasses expanded upward along a warming tropical elevation gradient (Angelo and Daehler, 2013). 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 the demise and possibly extinction of endemic species (Chen *et al*., 2009; Pauli *et al*., 2007; Sekercioglu *et al.*, 2008; Krushelnycky *et al.*, 2013). 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; Atkinson and LaPointe, 2009).

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 groundwater lens. Rainwater harvesting is also an important contribution to freshwater access and alternatives like desalination have had 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 yr $^{-1}$ reduction in rainfall, a trend that is projected to continue (Jury and Winter, 2010). In contrast, analysis of rainfall data over the past 100 years from the Seychelles has shown substantial variability related to ENSO. Nevertheless an increase in average rainfall from 1959 to 1997 and an increase in temperature of ~ 0.25 °C per decade have occurred (Payet and Agricole, 2006). Long-term reduction in streamflow (median reduction of 22 – 23%) has been detected in the Hawaiian Islands over the period 1913 – 2008, resulting in reduced freshwater availability for both human use and ecological processes (Bassiouni and Oki 2013). Detection of long-term statistical change in precipitation is an important prerequisite towards a better understanding the impacts of climate change in small island hydrology and water resources.

There is a paucity of empirical evidence linking saline (sea-water) intrusion into fresh groundwater reserves due simply to incremental sea-level rise at this time (e.g. Rozell and Wong, 2010). However this dynamic must be the subject of improved research given the importance of groundwater aquifers in small island environments. 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 washover 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. This caused the freshwater lenses to become immediately brackish and took 11 months to recover to conductivity levels appropriate for human use (Terry and Falkland, 2010). The ability of the freshwater lens to float upwards within the substrate of an island in step with incremental sea-level rise also means that in low-lying and central areas of many atoll islands the lens may pond at the surface. This phenomenon already occurs in 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 in Small Islands

29.3.3.1. Observed Impacts on Island Settlements and Tourism

Whilst traditional settlements on high islands in the Pacific were often located inland, the move to coastal locations was encouraged by colonial and religious authorities and more recently through the development of tourism (Barnett and Campbell, 2010). Now the majority of settlement, infrastructure and development are located on lowlands 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 centres and lack of accommodation space drives growing populations into ever more vulnerable locations (Connell, 2012). Additionally, without adequate resources and planning, engineering solutions such as shoreline reclamation also place communities and infrastructure in positions of increased risk (Duvat, 2013; Yamano *et al*., 2007).

Many of the environmental issues raised by the media relating to Tuvalu, the Marshall Islands and Maldives are primarily relevant to the major population centre and its surrounds, which are 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 pre-existing 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 studies of Fongafale Island, the capital of Tuvalu, show that engineering works during World War II, and rapid development and population growth since independence, has led 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. Increased risk can also result from lack of awareness, particularly in communities in rural areas and outer islands ('periphery') of archipelagic countries such as Cook Islands, Fiji, Kiribati and Vanuatu, whose climate change knowledge often contrasts sharply with that of communities in the major centres ('core'). In the core, communities tend to be better informed and have higher levels of awareness about the complex issues associated with climate change than in the periphery (Nunn *et. al.*, 2013).

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; 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 has placed great stress on the coast of some islands and has resulted in dense aggregations of infrastructure and people in potentially vulnerable locations.

Tourism is an important weather and climate-sensitive sector on many small islands and has been assessed on several occasions, including in previous IPCC assessments. There is currently no evidence that observed climatic changes in small island destinations or source markets have permanently altered patterns of demand for tourism to small islands, and the complex mix of factors that actually determines destination choices under a changing climate still need to be fully evaluated (Scott *et al.*, 2012a). However, there are cases reported that clearly show severe weather-related events in a destination country (e.g. heavy, persistent rainfall in Martinique: Hubner and Gössling, 2012; Hurricanes in Anguilla: Forster *et al*., 2012) can significantly influence visitors' perception of the desirability of the location as a vacation choice.

Climate can also impact directly on environmental resources that are major tourism attractions in small islands. Widespread resource degradation challenges such as beach erosion and coral bleaching have been found to negatively impact the perception of destination attractiveness in various locations, for example in Martinique (Schleupner, 2008), Barbados and Bonaire (Uyarra *et al*., 2005). Similarly dive tourists are well aware of coral bleaching, particularly the experienced diver segment (Gössling *et al*., 2012a; Klint *et al.*, 2012). Therefore more acute impacts are felt by tourism operators and resorts that cater to these markets. Houston (2002) and Buzinde *et al.* (2010) also indicate that beach erosion may similarly affect accommodation prices in some destinations. Consequently, some countries have begun to invest in a variety of resource restoration initiatives including artificial beach nourishment, coral and mangrove restoration and the establishment of marine parks and protected areas (McClanahan *et al*., 2008; Mycoo and Chadwick, 2012). There is no analysis of how widespread such 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) including those associated with the availability of freshwater. Freshwater is limited on many small islands, and changes in its availability or quality during drought events linked to climate change have adverse impacts on tourism operations (UNWTO 2012). 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 (Gössling *et al.*, 2012b). The increasing use of desalination plants is one adaptation to reduce the risk of water scarcity in tourism operations.

29.3.3.2. Observed Impacts on Human Health

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 problems, including morbidity and mortality from extreme weather events, certain vector- and food- and water-borne diseases (Lozano, 2006; 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 Trinidad and Tobago, Barbados and Jamaica representing the highest annual incidence (12, 10 and 7.8 cases 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 100,000 population in El Nino years as opposed to 4.5 cases per 100,000 inhabitants in La Niña and neutral years (Herrmann-Storck *et al.*, 2008). In addition, epidemiological studies conducted in Trinidad reviewed the incidence of leptospirosis during the period 1996-2007 and showed seasonal patterns in the occurrence of confirmed leptospirosis cases, with significantly ($P<0.001$) more cases 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 ones (Pappas *et al*., 2008). These factors may 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 2009; Koh *et al.*, 2008; Van Kleef *et al.*, 2010; Teles, 2011). In the specific cases of Trinidad and Tobago and Singapore the outbreaks have been significantly correlated with rainfall and temperature, respectively (Chadee *et al.*, 2007; 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, freshwater 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 and Pacific and Indian oceans, 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 (transmissible) 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 (Rongo and van Woesik, 2011; Chan *et al.*, 2011), the Mediterranean *(*Aligizaki and Nikolaidis, 2008; refer also to section 29.5.5), and the Canary Islands in the Atlantic (Pérez-Arellano *et al*., 2005). A recent Caribbean study sought to characterise the relationship between sea surface temperatures (SSTs) and CFP incidence and to determine the effects of temperature on the growth rate of organisms responsible for CFP. Results from this work show that in the Lesser Antilles high rates occur in areas that experience the warmest water temperatures and which show the least temperature variability (Tester *et al*., 2010). There are also high rates in the Pacific in Tokelau, Tuvalu, Kiribati, Cook Islands and Vanuatu (Chan *et al*., 2011).

The influence of climatic factors on malaria vector density and parasite development is well established (Béguin *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. Rawlins *et al*. (2008) call for enhanced surveillance, recognizing the possible impact of climate change on the spread of the anopheles mosquito vector and malaria transmission.

29.3.3.3. Observed Impacts of Climate Change on Relocation and Migration

Evidence of human migration as a response to climate change is scarce for small islands. While there is general agreement that migration is usually driven by multiple factors (Black et al., 2011), several authors highlight the lack of empirical studies of the effect of climate-related factors, such as sea-level rise, on island migration (Lilleør and Van den Broeck, 2011; Mortreux and Barnett, 2009). Furthermore, 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 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).

Studies of island migration commonly reveal the complexity of a decision to migrate and rarely identify a single cause. 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 (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). To date there is no unequivocal evidence that reveals migration from islands is being driven by anthropogenic climate change.

There is however some evidence that environmental change has played a role in Pacific Island migration in the past (Nunn, 2007). In the Pacific environmental change has been shown to affect land use and land rights, which in turn have become 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 all 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 vulnerable states, and are not usually governance induced. However, governance does remain one of the challenges for island countries in the Pacific in the pursuit of sustainable development through economic growth (Prasad, 2008). Economic vulnerability is often 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 that 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, and sales of local produced products to distant markets. 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).

High costs are also associated with the small size of island states when impacted by extreme events such as hurricanes and droughts. On small islands such events often disrupt most of the territory, especially on single-island states, and have a very large negative impact on the state’s GDP, in comparison with larger and more populous states where individual events generally only affect a small proportion of the country and have a small impact on its GDP (Anthoff *et al.,* 2010). Moreover, the dependence of many small islands on a limited number of economic sectors such as tourism, fisheries and agricultural crops, all of which are climate-sensitive, means that on the one hand climate change adaptation is integral to social stability and economic vitality but that government adaptation efforts are constrained because of the high cost on the other.

