29

Small Islands

Coordinating Lead Authors:
Leonard A. Nurse (Barbados), Roger F. McLean (Australia)

Lead Authors:
John Agard (Trinidad and Tobago), Lino Pascal Briguglio (Malta), Virginie Duvat-Magnan (France), Netatua Pelesikoti (Samoa), Emma Tompkins (UK), Arthur Webb (Fiji)

Contributing Authors:
John Campbell (New Zealand), Dave Chadee (Trinidad and Tobago), Shobha Maharaj (Trinidad and Tobago), Veronique Morin (Canada), Geert Jan van Oldenborgh (Netherlands), Rolph Payet (Seychelles), Daniel Scott (Canada)

Review Editors:
Thomas Spencer (UK), Kazuya Yasuhara (Japan)

Volunteer Chapter Scientist:
Veronique Morin (Canada)

This chapter should be cited as:

Nurse, L.A., R.F. McLean, J. Agard, L.P. Briguglio, V. Duvat-Magnan, N. Pelesikoti, E. Tompkins, and A. Webb, 2014: Small islands. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1613-1654.

Table of Contents

Frequently Asked Questions

Executive Summary

Current and future climate-related drivers of risk for small islands during the 21st century include sea level rise (SLR), tropical and extratropical cyclones, increasing air and sea surface temperatures, and changing rainfall patterns (*high confidence*; *robust evidence*, *high agreement*). {WGI AR5 Chapter 14; Table 29-1} Current impacts associated with these changes confirm findings reported on small islands from the Fourth Assessment Report (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. {29.3.1-3}

SLR poses one of the most widely recognized climate change threats to low-lying coastal areas on islands and atolls (*high confidence*; *robust evidence*, *high agreement*). {29.3.1} It is *virtually certain* that global mean SLR rates are accelerating. {WGI AR5 13.2.2.1} Projected increases to the year 2100 (RCP4.5: 0.35 m to 0.70 m) {WGI AR5 13.5.1; Table 29-1} superimposed on extreme sea level events (e.g., swell waves, storm surges, El Niño-Southern Oscillation) 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 seawater will degrade fresh groundwater 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 AR5 9.6; 29.3-4, 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. {Figure 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 transboundary processes already have a negative impact on small islands (*high confidence*; *robust evidence*, *medium agreement*). These include air-borne dust from the Sahara and Asia, distant-source ocean swells from mid to 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 interlinkages 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, socioeconomic, 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. {29.6.2.3, 29.6.3, 29.8}

29.1. Introduction

It has long been recognized that greenhouse gas (GHG) emissions from small islands are negligible in relation to global emissions, but that the threats of climate change and sea level rise (SLR) 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. Although 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 socioeconomic conditions and biophysical 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 homogeneous politically, socially, or culturally, or in terms of physical size and character or economic development, there has been a tendency to generalize 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 and at the same time recognizing 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 while emphasizing a number of additional themes that have emerged in the literature on small islands since the IPCC Fourth Assessment Report (AR4). These include the relationship among climate change policy, activities, and development issues; externally generated transboundary 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 Report (FAR) in 1990 though they were discussed in the chapter on "World Oceans and Coastal Zones" (Tsyban et al., 1990). Two points were highlighted. First, a 30- to 50-cm SLR projected by 2050 would threaten low islands, and a 1-m rise by 2100 "would render some island countries uninhabitable" (Tegart et al., 1990, p. 4). Second, the costs of protection works to combat SLR would be extremely high for small island nations. Indeed, as a percentage of gross domestic product (GDP), the Maldives, Kiribati, Tuvalu, Tokelau, Anguilla, Turks and Caicos, Marshall Islands, and Seychelles were ranked among the 10 nations with the highest protection costs in relation to GDP (Tsyban et al., 1990). More than 20 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 as a result of a SLR of 1.0 m by 2100 (*Special Report on Emission Scenarios* (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 10 countries with the highest relative impact projected for 2100 (Anthoff et al., 2010).

The Second Assessment Report (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, p. 291). The report also summarized results from the application of a common methodology for vulnerability and adaptation analysis that gave new insights into the socioeconomic implications of SLR 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 trade-offs. 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 Report (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, p. 845). The second noted 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, p. 846). In the present chapter, both of these themes are raised again and assessed in light of recent findings.

Until the AR4 in 2007, SLR 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, p. 690).

Since AR4, the literature on small islands and climate change has increased substantially. A number of features distinguish the literature we review here from that included in earlier assessments. First, the literature appears more sophisticated and does not shirk from dealing with the complexity of small island vulnerability, impacts, and adaptation or the differences between 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 (Section 29.3.3.1) as well as the possibility that some proposed adaptation measures may prove to be maladaptive (Section 29.8). Fourth, many initiatives have been identified in recent times that will reduce vulnerability and enhance resilience of small islands to ongoing global change including improving risk knowledge and island resource management while also strengthening socioeconomic 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 as a result of 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, and temporal and spatial extent of the event, as well as on the biophysical nature of the island (Figure 29-1) and its social, economic, and political setting.

29.3.1. Observed Impacts on Island Coasts and Marine Biophysical Systems

29.3.1.1. Sea Level Rise, Inundation, and Shoreline Change

SLR poses one of the most widely recognized climate change threats to low-lying coastal areas (Cazenave and Llovel, 2010; Nicholls and Cazenave, 2010; Church and White, 2011). 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 and 1.7 mm yr^{-1} and since 1993, at a rate between 2.8 and 3.6 mm yr^{-1} (WGI AR5 Table 13.1), and acceleration is detected in longer records since 1870 (Merrifield et al., 2009; Church and White, 2011; see also WGI AR5 Section 13.2.2.1). Rates of SLR, however, are 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; see also Section 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 El Niño-Southern Oscillation (ENSO), which has a strong modulating effect on sea level variability with lower/higher-than-average sea level during El Niño/La Niña events of the order of ±20 to 30 cm (Cazenave and Remy, 2011; Becker et al., 2012). Large interannual variability in sea level has also been demonstrated from the Indian Ocean (e.g., Chagos Archipelago; Dunne et al., 2012) while Palanisamy et al. (2012) found that over the last 60 years the mean rate of SLR in the Caribbean region was similar to the global average of approximately 1.8 mm 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