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 the 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 gradual incremental change of climate drivers. Notwithstanding these limitations a summary of the relationship between detection and attribution to climate change of several of the phenomena described in the above sections has been prepared. Figure 29-2 reflects the 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: A comparison of the degree of confidence in the detection of observed impacts of climate change on tropical small islands with the degree of confidence in attribution to climate change drivers at this time. 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 red symbol No. 17 (Human Systems) indicates whilst detection of 'casualties and damage during extreme events' is *very high*, there is presently *low confidence* in the attribution to climate change. It is important to note that *low confidence* in attribution frequently arises due to the limited research available on 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 (Keener *et al*., 2012). Among these is the inaction inherent in the mismatch of the short-term time scale on which government decisions are generally taken compared with the long-term time scale required for decisions related to climate change. This is further magnified by the general absence of credible regional socio-economic scenarios relevant at the spatial 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. There is however a problem in generating formal climate scenarios at the scale of small islands since they are generally much smaller than the resolution of the global climate 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 that provides inadequate resolution over the land areas of most small islands. This has recently improved with the new RCP scenario GCMs with grid boxes generally between 100 and 200 km^2 in size.

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 datapoint. 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 are generally sparse, so that in widely dispersed islands such as in the Pacific, observational records are usually supplemented with satellite observations combined with dynamical downscaling computer models (Australian Bureau of Meteorology [ABoM] and CSIRO, 2011a; Keener *et al*., 2012). However where adequate local data are available for several stations for at least 30 years, downscaling techniques have demonstrated that they can provide projections at fine scales ranging from about 10 – 25 km^2 (e.g. Charlery and Nurse, 2010; ABoM and CSIRO, 2011a). 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 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 or broad order of magnitude climate projections approach based on expected changes in some physical climate signal from literature review rather than projections based on direct location specific modelling. Usually this is proposed as a 'what if' question which is then quantified using a numerical method. For example in the Pacific, digital elevation models of Fiji's islands have been used to identify high risk areas for flooding based on six scenarios for sea-level rise from 0.09 to 0.88 m in combination with six scenarios for storm surge with return intervals from 1 to 50 years (Gravelle and Mimura, 2008). 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.,* 2013a). Climate change also poses risks for food security in the Pacific islands, including agriculture and fisheries (Barnett, 2011) Projections have also been used in the islands of the Republic of Baharain to estimate proness to inundation for sea-level rise of 0.5, 1.0 and 1.5 m (Al-Jeneid *et al*., 2008). Similarly, in the Caribbean the elevation equivalent of a projected sea-level rise of 1 m has been superimposed on topographic maps to estimate that 49-60% of tourist resort properties would be damaged, potentially transforming the competitive position and sustainability of coastal tourism destinations in the region (Scott *et al*., 2012c). This method has also been used to quantify the area loss for over 12 900 islands and over 3000 terrestrial vertebrates in the tropical Pacific region for three sea-level rise scenarios. The study estimated that for sea-level rise of 1 m, 37 island endemic species in this region risk complete inundation (Wetzel *et al*., 2013).

29.4.2. Projected Impacts for Islands based on Scenario Projections

Another approach to scenario development is to use the region specific projections more directly. It is worth noting that the broad synthesis in the AR4 of medium emissions climate scenario projections for small island regions (Mimura *et al*., 2007) shows concordance with the new RCP scenarios (see Table 29-1 and new RCP projections in Figure 29-3). For example, the SRES A1B medium emissions scenario suggests about a 1.8 to 2.3 °C median annual increase in surface temperature in the Caribbean, Indian Ocean and Pacific Ocean small islands regions by 2100 compared to a 1980-1999 baseline, with an overall annual decrease in precipitation of about 12% in the Caribbean (Table 11.1 in AR4 WG1; AR5 WG 1, 14.7.4) and a 3-5 per cent increase in the Indian and Pacific Oceans small island regions. Comparative projections for the new RCP4.5 scenario suggests about a 1.2 to 2.3 °C increase in surface temperature by 2100 compared to a 1986-2005 baseline and a decrease in precipitation of about 5 or 6 per cent in the Caribbean and Mediterranean respectively signaling potential future problems for agriculture and water availability compared to a 1-9 per cent increase in the Indian Ocean and Pacific Ocean small islands regions (Table 29.1). However, there are important spatial and high-island topography differences. Thus for example, among the more dispersed Pacific islands where the equatorial regions are *likely* to get wetter and the sub-tropical high pressure belts drier (as reported by AR5 WG I) in regions directly affected by the South Pacific Convergent Zone (SPCZ) and western portion of the Inter-Tropical Convergent Zone (ITCZ), the rainfall outlook is uncertain (AR5 WG1, 14.7.13). Projections for the Mediterranean islands also differ from those for the tropical small islands. 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 WGI, 14.7.6). Sea-level rise projections in the small islands regions for RCP4.5 are similar to the global projections of 0.41 to 0.71m (WGI AR5 13.5.1) ranging from 0.5-0.6 m by 2100 compared to 1986-2005 in the Caribbean, Pacific and Indian Ocean to 0.4-0.5 m in the Mediterranean and North Indian Ocean (Table 29-1).

[INSERT TABLE 29-1 HERE
Table 29-1: Climate change projections for the intermediate low (500-700 ppm CO2-e) RCP4.5 scenario for six Small Islands regions. The table shows the 25th, 50th (median) and 75th percentiles for surface air temperature and precipitation based on averages from 42 CMIP5 global models (adapted from WGI AR5 Table 14.1). Mean net regional sea-level change is evaluated from 21 CMIP5 models and includes regional non-scenario components (adapted from WGI AR5 Figure 13-20).]

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 even less illustrating the experience gained from their use for policy making. A possible 2 °C temperature increase by the year 2100 has potentially 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 °C-month are the determining threshold for severe coral bleaching (Donner, 2009). For example 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, Donner (2009) 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 stated that thermal adaptation of 1.5 °C 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, 2088 in the western Indian Ocean, 2082 in the central Indian Ocean, 2065 in Micronesia, 2051 in the central Pacific, 2094 in Polynesia and 2073 in the eastern Pacific small islands regions. Using the new RCP scenarios by comparison, van Hooidonk *et al*. (2013) found that the onset of annual bleaching conditions is associated with about 510 ppm CO^2 equivalent. The conclusion based on outputs from a wide range of emissions scenarios and models is that preserving >10 per cent of coral reefs worldwide would require limiting warming to less than 1.5±1.3 °C compared to pre-industrial levels (Frieler *et al*., 2013).

Small island economies can also be objectively shown to be at greater risk from sea-level rise in comparison to other geographic areas since most of their population and infrastructure are in the coastal zone. This is demonstrated in a study using the Climate Framework for Uncertainty, Negotiation and Distribution (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 showed that in magnitude, a few regions will experience most of the absolute 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 showed that most of the top ten and four of the top five most impacted are small islands from the Pacific (Federated States of Micronesia, Palau, Marshall Islands, Nauru) and Caribbean (Bahamas). 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 adequate coastal protection (Anthoff *et al*., 2010).

In the Caribbean, downscaled climate projections have been generated for some 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 compared to a 1960-1990 baseline, 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 linked to changes in the Caribbean Low Level Jet (CLLJ) 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 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 an approximate 1.8 °C increase in air temperature by 2070, probable drier dry seasons and wet seasons, about a 40 cm rise in sea-level and a decrease in the number of intense tropical cyclones.

In the western tropical Pacific, extensive climate projections have been made for several Pacific Island Countries based on downscaling from an ensemble of models (ABoM 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, extreme rainfall events that currently occur once every 20 years on average are generally simulated to occur four times per 20-year period, on average, by 2055 and seven times per 20-year period, on average, by 2090 under the A2 (high emissions) scenario (ABoM and CSIRO, 2011b). The results are not very different from the tropical Pacific RCP4.5 projections with projected temperature increases of about +1.2 to 1.4 °C by 2100 and an increase in rainfall of about 4% (Table 29-1). A comprehensive assessment of the vulnerability of the fisheries and aquaculture sectors to climate change in 22 Pacific island countries and territories focused on two future time-frames (2035 and 2100) and two SRES emissions scenarios, B1 (low emissions) and A2 (high emissions) (Bell *et al*., 2013). Many anticipated changes in habitat and resource availability such as coral reef-based fisheries are negative. By contrast, projected changes in tuna fisheries and freshwater aquaculture/fisheries can be positive with implications for government revenue and island food security (Bell *et al*., 2013). Simulation studies on changes in stocks of skipjack and bigeye tuna in the tropical Pacific area summarized in Table 29-2 and also discussed in 7.4.2.1 and 30.6.2.1.1. Some of these projected changes may favour the large international fishing fleets that can shift operations over large distances compared to local, artisanal fishers (Polovina *et al*., 2011).

[INSERT TABLE 29-2 HERE
Table 29-2: Summary of projected percentage changes in tropical Pacific tuna catches by 2035 and 2100 relative to 1980-2000 and the estimated resulting percentage changes to government revenue (After Bell *et al.*, 2011).]

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 to the year 2050. The simulations indicate that the effects of climate change are expected to be negligible within most ecosystems except for mountainous areas. These areas 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 Atlantic. 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). Typical model ensemble representations of low, intermediate low, intermediate high and high RCP projections for annual temperature and precipitation in some small islands regions are presented in Figure 29-3. Highlighted in Figure 29-3 is the ensemble mean of each RCP. A more comprehensive compilation of quarterly global RCP projections can be found in the Annex I Atlas of Global and Regional Climate Projections in the WGI AR5 Report.

[INSERT FIGURE 29-3 HERE
Figure 29-3: Time series of RCP scenarios annual projected temperature and precipitation change relative to 1986-2005 for six small islands regions (using regions defined in AR5 WG1, Annex 1: Atlas of Global and Regional Climate Projections).] Thin lines denote one ensemble member per model, thick lines the CMIP5 multi-model mean. On the right-hand side the 5th, 25th, 50th (median), 75th and 95th percentiles of the distribution of 20-yr mean changes are given for 2081–2100 in the four RCP scenarios. Note that the model ensemble averages in the figure are for grid points over wide areas and encompass many different climate change signals. To get projections for a specific location and time period use the maps in the Atlas or the online interactive version at but please note that in regions with small islands the models basically simulate the climate of the surrounding ocean and local conditions on land may differ.]

During negotiations towards a new multi-lateral climate change regime Small Island Developing States (SIDS) have advocated that any agreement should be based on Global Mean Surface Temperature (GMST) increase 'well below' 1.5 °C above pre-industrial levels (Hare *et al*., 2011; Riedy and McGregor, 2011). Inspection of column 1 in Figure 29-3 suggests that for the Caribbean, Indian Ocean and Pacific SIDS in the tropics, the median projected regional increase is in the range 0.5-0.9 °C by 2100 compared to 1986-2005. This together with the temperature change that has already occurred since the industrial revolution suggests that a temperature 'well below' 1.5 °C is unlikely to be achieved with the lowest RCP2.6 projection (Peters *et al.*, 2013). By comparison temperature projections for the intermediate low RCP4.5 scenario, Table 29-1 and Figure 29-3 suggest possible 1.2-1.5 °C temperature increases in Caribbean, Indian Ocean and Pacific SIDS by 2100 compared to 1986-2005. Similarly, the projections for the Mediterranean would be about a 2.3 °C increase by 2100 compared to 1986-2005 that would represent a 2.7 °C increase compared to pre-industrial temperatures. Associated with this change, the Caribbean and Mediterranean regions may experience a noticeable 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 (Table 29-1).

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

Available literature since AR4 has highlighted previously less well understood impacts on small islands that 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 sources in the mid- and high-latitudes by Extra-Tropical Cyclones (ETC) cause considerable damage on the coasts of small islands thousands of kilometres away in the tropics. Impacts include sea-flooding and inundation of settlements, infrastructure and tourism facilities as well as severe erosion of beaches (see also 5.4.3.4). 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 since the 1950s (Donn and McGuinness, 1959). They cause considerable seasonal damage to beaches, marine ecosystems and coastal infrastructure throughout the region (Cambers, 2009; Bush *et al.*, 2009). These high-energy events manifest themselves as long period high-amplitude waves that occur during the northern hemisphere winter and often impact the normally sheltered, low-energy leeward coasts of the islands. 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 and in their morphological impact (Cooper *et al.*, 2013). Swells of similar origin and characteristics also occur in the Pacific (Fletcher *et al.*, 2008; Keener *et al.*, 2012). These events frequently occur 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*. (2013) 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 100,000 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.,* 2013).

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). 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. Projected changes in global wind-wave climate to 2070-2100, compared to a base period 1979-2009, show considerable regional and seasonal differences with both decreases and increases in annual mean significant wave height. Of particular relevance in the present context is the projected increase in wave activity in the Southern Ocean which influences a large portion of the global ocean as swell waves propagate northwards into the Pacific, Indian and Atlantic oceans (Hemer *et al.*, 2013).

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. Four types of impacts are distinguished here, black arrows showing the connections between them, based on the existing literature. An example of the chain of impacts associated with two extra-tropical cyclones centred to the east of Japan is illustrated by the red arrows. Swell waves generated by these events in December 2008 reached islands in the southwest Pacific and caused extensive flooding (3) that impacted soil quality (8), freshwater resources (9), and damaged crops (10), buildings (15), and transport facilities (16) in the region (Example based on Hoeke *et al*., 2013).

Examples of tropical cyclone impacts on small island coasts with reference

1. Society Islands, French Polynesia, February 2010 (Etienne, 2012); 2. Taveuni, Fiji, March 2010 (Etienne and Terry, 2012); 3. Cook Islands (de Scally, 2008); Society and Autral Islands, French Polynesia, February 2010 (Etienne, 2012); 4. Viti Levu, Fiji, March 1997 (Terry *et al.*, 2002); 5. Society Islands, French Polynesia, February 2010 (Etienne, 2012); 6. Curacao, Bonaire, Netherlands Antilles, November 1999 (Scheffers and Scheffers, 2006); Hawaiian Islands (Fletcher *et al.,* 2008); 7. Bay Islands, Honduras, October 1998 (Cahoon *et al.*, 2003); 8. Marshall Islands, June 1905 (Spennemann, 1996); 9. Pukapuka atoll, Cook Islands, February 2005 (Terry and Falkland, 2010); 10. Vanuatu, February 2004 (Richmond and Sovacool, 2012); 11. 12. 13. Tuamotu Islands, French Polynesia, 1982-83 (Dupon, 1987); 14. Grenada, September 2004 (OECS, 2004); 15. Grenada, September 2004 (OECS, 2004); Tubuai, Austral Islands, French Polynesia, February 2010 (Etienne, 2012); 16. Vanuatu, February 2004 (Richmond and Sovacool, 2012); Guadeloupe Island, October 2008 (Dorville and Zahibo, 2010); 17. Bora Bora, Raiatea, Maupiti, Tahaa, Huahine, Society Islands, February 2010 (Etienne, 2012); 18. Vanuatu, February 2004 (Richmond and Sovacool, 2012); 19. Tuamotu, French Polynesia, 1982-83 (Dupon, 1987).

Examples of extra-tropical cyclone impacts on small island coasts with reference

1. Maldives, April 1987 (Harangozo, 1992); 2. Maldives, January 1955 (Maniku, 1990); 3. Maldives, April 1987 (Harangozo, 1992); 9. Solomon Islands, December 2008 (Hoeke *et al*., 2013); 10. Chuck, Pohnpei, Kosrae, Federated States of Micronesia, December 2008 (Hoeke *et al*., 2013); 15. Majuro, Marshall Islands, November 1979

(Hoeke *et al*., 2013); 16. Coral Coast, Viti Levu, Fiji, May 2011 (Hoeke *et al*., 2013); 17. Majuro, Kwajalein, Arno, Marshall Islands, December 2008 (Hoeke *et al*., 2013); 18. Bismark Archipelago, Papua New Guinea, December 2008 (Hoeke *et al*., 2013).]

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 and pesticides (Prospero *et al*., 2005; Middleton *et al*., 2008; Monteil, 2008; López-Villarrubia *et al*., 2010; Garrison *et al*., 2006). During major events, dust concentrations can exceed 100 µg m^{-3} (Prospero, 2006). 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, compared to the 1980s, a period of intense drought in the Sahel region (Nicoll *et al*., 2011). Dust from the Sahara has also reached 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 (Griffin, 2007) 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 coloniser species that establish populations outside their normal distribution ranges. 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 *et al.* (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 of 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 will decrease (Albins and Hixon, 2013; 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) 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; 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 and Caribbean 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 (Danovaro *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.*, 2009a; Weil and Croquer, 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 Hawai'i 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 (Otero *et al*., 2010; Tester *et al*., 2010) and Mediterranean (Aligizaki and Nikolaidis, 2008) (see also 29.3.3.2).

29.6. Adaptation and Management of Risks

Islands face risks from both climate-related hazards that have occurred for centuries, as well as new risks from climate change. There have been extensive studies of the risks associated with past climate-related hazards and adaptations to these, such as tropical cyclones, drought, and disease, and their attendant impacts on human health, tourism, fisheries and other areas (Bijlsma *et al*., 1996; Cronk 1997; Solomon and Forbes 1999; Pelling and Uitto 2001). There have also been many studies that have used a variety of vulnerability, risk and adaptation assessment methods particularly in the Pacific that have recently been summarized by Hay *et al*., (2013). But for most islands, there is very little published literature documenting the probability, frequency, severity or consequences of climate change risks such as sea-level rise, ocean acidification, and salinisation of freshwater resources – or associated adaptation measures. Projections of future climate change risks are limited by: 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*., 2013b); inadequate projections of regional sea levels (Willis and Church, 2012), and a lack of long term baseline monitoring of changes in climatic risk, or to ground-truth models (Voccia, 2012), such as risk of saline intrusion, risk of invasive species, risk of biodiversity loss, or risk of large ocean waves. In their absence, qualitative studies have documented perceptions of change in current risks (Fazey *et al.*, 2011; Lata and Nunn, 2012), reviewed effective coping mechanisms for current stressors (Bunce *et al*. 2009; Campbell et al., 2011) and have considered future scenarios of change (Weir and Virani 2011). These studies highlight that change is occurring, but they do not quantify the probability, speed, scale or distribution of future climate risks. The lack of quantitative published assessments of climate risk for many small islands means that future adaptation decisions have to rely on analogues of responses to past and present weather extremes and climate variability, or assumed/hypothesised impacts of climate change based on island type (Table 29-3). Differences in island type and differences in exposure to climate forcing and hazards vary with island form that provides a framework for consideration of vulnerability and adaptation strategies. Critical is a place-based understanding of island landscapes and of processes operating on individual islands (Forbes *et al.*, 2013).