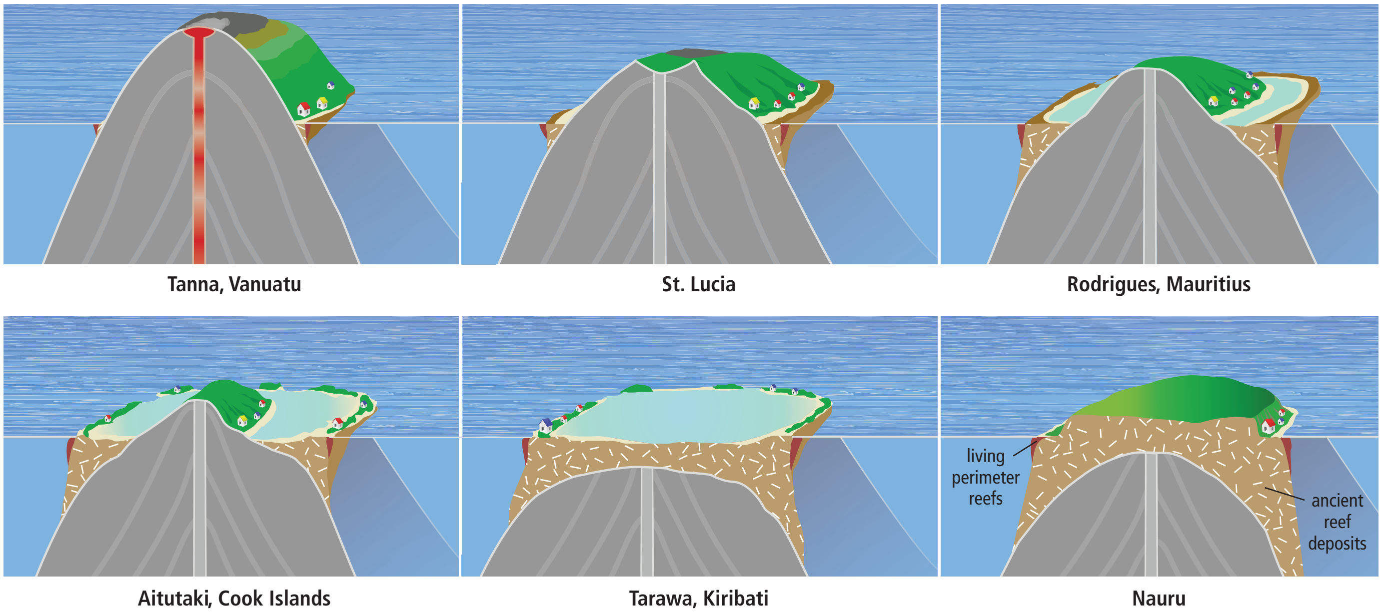

Tanna, Vanuatu
St. Lucia
Rodrigues, Mauritius
Aitutaki, Cook Islands
Tarawa, Kiribati
Nauru

Figure 29-1 | Representative tropical island typologies. From top left: A young, active volcanic island (with altitudinal zonation) and limited living perimeter reefs (red zone at outer reef edge), through to an atoll (center 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.

Frequently Asked Questions

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

In the last 2 or 3 decades many small islands have undergone substantial changes in human settlement patterns and in socioeconomic 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 although 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.

already below high spring tide level. However, rates of relative SLR at Funafuti between 1950 and 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 as a result of increasing inundation of low-lying settlement areas owing to a combination of tectonic subsidence and SLR (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 caused primarily by remotely generated swell waves, and the severity of flooding was greatly increased by anomalously high regional sea levels linked with ENSO and ongoing SLR. 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 to 60 years on 27 central Pacific atoll islands showed that total land area remained relatively stable in 43% of islands, while another 43% 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 4-year study of 17 relatively pristine islands on two other central Pacific atolls in Kiribati by Rankey (2011), who concluded that SLR 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 to 50 years with examples of both erosion and accretion in the 47 atoll islands assessed. SLR 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 and 4%, 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; Novelo-Casanova and Suarez, 2010; Storey and Hunter, 2010) and mask attribution to SLR. A study of Majuro atoll (Marshall Islands) found that erosion was widespread but attribution to SLR was obscured by pervasive anthropogenic impacts to the coastal system (Ford, 2012; see Section 5.4.4). Similarly a study of three islands in the Rosario Archipelago (Colombia) reported shoreline retreat over a 50- to 55-year period and found Grande, Rosario, and Tesoro Islands had lost 6.7, 8.2, and 48.7% of their land area, respectively. Erosion was largely attributed to poor management on densely settled Grande Island, while SLR 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 to 2000. Although 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. Although 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 SLR 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 the well-being of many island communities is linked to their ongoing 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 on which many island communities are dependent for subsistence foods as well as underpinning beach and reef-based tourism and economic activity (Perch-Nielsen, 2010; Bell et al., 2011). The documented sensitivity of coral reef ecosystems to climate change is summarized elsewhere (see Chapter 5; Box CC-CR).

Increased coral bleaching and reduced reef calcification rates due to thermal stress and increasing carbon dioxide (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% coral mortality in the lagoon and 62% 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% of the dominant species affected in some areas (Hardman et al., 2007). Studies of the severe 1998 El Niño bleaching event in the tropical Indian Ocean showed reefs in the Maldives, Seychelles, and Chagos Islands were among the most impacted (Cinner et al., 2012; Tkachenko, 2012). In 2005 a reef survey around Barbados following a Caribbean regional bleaching event revealed the most severe bleaching ever recorded, with approximately 70% of corals impacted (Oxenford et al., 2008). Globally, the incidence and implications of temperature-related coral bleaching in small islands is well documented, and combined with the effects of increasing ocean acidification these stressors could threaten the function and persistence of island coral reef ecosystems (see Chapter 5; Box CC-OA).

Island coral reefs have limited defenses against thermal stress and acidification. However, studies such as Cinner et al. (2012) and Tkachenko (2012) highlight that although 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 to 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°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 well-being and economies of islands (Bell et al., 2011). In Kimbe Bay, Papua New Guinea, 65% of coastal fish are dependent on living reefs at some stage in their life cycle and there is evidence that fish abundance declined following degradation of the reef (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 seagrass environments provide a range of ecosystem goods and services (Waycott et al., 2009; Polidoro et al., 2010) and both habitats play a significant role in the well-being 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).

SLR 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 SLR and the inability of mangroves to tolerate increased water depth at the seaward margin. Elsewhere in the Caribbean and tropical Pacific, observations vary in regard to the potential for sedimentation rates in mangroves forests to keep pace with SLR (Krauss et al., 2003; McKee et al., 2007). 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 yr^{-1} to an accretion surplus of 3.28 mm yr^{-1} relative to the estimated rate of SLR. 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 40 m) 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 seagrasses 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 seagrass 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 the 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 6-year study, seagrass shoot mortality and recruitment rates were negatively influenced by higher temperature (Marbá and Duarte, 2010; see also Section 5.4.2.3 for further discussion of impacts on mangrove and seagrass 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: (1) ecosystem and species horizontal shifts and range decline; (2) altitudinal species range shifts and decline mainly due to temperature increase on high islands; and (3) exotic and pest species range increase and invasions mainly due to temperature increase in high-latitude islands. Owing 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. SLR 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 ha from 1935 to 1991 due to increasing salinization and rising groundwater, with vegetation transitioning to more saline-tolerant species such as mangroves.

Although 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 (Le Roux et al., 2005; Bokhorst et al., 2007, 2008) 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 indicates 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). For instance, in the central mountain ranges of the subtropical island of Taiwan, Province of China, historical survey and resurvey data from 1906 to 2006 showed that the upper altitudinal limits of plant distributions had risen by about 3.6 m yr^{-1} during the last century in parallel with rising temperatures in the region (Jump et al., 2012). 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 1966/1967 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 (Pauli et al., 2007; Chen et al., 2009; Sekercioglu et al., 2008; Krushelnycky et al., 2013). Altitudinal temperature change has also been reported to influence the distribution of 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 such as desalination have had mixed success in small island settings owing to operational costs (White and Falkland, 2010).