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

29.6.1. Addressing Current Vulnerabilities on Small Islands

Islands are heterogeneous in geomorphology, culture, ecosystems, populations and hence also in their vulnerability to climate change Vulnerabilities and adaptation needs are as diverse as the variety of islands between regions and even within nation states (e.g. in Solomon Islands, Rasmussen *et al.*, 2011), often with little climate adaptation occurring in peripheral islands, for example in parts of the Pacific (Nunn *et al*. 2013). Quantitative comparison of vulnerability is difficult due to the paucity of vulnerability indicators. Generic indices of national level vulnerability continue to emerge (Cardona, 2007) but only a minority are focused on small islands (e.g. Blancard and Hoarau, 2013). The island-specific indicators that exist often suffer from lack of data (Hughes *et al*., 2012; Peduzzi *et al*., 2009), 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, 2011). As a result indicators of vulnerability for small islands often misrepresent actual vulnerability Recent moves towards participatory approaches that link scientific knowledge with local visions of vulnerability (see Park *et al.*, 2012) offers an important way forward to understanding island vulnerability in the absence of certainty in model-based scenarios.

Island vulnerability is often a function of four key stressors: socio-economic, physical, socio-ecological and climate-induced , whose reinforcing mechanisms are important in determining the magnitude of impacts. 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 (see Table 29-2; Figure 29-1) create inherent physical vulnerabilities. Thus, 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, it is necessary to assess all of these dimensions of vulnerability (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 atoll (Marshall Islands), 34-37 years of aerial photography shows that socio-ecological stress is exacerbating shoreline change associated with sea-level rise, especially on the lagoon-side of islands (Ford, 2012; see also 29.3.1.1). Islands faced with multiple stressors can therefore be assumed to be more at risk from climate impacts.

Despite the limited ability of continental scale models to predict climate risks for specific islands, or the limited capacity of island vulnerability indicators, scenario based damage assessments can be undertaken. Storm surge risks have been effectively modeled for the Andaman and Nicobar Islands (Kumar *et al*., 2008). Rainfall induced landslide risk maps have been produced for both Jamaica (Miller *et al*., 2009b) and the Chuuk Islands (Federated States of Micronesia) (Harp *et al*., 2009). However the probability of change in frequency and severity of extreme rainfall events and storm surges remains poorly understood for most small islands. Other risks, such as the climate change driven health risks from the spread of infectious disease, loss of settlements and infrastructure, and decline of ecosystems that affect island economies, livelihoods and human well-being also remain under-researched. Nevertheless, it is possible to consider these risks along with the threat of rising sea level and suggest a range of contemporary and future adaptation issues and prospects for small islands (Table 29-4).

[INSERT TABLE 29-4 HERE
Table 29-4: Selected key risks and potential for adaptation for small islands from the present-day to the long-term.]

29.6.2. Practical Experiences of Adaptation on Small Islands

There is disagreement about whether islands and islanders have successfully adapted to past weather variability and climate change. Nunn (2007) argues that past climate changes have had a ‘crisis effect’ on prehistoric societies in much of the Pacific Basin. In contrast a variety of studies argue that past experiences of hydro-meteorological extreme events have enabled islands to become resilient to weather extremes (Barnett, 2001). 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 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, all of which produced high adaptive capacity (Cinner *et al.,* 2012). Despite this resilience, islands are assumed to be generically vulnerable to long term future climate change (Parks and Roberts, 2006; Myers, 2002).

There are many ways in which *in-situ* 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 implications of the various options. Not all adaptations are 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: The impact of alternative climate change adaptation actions or policies.]

29.6.2.1. Building Adaptive Capacity with Traditional Knowledge, Technologies, and Skills on Small Islands

As in previous IPCC Assessments, there is continuing strong support for the incorporation of indigenous knowledge into adaptation planning. However this is moderated by the recognition that current practices alone may not be adequate to cope with future climate extremes or trend changes The ability of a small island population to deal with current climate risks may be positively correlated with the ability to adapt to future climate change, but evidence confirming this remains limited (such as Lefale, 2010). Consequently, this section focuses on evidence for adaptive capacity that reduces vulnerability to existing stressors, enables adaptation to current stresses, and supports current disaster risk management.

Traditional knowledge has proven to be useful in short term weather forecasting (e.g. Lefale, 2010) although evidence is inconclusive on local capacity to observe long-term climate change (e.g. Hornidge and Scholtes, 2011). In 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 vulnerability reduction in indigenous communities 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 effectiveness and limits to the use of traditional methods of weather forecasting under climate change on small islands.

Traditional technologies and skills can be effective for current disaster risk management but there is currently a lack of supporting evidence to suggest that they will be equally appropriate under changing cultural conditions and future climate changes on islands. Campbell (2009) identified that traditional disaster reduction measures used in Pacific islands focused 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). Two discrete studies from Solomon Islands highlight the importance of traditional patterns of social organisation 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. Nonetheless there are physical and cultural limits to traditional disaster risk management. In relation 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). Ongoing processes of rapid urbanization, and loss of language and tradition suggest that traditional approaches may not always be efficacious in longer-term adaptation.

Traditional construction methods have long been identified across the Pacific as a means of reducing vulnerability to tropical cyclones and floods in rural areas. In Solomon Islands traditional practices include: elevating concrete floors on Ontong Java to keep floors dry during heavy rainfall events; building 'low, aerodynamic houses with 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). 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. Squatter settlements in urban areas, especially on steep hillsides in the Caribbean often use poor construction practices frequently driven by poverty and inadequate building code enforcement (Prevatt *et al*., 2010).

Traditional systems appear less effective when multiple civilization-nature stresses are introduced. For example in Reunion and Mayotte, population growth, and consequent rises in land and house prices have led low-income families to settle closer to hazardous slopes that are prone to landslides and to river-banks which are prone to flooding (Le Masson and Kelman, 2011). Traditional belief systems can also limit adaptive capacity. Thus, 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 emphasised by Kelman and West (2009) and McNamara and Westoby (2011), yet evidence does not yet exist that reveals the limits to such knowledge, such as in the context of rapid socio-ecological change, or the impact of belief systems on adaptive capacity.

While there is clear evidence that traditional knowledge networks, technologies and skills can be used effectively to support adaptation in certain contexts, the limits to these tools are not well understood. 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 on this topic.

29.6.2.2. Addressing Risks on Small Islands

Relative to other areas, small islands are disproportionately affected by current hydro-meteorological extreme events, both in terms of the percentage of the population affected, and losses as a percentage of GDP (Anthoff *et al*., 2010; Table 29-5). Under climate change the risks of damage and associated losses are expected to continue to rise (Nicholls and Cazenave, 2010). Yet much of the existing literature on climate risk in small islands does not consider how to address high future risks, but instead focuses on managing present day risks through risk transfer, risk spreading or risk avoidance. Risk transfer is largely undertaken through insurance; risk spreading through access to and use of common property resources, livelihood diversification, or mutual support through networks (see 29.6.2.3); and risk avoidance through structural engineering measures or migration (see 29.6.2.4).

[INSERT TABLE 29-5 HERE
Table 29-5: 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).]

Risk transfer through insurance markets has had limited uptake in small islands, as insurance 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 that provide payouts 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 and there remains limited evidence of the long-term effectiveness of index-based or pooled-risk insurance in supporting household level adaptation. Small island governments also face expensive climate risk insurance. The Caribbean Catastrophe Risk Insurance Facility (CCRIF) which has been operating since 2007 pools Caribbean-wide country-level risks into a central, more diversified risk portfolio – offering lower premiums for participating national governments (CCRIF, 2008). The potential for a similar scheme in the Pacific is being explored (ADB, 2009; Cummins and Mahul, 2009).

Risk can be spread socially e.g. through social networks and familial ties (see also 29.6.2.3), or ecologically, e.g. by changing resource management approach. Social networks can be used to spread risk among households. In Fiji, after Tropical 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) – mutual support formed a central pillar for community-based adaptation. In the case of natural systems, risks can be spread through enhancing representation of habitat types and replication of species e.g. 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). 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 in several Pacific islands (Techera, 2008; Game *et al*., 2011). By creating a network of protected areas supported by local communities the risks associated with some forms of climate change can be spread and potentially reduced (Mills *et al*., 2010) although such initiatives may not preserve thermally sensitive corals in the face of rising SST.

Risk avoidance through engineered structures can reduce risk from some climate-related hazards (*medium evidence, medium agreement*). In Jamaica, recommendations to reduce rainfall-driven land surface movements resulting in landslides include: engineering structures such as soil nailing, gabion baskets (i.e. cages filled with rocks), rip rapped surfaces (i.e. permanent cover with rock) and retaining walls together with engineered drainage systems (Miller *et al*., 2009b). Engineering principles to reduce residential damage from hurricanes have been identified, tested, and recommended for decades in the Caribbean. However, expected levels of success have often not been achieved due to inadequate training of construction workers, minimal inspection of new buildings, and lack of enforcement of building code requirements (Prevatt *et al.*, 2010). Some island states do not even have the technical or financial capacity to build effective shore protection structures as highlighted by a recent assessment in south Tarawa, Kiribati (Duvat, 2013). In addition not all engineered structures are seen as effective risk avoidance mechanisms. In the Azores archipelago, a proliferation of permanent engineered structures along the coastline to prevent erosion have resulted in a loss of natural shoreline protection against wave erosion (Calado *et al.*, 2011)). In Barbados it is recognized that seawalls can protect human assets in areas prone to high levels of erosion, however they can also cause sediment starvation in other areas, interfere with natural processes of habitat migration and cause coastal squeeze – which may render them less desirable for long term adaptation (Mycoo and Chadwick, 2012) (see also 5.4.2.1). To reduce erosion risk an approach with less detrimental downstream effects that also supports tourism is beach nourishment. This is increasingly being recommended, for example in the Caribbean (Mycoo and Chadwick, 2012), the Mediterranean (Anagnostou *et al*., 2011), and western Indian Ocean (Duvat, 2009). Beach nourishment however is not without its challenges, as requirements such as site-specific oceanographic and wave climate data, adequate sand resources and critical engineering design skills may not be readily available in some small islands.

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). CBA research is focusing on empowerment that helps people to help themselves e.g. through marine catch monitoring (Breckwoldt and Seidel, 2012), while addressing local priorities and building on local knowledge and capacity. This approach to adaptation is being promoted as an appropriate strategy for small islands, since it is something done ‘with’ rather than ‘to’ communities (Warrick, 2009). Nonetheless externally driven programs 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 CBA 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. More long term monitoring and evaluation of the effectiveness of community level action is needed.

Collaboration between stakeholders can lessen the occurrence of simple mistakes that can reduce the effectiveness of adaptation actions (*medium evidence, medium agreement*). 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). Landslide risk can be significantly reduced through better hillside drainage. In the Eastern Caribbean, community groups, with input from engineers, have constructed these networks of drains to capture surface runoff, household roof-water and grey water. 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 is needed, as well as strong pre-existing relationships founded on routine daily activities, to make CBDRR effective. Research from both Solomon Islands and the Cayman Islands reinforce the conclusion that drivers of community resilience to hazard maps closely onto factors driving 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 expected 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 (*medium evidence, high agreement*).

All of these studies reinforce the earlier work of Barnett (2001), providing empirical 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 either a coincidental benefit of island lifestyle and culture, 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

Sea-level rise poses one of the most widely recognized climate change threats to low-lying coastal areas on islands (29.3.1). However long term climate impacts depend on the type of island (see Figure 29-1) and the adaptation strategy adopted. 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). Statistics like these underpin the widely held view about small islands being ‘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, west African islands) will experience the largest sea-level rise (Willis and Church, 2012) and which islands will experience the worst climate impacts. 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 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 for different island types under those scenarios. 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).

Due to the high costs of adapting on islands it has been suggested that there will be a need for migration (Nicholls *et al.*, 2011; Gemenne, 2011; Biermann and Boas, 2010; Voccia 2012). Relocation and displacement are frequently cited as outcomes of sea-level rise, salinisation and land loss on islands (Byravan and Rajan, 2006; Kolmannskog and Trebbi, 2010; see also 29.3.3.3). 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 on islands often live in highly exposed locations, lacking basic amenities, leaving them highly vulnerable to climate risks (Baker, 2012). However, a lack of research in this area makes it difficult to draw clear conclusions on the impact of climate change on the growing number of urban migrants in islands.

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 an 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 extreme scenarios island communities may need to consider relocating in the future (Gemenne, 2011). In reality, financial and legal barriers are expected to inhibit significant levels of international environmentally induced migration in the Pacific (Barnett and Chamberlain, 2010).

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 such as seawalls instead of “soft” measures such as beach nourishment (Sovacool, 2012). Heger *et al*. (2008) recognised 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 benefit from the provision of social services somewhat similar to what obtains in the Metropole, but not the level of enforcement of building codes and land use planning as in France (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 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. 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 plans. 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). Agrawala 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 in the areas of: disaster risk reduction, community-based approaches to development, and building adaptive capacity. Boyd *et al.* (2009) support the need 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, 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, peri-urban and rural planning provide important adaptation, development and mitigation opportunities. While the potential to deliver such an integrated approach may be reasonably strong in urban centres on islands, there appears to be limited capacity to mainstream climate change adaptation into local decision making in out-lying islands or peripheral areas (Nunn *et al*., 2013).

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). ‘However, many small island governments and communities have chosen to attempt to reduce their greenhouse gas emissions because of the cost andthe 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. Rather they have diverse geo-physical characteristics and economic structures (see Table 29-2, Figure 29-1). Following Nunn (2009) 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 to income levels, resources endowment, technology and knowledge (see 29.6.2).

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 generally 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.

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; 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 the relocation of communities 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 this, there remain significant barriers to the wider institutionalization of renewable technologies in small islands. Research in Europe and the United States has shown the mitigation and cost savings benefits of Energy Service Companies (ESCOs): 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). IPCC (2011) presents examples of opportunities for renewable energy, including wind energy sources, as deployed in the Canary Islands.

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 to provide visitor attractions and accommodation space. Recognising 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. Gössling 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 emphasised 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, or burdensome opportunity costs on local communities. There is also 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 further argue that a priori acceptance of adaptation as an efficacious option for places like the Pacific islands, may also act as a disincentive for reducing greenhouse gas emissions (Barnett and O'Neill, 2012).

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. For example, Bunce *et al*. (2009) have shown that as an adaptive response to poverty, young fishers from Rodrigues Island periodically resort to temporary migration to the main capital island, Mauritius, where greater employment prospects exist. 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). Negotiations with the Government of Australia collapsed before a mutually acceptable agreement was reached, and the Nauruans opted to abandon the proposal to relocate (Tabucanon and Opeskin, 2011). Overall however, it is suggested that states contemplating long term, off-island migration 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 29.3.3.3). A related challenge facing small islands is the need to find the middle ground between 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, concerns have been expressed 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.*, 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 renewable energy. 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.*, 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 (López-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), which 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, '*no-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 '*low-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; 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.

Some authors suggest that 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 may not always address the salient challenges on small islands, and may lead to inadequate adaptation or a waste of scarce resources (Barnett, 2010; Nunn, 2009). Others argue 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

Several advances have taken place in our understanding of the observed and potential effects of climate change on small islands since the AR4. These 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 themes in small island situations, especially comparative research. 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**. Although some advances have been made (ABoM and CSIRO, 2011a, 2011b; Taylor *et al*., 2007), much of the work in the Caribbean, Pacific, Indian Ocean and Mediterranean islands, is focused at the regional scale rather than being country specific. Since most socio-economic decisions are taken at the local level, there is need for a more extensive database of simulations of future small island climates and socio-economic conditions at smaller spatial 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 in the projections is not a sufficiently valid reason to postpone adaptation planning in small islands**. In several small islands adaptation is being progressed without a full 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 based on a general understanding of broad trends could be used in 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. While some such work has been undertaken for some parts of the Pacific (ABoM and CSIRO, 2011a, 2011b), similar work still needs to be carried out in other small island regions. In addition, the reliability of existing projections for some of the other parameters needs to be improved and the data should be in suitable formats for use in risk assessments.
- **Need to acknowledge the heterogeneity and complexity of small island states and territories.** Although small islands have several characteristics in common, neither the variety nor complexity of small islands is sufficiently reflected in the literature. Thus, transferring data and practices from a continental situation, or from one small island state to another, needs to be done with care and in a manner that takes full cognizance of such heterogeneity and complexity.
- **Within country/territory differences need to be better understood**. Many of the environmental and human impacts reported in the literature on islands 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.

The foregoing list is a sample of the gaps, needs and research agenda that urgently need to be filled for small islands. While some countries have begun to fill these gaps, this work needs to be replicated and expanded across all island regions to improve the database available for ongoing climate change assessments. Such information would raise the level of confidence in the adaptation planning and implementation process in small islands.

Frequently Asked Questions

FAQ 29.1: Why is it difficult to detect and attribute changes on small islands to climate change?

[to be inserted in Section 29.3.1.1]

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. Those changes may have masked any clear evidence of the effects of climate change. For example, on many small islands coastal erosion has been widespread and has adversely affected important tourist facilities, settlements, utilities and infrastructure. But specific case studies from islands in the Pacific, Indian and Atlantic oceans and the Caribbean have shown that human impacts play an important role in this erosion, as do episodic extreme events that have long been part of the natural cycle of events affecting small islands. So while coastal erosion is consistent with models of sea-level rise resulting from climate change, determining just how much of this erosion might have been caused by climate change impacts is difficult. Given the range of natural processes and human activities that could impact the coasts of small islands in the future, without more and better empirical monitoring the role of climate change-related processes on small islands may continue to be difficult to identify and quantify.

FAQ 29.2: Why is the cost of adaptation to climate change so high in small islands?