Rapidly growing demand, land use change, urbanization, and tourism are already placing significant strain on the limited freshwater reserves in small island environments (Emmanuel and Spence, 2009; Cashman et al., 2010; White and Falkland, 2010). In the Caribbean, where there is considerable variation in the types of freshwater supplies utilized, 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 (White et al., 2007; Moglia et al., 2008a,b).

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 approximately 0.25°C per decade have occurred (Payet and Agricole, 2006). Long-term reduction in streamflow (median reduction of 22 to 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 toward a better understanding the impacts of climate change in small island hydrology and water resources.

There is a paucity of empirical evidence linking saline (seawater) intrusion into fresh groundwater reserves due simply to incremental SLR 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 wash-over can be expected to become more frequent with SLR, 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 upward within the substrate of an island in step with incremental SLR 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

While 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 SLR (Walsh et al., 2012). Population drift from outer islands or from inland, together with rapid population growth in main centers and lack of accommodation space, drives growing populations into ever more vulnerable locations (Connell, 2012). In addition, without adequate resources and planning, engineering solutions such as shoreline reclamation also place communities and infrastructure in positions of increased risk (Yamano et al., 2007; Duvat, 2013).

Many of the environmental issues raised by the media relating to Tuvalu, the Marshall Islands, and Maldives are primarily relevant to the major population center 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 preexisting issues of severe overcrowding, proliferation of informal housing and unplanned settlement, inadequate water supply, poor sanitation and solid waste disposal, pollution, and conflict over land ownership are of concern. They argue that these problems require immediate resolution if the vulnerability of the South Tarawa community to the "real and alarming threat" of climate change is to be managed effectively (Storey and Hunter, 2010).

On Majuro atoll, rapid urban development and the abandonment of traditional settlement patterns has resulted in movement from less vulnerable to more vulnerable locations on the island (Spennemann, 1996). Likewise, geophysical studies of Fongafale Island, the capital of Tuvalu, show that engineering works during World War II, and rapid development and population growth since independence, have 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 owing to the existing multiple lines of stress on the island's biophysical and social systems. However, it is clear that such preexisting 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 centers ("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 Sections 11.3, 11.5, 11.6.1). 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, respectively) 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 Niño 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). Although studies conducted so far in the Pacific have established a direct link only 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; see also Sections 11.2.4-5 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 (Koh et al., 2008; Chadee, 2009; 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 Sea and Pacific and Indian Oceans that freshwater scarcity and 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 (Chan et al., 2011; Rongo and van Woesik, 2011), the Mediterranean (Aligizaki and Nikolaidis, 2008; see also Section 29.5.5), and the Canary Islands in the Atlantic (Pérez-Arellano et al., 2005). A recent Caribbean study sought to characterize the relationship between 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 that 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 (Chaves and Koenraadt, 2010; Béguin et al., 2011). Previous studies have assessed the potential influence of climate change on malaria, using deterministic or statistical models (Martens et al., 1999; Pascual et al., 2006; Hay et al., 2009; Parham and Michael, 2010). Although the present incidence of malaria on small islands is not reported to be high, favorable 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; Figueroa, 2008; Rawlins et al., 2008). In the Caribbean, the occurrence of autochthonous malaria in non-endemic island countries in the last 10 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. Although 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 SLR, on island migration (Mortreux and Barnett, 2009; Lilleør and Van den Broeck, 2011). 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 criticized 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). Although 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 understand better 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

Frequently Asked Questions

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

Adaptation to climate change that involves infrastructural works generally requires 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 socioeconomic 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 gross domestic product, 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 have high transport costs.

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 owing 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 preceding sections has been prepared. Figure 29-2 reflects the degree of confidence in the link between observed changes in several components of the coastal, terrestrial, and human systems of small islands and the drivers of climate change.

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 socioeconomic 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 socioeconomic conditions and governance. There is, however, a problem in generating formal climate scenarios at the scale of small islands because 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, which provides inadequate resolution over the land areas of most small islands. This has recently improved with the new Representative Concentration Pathway (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 data point. The limitation of this approach is the need for observed data ideally for at least 3 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 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 to 25 km^2 (e.g., Charlery and Nurse, 2010; Australian Bureau of Meteorology and CSIRO, 2011a). Even so, most projected changes in climate for the Caribbean Sea, Pacific and Indian Oceans, 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

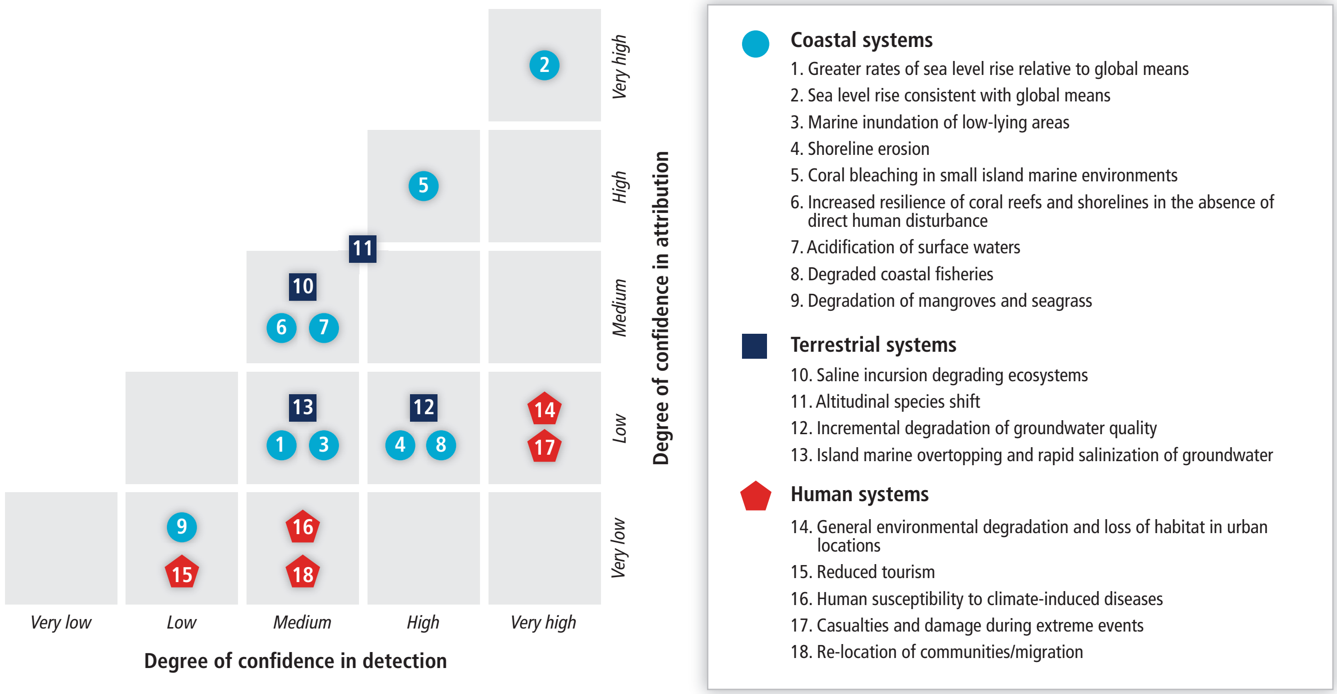


Figure 29-2 | A comparison of the degree of confidence in the detection of observed impacts of climate change on tropical small islands with the degree of confidence in attribution to climate change drivers at this time. For example, the blue symbol No. 2 (Coastal Systems) indicates there is *very high 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 that although confidence in detection of "casualties and damage during extreme events" is *very high*, there is at present *low confidence* in the attribution to climate change. It is important to note that *low confidence* in attribution frequently arises owing to the limited research available on small island environments.

in some physical climate signal from literature review rather than projections based on direct location-specific modeling. Usually this is proposed as a "what if" question that 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 SLR 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 modeling from the Pacific is a case study from Nauru that 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 that arise include water security and potential changes in extreme wet events that 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 proneness to inundation for SLR of 0.5, 1.0, and 1.5 m (Al-Jeneid et al., 2008). Similarly, in the Caribbean the elevation equivalent of a projected SLR of 1 m has been superimposed on topographic maps to estimate that 49 to 60% of tourist resort properties would be at risk of beach erosion damage, 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 more than 12,900 islands and more than 3000 terrestrial vertebrates in the tropical Pacific region for three SLR scenarios. The study estimated that for SLR 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°C to 2.3°C median annual increase in surface temperature in the Caribbean Sea and Indian 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 (WGI AR4 Table 11.1; WGI AR5 Section 14.7.4) and a 3 to 5% increase in the Indian and Pacific Ocean small island regions. Comparative projections for the new RCP4.5 scenario suggests about a 1.2°C 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% in the Caribbean and Mediterranean, respectively, signaling potential future problems for agriculture and water availability compared to a 1 to 9% increase in the Indian 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 subtropical high pressure belts

Table 29-1 | Climate change projections for the intermediate low (500–700 ppm CO_2e) Representative Concentration Pathway 4.5 (RCP4.5) scenario for the main small island regions. The table shows the 25th, 50th (median), and 75th percentiles for surface temperature and precipitation based on averages from 42 Coupled Model Intercomparison Project Phase 5 (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 (°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 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

drier (as reported by WGI AR5) 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 (WGI AR5 Section 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 (WGI AR5 Section 14.7.6). SLR projections in the small islands regions for RCP4.5 are similar to the global projections of 0.41 to 0.71 m (WGI AR5 Section 13.5.1), ranging from 0.5 to 0.6 m by 2100 compared to 1986–2005 in the Caribbean Sea and Pacific and Indian Oceans to 0.4 to 0.5 m in the Mediterranean and north Indian Ocean (Table 29-1).

In the main regions in which most tropical or subtropical 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 Section 6.2.2.4.4). This is because "degree heating months" (DHMs) greater than 2°C per month are the determining threshold for severe coral bleaching (Donner, 2009). For example, in a study of 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 GHGs in the atmosphere could cause more than 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 delay the thermal stress forecast by only 50 to 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-eq. The conclusion based on outputs from a wide range of emissions scenarios and models is that preserving more than 10% of coral reefs worldwide would require limiting warming to less than 1.5°C (1.3°C to 1.8°C Atmosphere-Ocean General Circulation Model (AOGCM) range) compared to pre-industrial levels (Frieler et al., 2013).

Small island economies can also be objectively shown to be at greater risk from SLR in comparison to other geographic areas because 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 SLR in a range of socioeconomic 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 SLR 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 (Providing REgional Climates for Impact Studies) 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°C to 4°C compared to a 1960–1990 baseline, with increasing rainfall during the latter part of the wet season from November to 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 to 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 to 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$ 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 (Commonwealth Scientific and Industrial Research Organisation) 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 (Australian Bureau of Meteorology and CSIRO, 2011b). The temperature projections in this region dominated by oceans seem less than those seen globally, ranging from +1.5 to 2.0°C for the B1 low-emissions scenario to +2.5 to 3.0°C for the A2 high-emissions scenario by the year 2090 relative to a 20-year period centered 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 (Australian Bureau of Meteorology 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 Sections 7.4.2.1 and 30.6.2.1.1. Some of these projected changes may favor the large international fishing fleets that can shift operations over large distances compared to local, artisanal fishers (Polovina 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 upward 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.

Table 29-2 | Summary of projected percentage changes in tropical Pacific tuna catches by 2036 and 2100 relative to 1980–2000 for SRES scenarios A2 and B1, and the estimated resulting percentage change to government revenue (after Tables 12.7 and 12.9 of Bell et al., 2011).

Tuna fishery		**Change in catch (%)**		
		2035: B1/A2	**2100: B1**	**2100: A2**
Skipjack tuna	Western fishery	+11	–0.2	–21
	Eastern fishery	+37	+43	+27
	Total	+19	+12	–7
Bigeye tuna	Western fishery	–2	–12	–34
	Eastern fishery	+3	–4	–18
	Total	+0.3	–9	–27
Country		**Change in government revenue (%)**		
		2035: B1/A2	**2100: B1**	**2100: A2**
Federated States of Micronesia		+1 to +2	0 to +1	–1 to –2
Solomon Islands		0 to +0.2	0 to –0.3	0 to +0.8
Kiribati		+11 to +18	+13 to +21	+7 to +12
Tuvalu		+4 to +9	+4 to +10	+2 to +6

29.4.3. Representative Concentration Pathway Projections and Implications for Small Islands

Utilizing updated historical GHG emissions data the scientific community has produced future projections for four plausible new global RCPs 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 WGI AR5 Annex I: Atlas of Global and Regional Climate Projections.

During negotiations toward a new multilateral 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°C to 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; Figure 29-3) suggest possible 1.2°C to 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 RCP6.0 and steeply for RCP8.5 (Table 29-1).

29.5. Inter- and Intra-regional Transboundary 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 transboundary impacts. Intra-regional transboundary impacts originate from a within-region source (e.g., the Caribbean). Some transboundary processes may have positive effects on the receiving small island or nation, though most that are reported have negative impacts. Deciphering a climate change signal in inter- and intra-regional transboundary impacts on small islands is not easy and usually involves a chain of linkages tracing back from island-impact to a distant climate or climate-related bio-physical or human process. Some examples are given below.