[to be inserted after Section 29.3.3.4]

Adaptation to climate change that involves infrastructural works generally require large up-front overhead costs, which in the case of small islands cannot be easily downscaled in proportion to the size of the population or territory. This is a major socio-economic reality that confronts many small islands, notwithstanding the benefits that could accrue to island communities through adaptation. Referred to as ‘indivisibility’ in economics, the problem can be illustrated by the cost of shore protection works aimed at reducing the impact of sea-level rise. The unit cost of shoreline protection per capita in small islands is substantially higher than the unit cost for a similar structure in a larger territory with a larger population. This scale-reality applies throughout much of a small island economy including the indivisibility of public utilities, services and all forms of development. Moreover, the relative impact of an extreme event such as a tropical cyclone that can affect most of a small island’s territory has a disproportionate impact on that state’s GDP, compared to a larger country where an individual event generally affects a small proportion of its total territory and its GDP. The result is relatively higher adaptation and disaster risk reduction costs per capita in countries with small populations and areas, especially those that are also geographically isolated, have a poor resource base and high transport costs

FAQ 29.3: Is it appropriate to transfer adaptation and mitigation strategies between and within small island countries and regions? *[to be inserted after Section 29.7.2]*

While lessons learned from adaptation and mitigation experiences in one island or island region may offer some guidance, caution must be exercised to ensure that the transfer of such experiences is appropriate to local biophysical, social, economic, political, and cultural circumstances. If this approach is not purposefully incorporated into the implementation process, it is possible that maladaptation and inappropriate mitigation may result. It is therefore necessary to carefully assess the risk profile of each individual island so as to ensure that any investments in adaptation and mitigation are context specific. The varying risk profiles between individual small islands and small island regions have not always been adequately acknowledged in the past.

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Table 29-1: Climate change projections for the medium (500-700 ppm CO2-e) RCP4.5 scenario for the main Small Islands regions. The table shows the 25th, 50th (median) and 75th percentiles for surface temperature and precipitation based on averages from 42 CMIP5 global models (adapted from WGI AR5 Table 14.1). Mean net regional sea level change is evaluated from 21 CMIP5 models and includes regional non-scenario components (adapted from WGI AR5 Figure 13-20).

Small Island Region	RCP4.5 Annual Projected Change for 2081-2100 compared to 1986-2005						
	Temperature (^{O}C)			Precipitation (%)			Sea Level (m)
	25%	50%	75%	25%	50%	75%	Range
Caribbean	1.2	1.4	1.9	-10	-5	-1	0.5 – 0.6
Mediterranean	2.0	2.3	2.7	-10	-6	-3	0.4 - 0.5
Northern tropical Pacific	1.2	1.4	1.7	0	1	4	0.5 – 0.6
Southern tropical Pacific	1.1	1.2	1.5	0	2	4	0.5 – 0.6
North Indian Ocean	1.3	1.5	2.0	5	9	20	0.4 – 0.5
West Indian Ocean	1.2	1.4	1.8	0	2	5	0.5 – 0.6

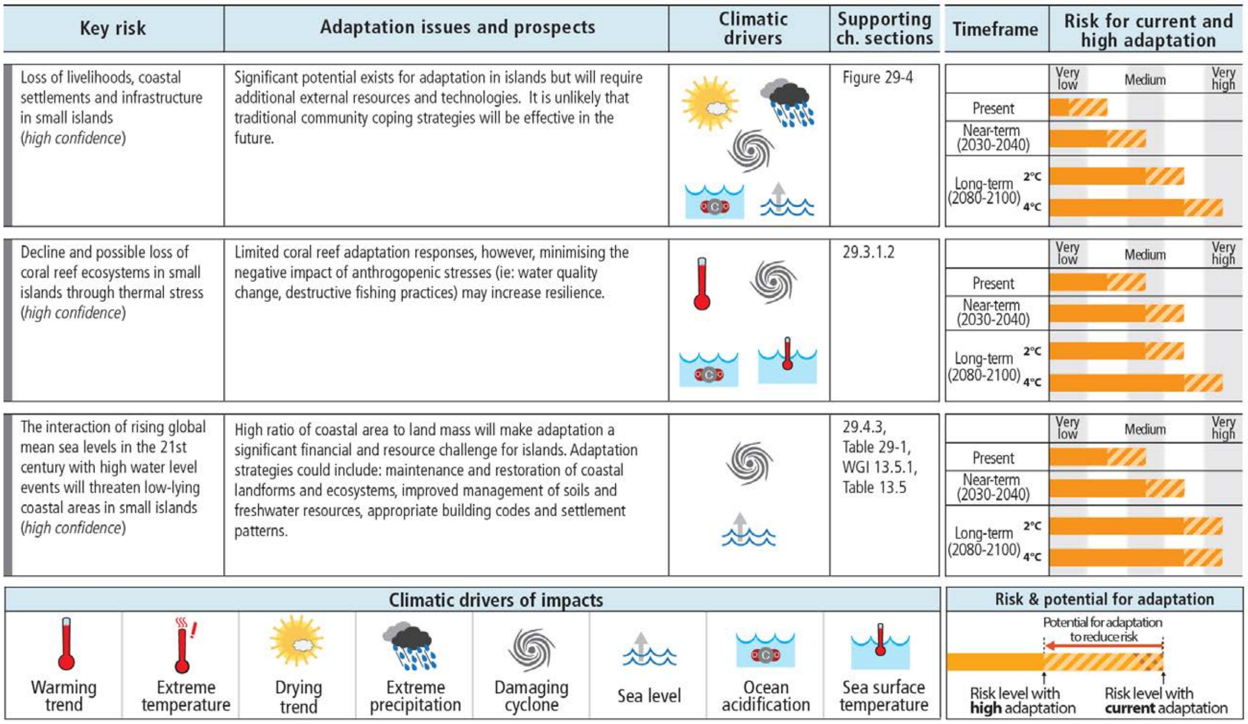
Table 29-2: Summary of projected percentage changes in tropical Pacific tuna catches by 2036 and 2100 relative to 1980-2000 and the estimated resulting percentage change to government revenue (after Bell *et al.*, 2011).

Tuna Fishery		**Year and 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%
Total Change to Government Revenue (%)	**Federated States of Micronesia**	0.8 to 1.7%	-0.9 to -1.9%	
	Solomon Islands	0.01 to 0.16%	-0.03 to 0.77%	
	Kiribati	+11 to 18.4%	+7.2 to 12.0%	
	Tuvalu	+3.7 to 9.2%	+2.5 to 6.2%	

Table 29-3: Type of island in the Pacific region and implications for hydro-meteorological hazards (after Campbell, 2009).

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 Papua New Guinea 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.

Table 29-4: Selected key risks and potential for adaptation for small islands from the present-day to the long-term.



Key risk	Adaptation issues and prospects	Climatic drivers	Supporting ch. sections
Loss of livelihoods, coastal settlements and infrastructure in small islands (*high confidence*)	Significant potential exists for adaptation in islands but will require additional external resources and technologies. It is unlikely that traditional community coping strategies will be effective in the future.		Figure 29-4
Decline and possible loss of coral reef ecosystems in small islands through thermal stress (*high confidence*)	Limited coral reef adaptation responses, however, minimising the negative impact of anthrogopenic stresses (ie: water quality change, destructive fishing practices) may increase resilience.		29.3.1.2
The interaction of rising global mean sea levels in the 21st century with high water level events will threaten low-lying coastal areas in small islands (*high confidence*)	High ratio of coastal area to land mass will make adaptation a significant financial and resource challenge for islands. Adaptation strategies could include: maintenance and restoration of coastal landforms and ecosystems, improved management of soils and freshwater resources, appropriate building codes and settlement patterns.		29.4.3, Table 29-1, WGI 13.5.1, Table 13.5

Table 29-5: 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) (after ESCAP and UNISDR, 2010).

Rank	Absolute exposure (millions affected)	Relative exposure (% of the population affected)	Absolute GDP loss ($billions)	Loss (as a % of GDP)
1	Japan (30.9)	**North Mariana Islands (58.2)**	Japan (1,226.7)	**North Mariana Islands (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)	Japan (23.9)
6	Rep. of Korea (2.4)	**Samoa (21.4)**	India (8.0)	Philippines (23.9)
7	Myanmar (1.2)	**New Caledonia (20.7)**	Bangladesh (3.9)	**New Caledonia (22.4)**
8	Viet Nam (0.8)	**Vanuatu (18.3)**	**North Mariana Islands (1.5)**	**Samoa (19.2)**
9	Hong Kong (0.4)	**Tonga (18.1)**	Australia (0.8)	**Tonga (17.4)**
10	Pakistan (0.3)	**Cook Islands (10.5)**	**New Caledonia (0.7)**	Bangladesh (5.9)