29.5.1. Large Ocean Waves from Distant Sources

Unusually large deep ocean swells, generated from sources in the mid- and high latitudes by extratropical cyclones (ETCs) cause considerable damage on the coasts of small islands thousands of kilometers away in the tropics. Impacts include sea flooding and inundation of settlements, infrastructure, and tourism facilities as well as severe erosion of beaches (see also Section 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 SLR, occurred in the

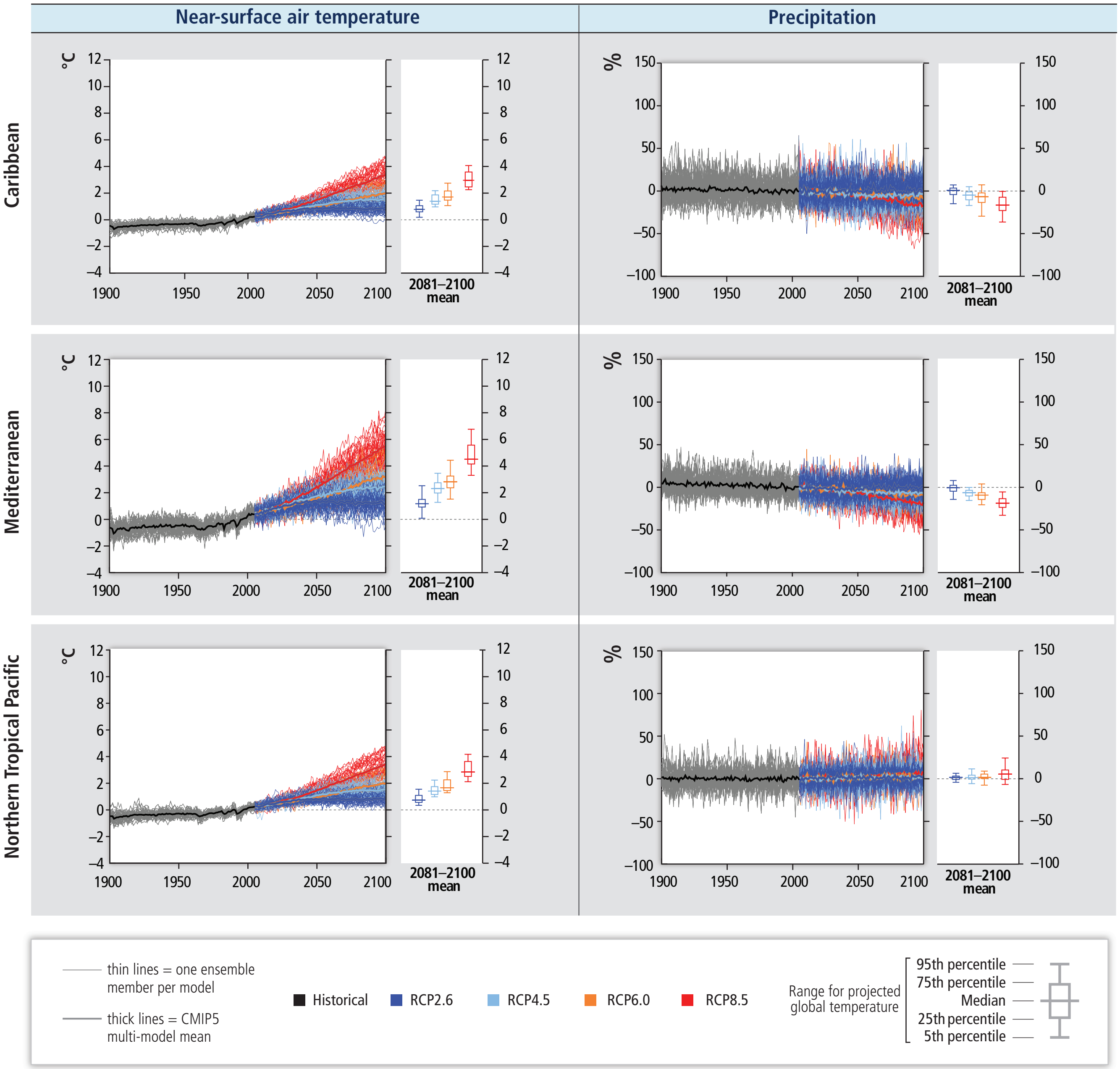
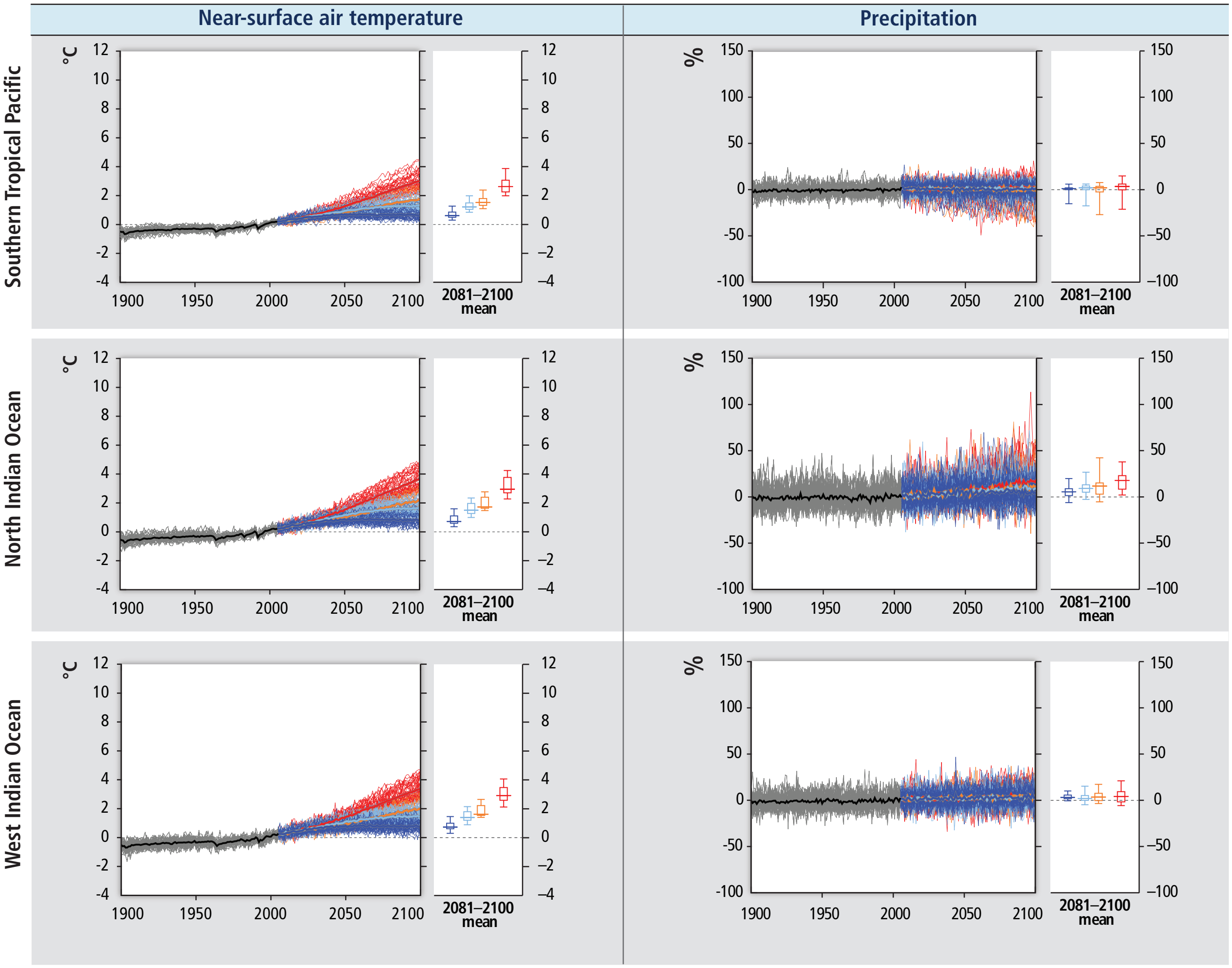