Note: Small islands are highlighted in **bold**

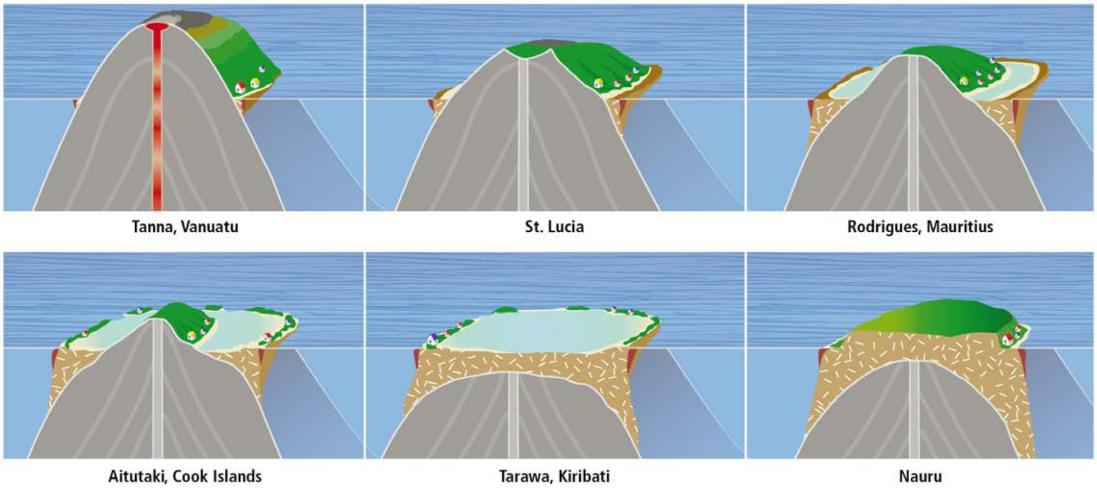


Figure 29-1: Representative tropical island typologies. From top-left: a young, active volcanic island (with altitudinal zones) and limited living perimeter reefs (purple zone at outer reef edge), through to an atoll (centre bottom) and raised limestone island (bottom right) dominated by ancient reef deposits (brown + white fleck). Atolls have limited, low-lying land areas but well developed reef/lagoon systems. Islands composed of 'continental rocks' are not included in this figure, but see Table 29-3]

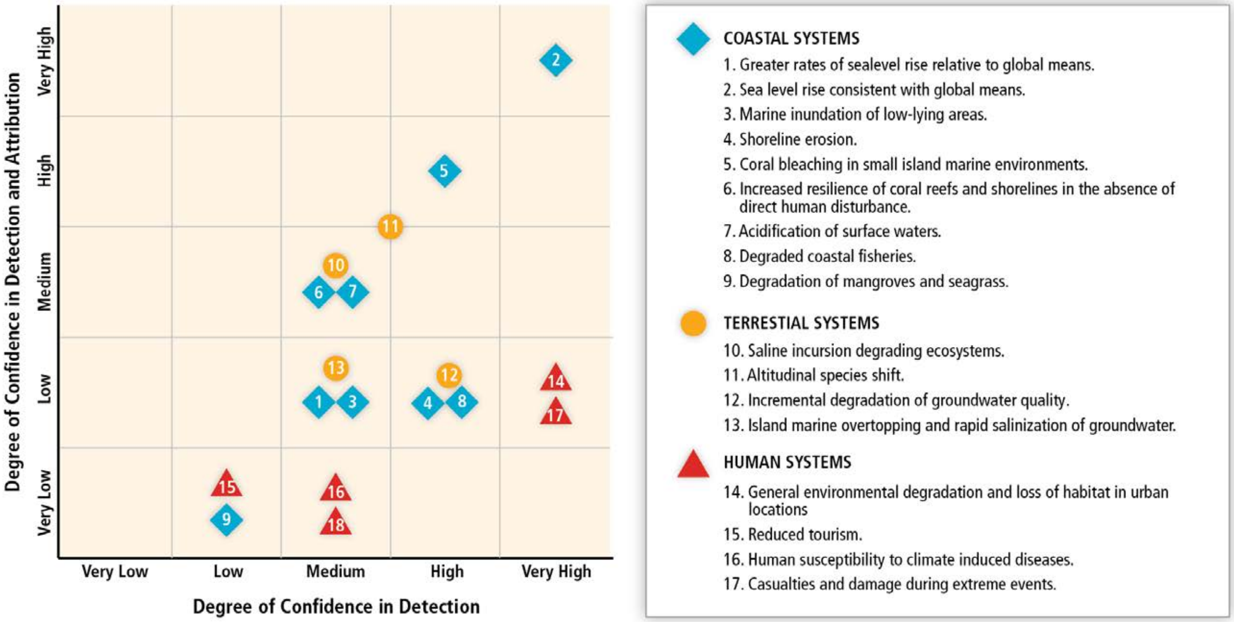
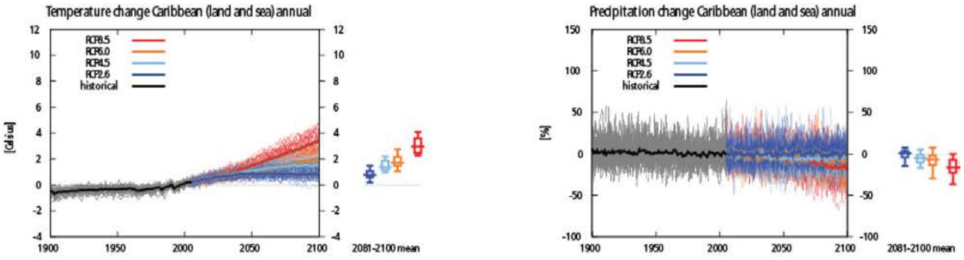
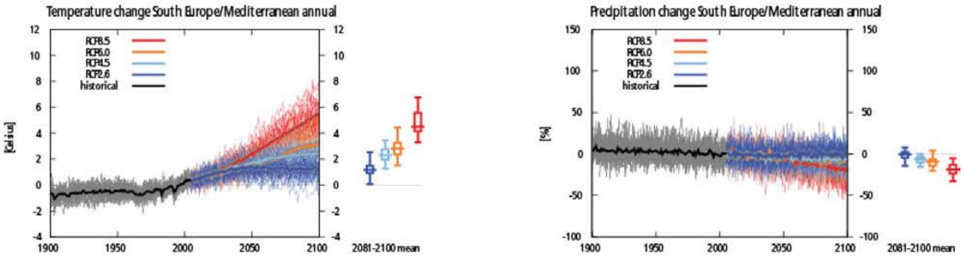


Figure 29-2: A comparison of the degree of confidence in the detection of observed impacts of climate change on tropical small islands with the degree of confidence in attribution to climate change drivers at this time. For example, the blue symbol No. 2 (Coastal Systems), indicates there is *very high confidence* in both the detection of 'sea-level rise consistent with global means' and its attribution to climate change drivers; whereas the red symbol No. 17 (Human Systems) indicates whilst detection of 'casualties and damage during extreme events' is *very high*, there is presently *low confidence* in the attribution to climate change. It is important to note that *low confidence* in attribution frequently arises due to the limited research available on small island environments.