Figure 29-3 | Time series of Representative Concentration Pathway (RCP) scenarios annual projected temperature and precipitation change relative to 1986–2005 for six small islands regions (using regions defined in WGI AR5 Annex 1: Atlas of Global and Regional Climate Projections). Thin lines denote one ensemble member per model, and thick lines the Coupled Model Intercomparison Project Phase 5 (CMIP5) multi-model mean. On the righthand side, the 5th, 25th, 50th (median), 75th, and 95th percentiles of the distribution of 20-year 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.

Continued next page →

Figure 29-3 (continued)



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 defenses, 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 (Maldives 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 (Bush et al., 2009; Cambers, 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 defenses (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 Islands, where there is evidence of damage to coral growth by swell from the north Pacific, especially during years with a strong El Niño signal (Fletcher et al., 2008).

Hoeke et al. (2013) describe inundation from mid- to 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 farthest 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, p. 1095). From the perspective of those islands that suffer damage from this coastal hazard on an annual basis, this is an area that warrants further investigation. 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 northward 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 transboundary processes; locally generated tropical cyclones (TCs) provide examples of intra-regional transboundary processes. Whereas 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).

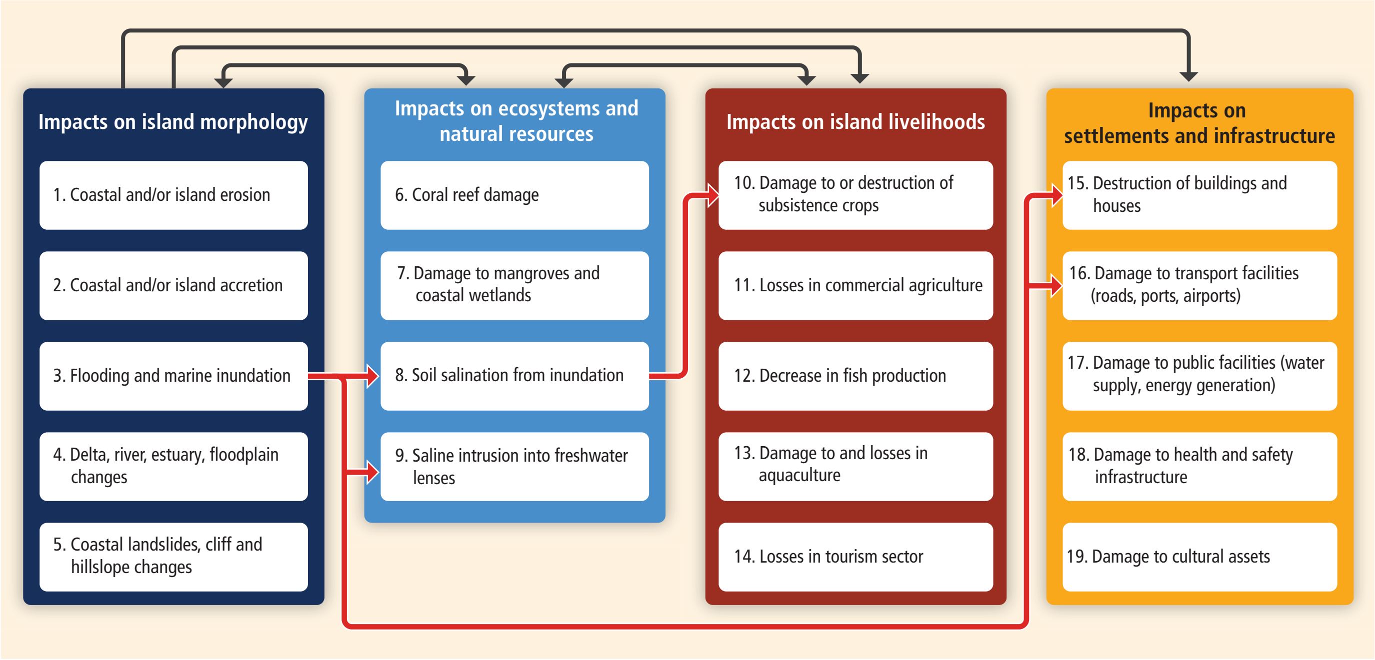


Figure 29-4 | Tropical and extratropical cyclone (ETC) impacts on the coasts of small islands. Four types of impacts are distinguished here, with black arrows showing the connections between them, based on the existing literature. An example of the chain of impacts associated with two ETCs centered to 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) and 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, 1982–1983 (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, 1982–1983 (Dupon, 1987).

Examples of ETC 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. Transcontinental 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; Garrison et al., 2006; Middleton et al., 2008; Monteil, 2008; López-Villarrubia et al., 2010). 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 transboundary 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; Prospero et al., 2008; Monteil and Antoine, 2009) and 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 among climate change, airborne aerosols, and human health in localities such as oceanic islands far distant from the continental source of the particulates.

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

Invasive species are colonizer species that establish populations outside their normal distribution ranges. The spread of invasive alien species is regarded as a significant transboundary 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 (Reaser et al., 2007; Westphal et al., 2008; Kenis et al., 2009; 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).

While 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, p. 2645).

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 (Albins and Hixon, 2008; Schofield, 2010; Green et al., 2011; Lesser and Slattery, 2011). Although there is no evidence that the lionfish invasion is climate-related, the concern is that when combined with preexisting stress factors the natural resilience of Caribbean reef communities will decrease (Green et al., 2012; Albins and Hixon, 2013), 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 Hawaii 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, p. 253).

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 kilometers 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 by more than 93% 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 (Brandt and McManus, 2009; Miller, J. et al., 2009; Rosenberg et al., 2009; Weil and Croquer, 2009; Weil and Rogers, 2011).

29.5.5. Transboundary Movements and Human Health

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

Like other aquatic pathogens, ciguatoxins that cause ciguatera fish poisoning may be readily dispersed by currents across and within boundaries in tropical and subtropical waters. Ciguatoxins are known to be highly temperature-sensitive and may flourish when certain seawater 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 Section 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 SLR, ocean acidification, and salinization 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 analogs of responses to past and present weather extremes and climate variability, or assumed/hypothesized impacts of

Table 29-3 | Types 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 Niño).
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 are 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 freshwater 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 freshwater shortages and drought. Water problems may lead to health hazards.

climate change based on island type (see Table 29-3). Differences in island type and differences in exposure to climate forcing and hazards vary with island form, providing a framework for consideration of vulnerability and adaptation strategies. Place-based understanding of island landscapes and of processes operating on individual islands is critical (Forbes et al., 2013).

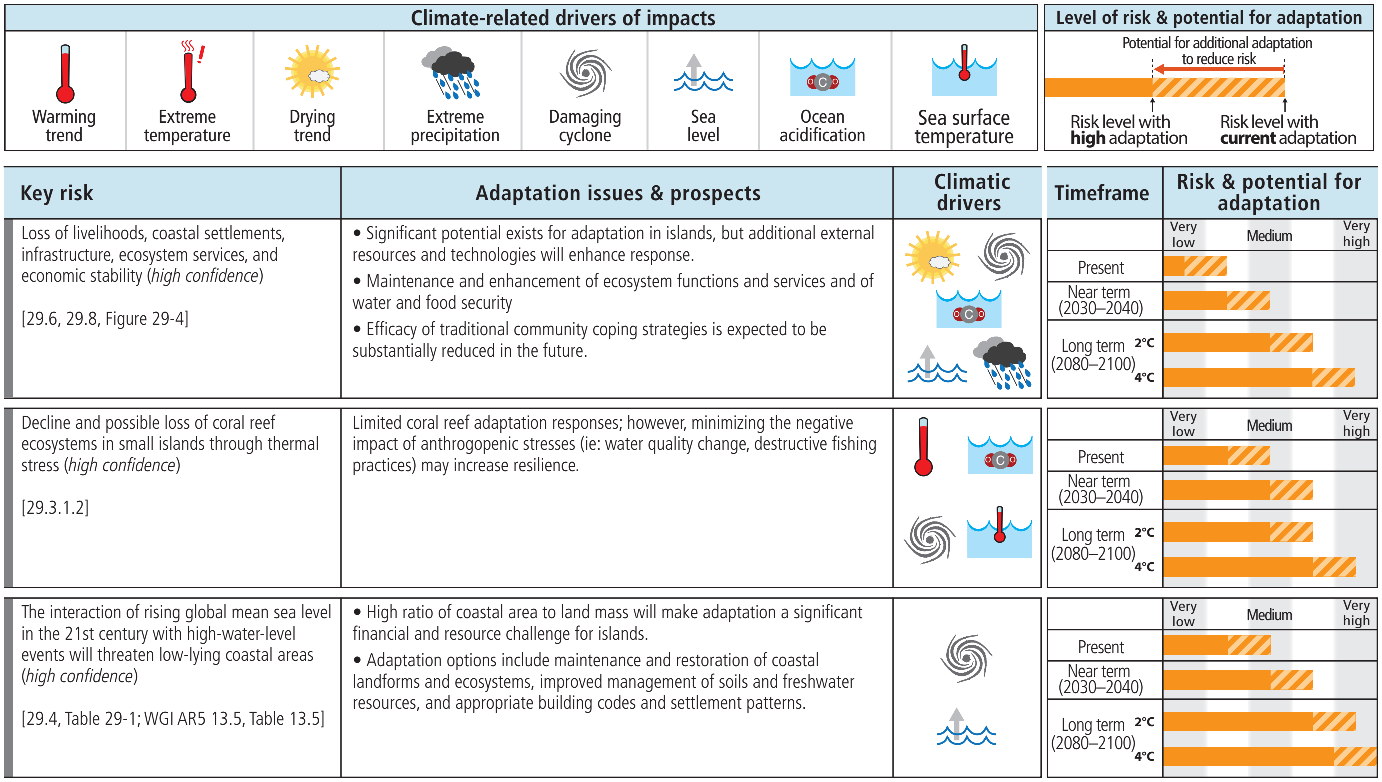
29.6.1. Addressing Current Vulnerabilities on Small Islands

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 owing 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 (Peduzzi et al., 2009; Hughes et al., 2012), use indicators that are not relevant in all islands (Barnett and Campbell, 2010), or use data of limited quality for islands, such as SLR (as used in Wheeler, 2011). As a result indicators of vulnerability for small islands often misrepresent actual vulnerability. Recent moves toward participatory approaches that link scientific knowledge with local visions of vulnerability (see Park et al., 2012) offer 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: physical, socioeconomic, socio-ecological, and climate-induced, whose reinforcing mechanisms are important in determining the magnitude of impacts. Geophysical 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). Socioeconomic vulnerabilities are related to ongoing challenges of managing urbanization, 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). 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 (Kingsford et al., 2009; Caujape-Castells et al., 2010), 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 (Hughes et al., 2003; Maina et al., 2011). Evidence is starting to emerge that shows the same applies at the island scale. In Majuro atoll (Marshall Islands), 34 to 37 years of aerial photography shows that socio-ecological stress is exacerbating shoreline change associated with SLR, especially on the lagoon side of islands (Ford, 2012; see also Section 29.3.1.1). Islands faced with multiple stressors can therefore be assumed to be more at risk from climate impacts.

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 & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation
Loss of livelihoods, coastal settlements, infrastructure, ecosystem services, and economic stability (*high confidence*) [29.6, 29.8, Figure 29-4]	• Significant potential exists for adaptation in islands, but additional external resources and technologies will enhance response. • Maintenance and enhancement of ecosystem functions and services and of water and food security • Efficacy of traditional community coping strategies is expected to be substantially reduced in the future.	Drying trend, Damaging cyclone, Ocean acidification, Sea level, Extreme precipitation	Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	
Decline and possible loss of coral reef ecosystems in small islands through thermal stress (*high confidence*) [29.3.1.2]	Limited coral reef adaptation responses; however, minimizing the negative impact of anthrogopenic stresses (ie: water quality change, destructive fishing practices) may increase resilience.	Warming trend, Ocean acidification, Damaging cyclone, Sea surface temperature	Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	
The interaction of rising global mean sea level in the 21st century with high-water-level events will threaten low-lying coastal areas (*high confidence*) [29.4, Table 29-1; WGI AR5 13.5, Table 13.5]	• High ratio of coastal area to land mass will make adaptation a significant financial and resource challenge for islands. • Adaptation options include maintenance and restoration of coastal landforms and ecosystems, improved management of soils and freshwater resources, and appropriate building codes and settlement patterns.	Damaging cyclone, Sea level	Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	

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, S. et al., 2009) 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 (see Table 29-4).

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 (Adger and Brown, 2009; Kuruppu and Liverman, 2011), 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 (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; and 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 (Myers, 2002; Parks and Roberts, 2006).