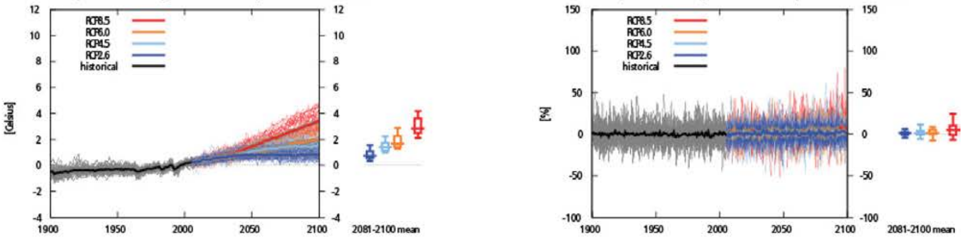
A. Caribbean



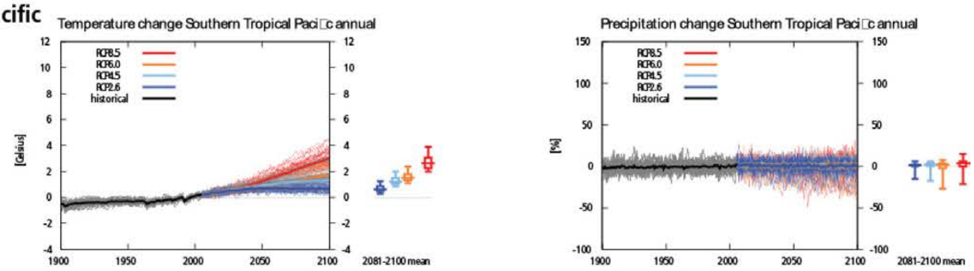
B. Mediterranean



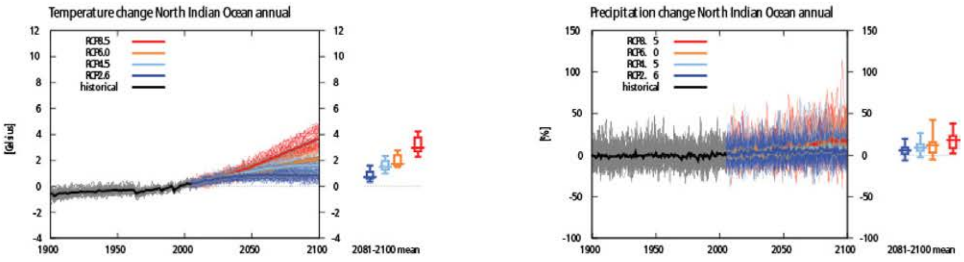
C. Northern Tropical Pacific



D. Southern Tropical Pacific



E. North Indian Ocean



F. West Indian Ocean

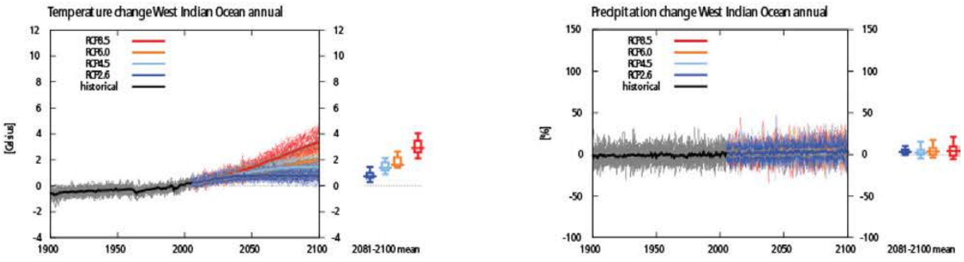


Figure 29-3: Time series of RCP scenarios annual projected temperature and precipitation change relative to 1986-2005 for six small islands regions (using regions defined in AR5 WG1, Annex 1: Atlas of Global and Regional Climate Projections).] Thin lines denote one ensemble member per model, thick lines the CMIP5 multi-model mean. On the right-hand side the 5th, 25th, 50th (median), 75th and 95th percentiles of the distribution of 20-yr mean changes are given for 2081–2100 in the four RCP scenarios. Note that the model ensemble averages in the figure are for grid points over wide areas and encompass many different climate change signals. To get projections for a specific location and time period use the maps in the Atlas or the online interactive version at but please note that in regions with small islands the models basically simulate the climate of the surrounding ocean and local conditions on land may differ. **[Illustration to be redrawn to conform to IPCC publication specifications.]**

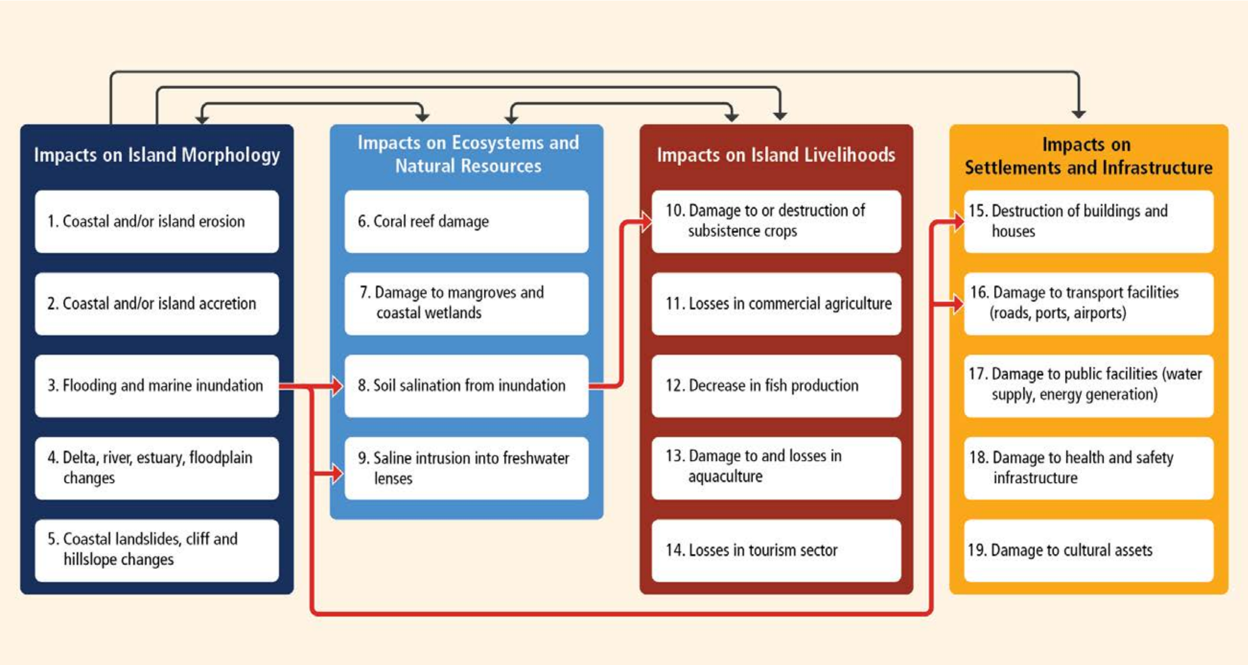


Figure 29-4: Tropical and extra-tropical cyclone impacts on the coasts of small islands. Four types of impacts are distinguished here, black arrows showing the connections between them, based on the existing literature. An example of the chain of impacts associated with two extra-tropical cyclones centred to the east of Japan is illustrated by the red arrows. Swell waves generated by these events in December 2008 reached islands in the southwest Pacific and caused extensive flooding (3) that impacted soil quality (8), freshwater resources (9), and damaged crops (10), buildings (15), and transport facilities (16) in the region (Example based on Hoeke *et al*., 2013).

Examples of tropical cyclone impacts on small island coasts with reference

1. Society Islands, French Polynesia, February 2010 (Etienne, 2012); 2. Taveuni, Fiji, March 2010 (Etienne and Terry, 2012); 3. Cook Islands (de Scally, 2008); Society and Autral Islands, French Polynesia, February 2010 (Etienne, 2012); 4. Viti Levu, Fiji, March 1997 (Terry *et al.*, 2002); 5. Society Islands, French Polynesia, February 2010 (Etienne, 2012); 6. Curacao, Bonaire, Netherlands Antilles, November 1999 (Scheffers and Scheffers, 2006); Hawaiian Islands (Fletcher *et al.*, 2008); 7. Bay Islands, Honduras, October 1998 (Cahoon *et al.*, 2003); 8. Marshall Islands, June 1905 (Spennemann, 1996); 9. Pukapuka atoll, Cook Islands, February 2005 (Terry and Falkland, 2010); 10. Vanuatu, February 2004 (Richmond and Sovacool, 2012); 11. 12. 13. Tuamotu Islands, French Polynesia, 1982-83 (Dupon, 1987); 14. Grenada, September 2004 (OECS, 2004); 15. Grenada, September 2004 (OECS, 2004); Tubuai, Austral Islands, French Polynesia, February 2010 (Etienne, 2012); 16. Vanuatu, February 2004 (Richmond and Sovacool, 2012); Guadeloupe Island, October 2008 (Dorville and Zahibo, 2010); 17. Bora Bora, Raiatea, Maupiti, Tahaa, Huahine, Society Islands, February 2010 (Etienne, 2012); 18. Vanuatu, February 2004 (Richmond and Sovacool, 2012); 19. Tuamotu, French Polynesia, 1982-83 (Dupon, 1987).

Examples of extra-tropical cyclone impacts on small island coasts with reference

1. Maldives, April 1987 (Harangozo, 1992); 2. Maldives, January 1955 (Maniku, 1990); 3. Maldives, April 1987 (Harangozo, 1992); 9. Solomon Islands, December 2008 (Hoeke *et al*., 2013); 10. Chuck, Pohnpei, Kosrae, Federated States of Micronesia, December 2008 (Hoeke *et al*., 2013); 15. Majuro, Marshall Islands, November 1979 (Hoeke *et al*., 2013); 16. Coral Coast, Viti Levu, Fiji, May 2011 (Hoeke *et al*., 2013); 17. Majuro, Kwajalein, Arno, Marshall Islands, December 2008 (Hoeke *et al*., 2013); 18. Bismark Archipelago, Papua New Guinea, December 2008 (Hoeke *et al*., 2013).

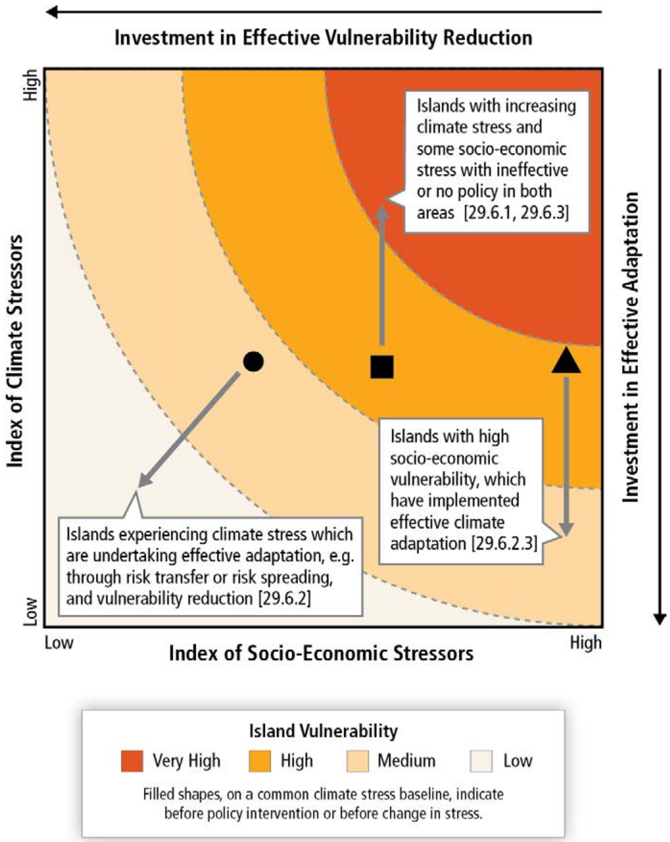


Figure 29-5. The impact of alternative climate change adaptation actions or policies.