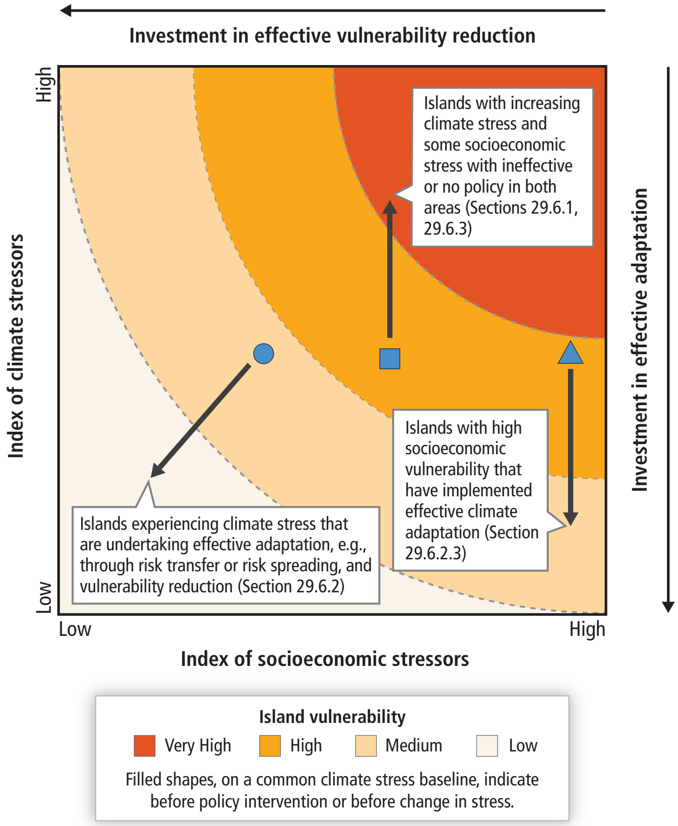


Figure 29-5 | The impact of alternative climate change adaptation actions or policies.

There are many ways in which *in situ* climate adaptation can be undertaken: reducing socioeconomic 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, recognizing the starting point for action is critical to maximizing the benefits from adaptation. The following section considers the benefits of pursuing the various options.

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 minimize specific damage to any one crop; and the growth of robust famine crops, unused in times of plenty that could be used in emergencies (Campbell, 2009). Two discrete studies from Solomon Islands highlight the importance of traditional patterns of social organization within communities to support food security under social and environmental change (Reenberg et al., 2008; Mertz et al., 2010). In both studies the strategy of relying on traditional systems of organization for farming and land use management have been shown to work effectively—largely as there has been little cultural and demographic change. 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 globalization, 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. Although 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 emphasized 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 Section 29.6.2.3); and risk avoidance through structural engineering measures or migration (see Section 29.6.2.4).

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 owing 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 under-supply 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, for example, when rainfall

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 Tables 1.10 and 1.11 of ESCAP and UNISDR, 2010).

Rank	Absolute exposure (millions affected)	Relative exposure (% of population affected)	Absolute GDP loss (US$ billions)	Loss (% of GDP)
1	Japan (30.9)	Northern Mariana Islands (58.2)	Japan (1,226.7)	Northern Mariana Islands (59.4)
2	Philippines (12.1)	Niue (25.4)	Republic 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	Republic 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	Vietnam (0.8)	Vanuatu (18.3)	Northern 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 yellow.

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, for example, through social networks and familial ties (see also Section 29.6.2.3), or ecologically, for example, 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, for example, 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, S. et al., 2009). 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 owing 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 Section 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, for example, 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, as 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 gray 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 preexisting 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 (Tompkins et al., 2008; Schwarz et al., 2011). Where community organizations 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

SLR poses one of the most widely recognized climate change threats to low-lying coastal areas on islands (Section 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 (<10 m) 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 SLR (Loughry and McAdam, 2008; Laczko and Aghazarm, 2009; Yamamoto and Esteban, 2010; Berringer, 2012; Dema, 2012; Gordon-Clark, 2012; Lazrus, 2012). Yet there remains *limited evidence* as to which regions (Caribbean, Pacific and Indian Oceans, West African islands) will experience the largest SLR (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 2.0 m SLR, 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 and Indian and Pacific Oceans. More research is needed to produce *robust agreement* on the impact of SLR 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 island's future (McNamara and Gibson, 2009; McLeman, 2011).

Owing to the high costs of adapting on islands, it has been suggested that there will be a need for migration (Biermann and Boas, 2010; Gemenne, 2011; Nicholls et al., 2011; Voccia 2012). Relocation and displacement are frequently cited as outcomes of SLR, salinization, and land loss on islands (Byravan and Rajan, 2006; Kolmannskog and Trebbi, 2010; see also Section 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 (Connell and Lea, 2002; Jones, 2005). 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 analogs 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 Section 29.5.1.1) islanders sought refuge on neighboring 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 (Krishnamurthy, 2012; Afifi et al., 2013). Although 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 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; 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) recognized that more diversified economies have more robust responses to climate stress, yet most small islands lack economies of scale in production, thus specializing in niche markets and developing monocultures (e.g., sugar or bananas). Non-sovereign island states face additional exogenous barriers to adaptation. For example, islands such as 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 ongoing 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, 13 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).

Although 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 (owing 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,b). 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; Gero et al., 2011; Kuruppu and Liverman, 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, e.g., 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. Although the potential to deliver such an integrated approach may be reasonably strong in urban centers 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

GHG 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 GHG emissions because of the cost and the potential co-benefits and synergies. Malta and Cyprus are obliged to do so in line with EU climate and energy policies. This section considers some of the interlinkages 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 interlinkages 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 geophysical 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 Section 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 (IPCC, 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 (Birkmann, 2011; Nelson, 2011). Nicholls et al. (2011) make a similar observation with respect to coastal protection as a response to SLR. They suggest that if global mean temperatures increase by around 4°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

IPCC (2007) suggest that adaptation and mitigation interactions occur in one of four main ways: adaptations that result in GHG 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, seagrasses, 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). Although 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 (Chen et al., 2007; Praene et al., 2012). 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 USA 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, e.g., 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 toward 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. While 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 because of 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). Realizing 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 small island developing states 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 small island developing states, 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. Recognizing 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 reuse 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 GHG 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

Although there is a clear consensus that adaptation to the risks posed by global climate change is necessary and urgent in small islands, the implementation of specific strategies and options is a complex process that requires critical evaluation of multiple factors, if expected outcomes are to be achieved (Kelman and West, 2009; Barnett and O'Neill, 2012). These considerations may include, *inter alia*, prior experience with similar or related threats, efficacy of the strategies or options and their co-benefits, costs (monetary and non-monetary), availability of alternatives, and social acceptability. In addition, previous work (e.g., Adger et al., 2005) has emphasized the relevance of scale as a critical factor when assessing the efficacy and value of adaptation strategies, as the extent to which an option is perceived to be a success, failure, or maladaptive may be conditioned by whether it is being assessed as a response to climate variability (shorter term) or climate change (longer term).

As in other regions, adaptation in islands is locally delivered and context specific (Tompkins et al., 2010). Yet, sectors and communities on small islands are often so intricately linked that there are many potential pathways that may lead to maladaptation, be it via increased GHG 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 GHG 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

Frequently Asked Questions

FAQ 29.3 | Is it appropriate to transfer adaptation and mitigation strategies between and within small island countries and regions?

Although 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.

in Australia after the collapse of phosphate mining (their only revenue source) in the 1950s, provides helpful insight into 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; see also Section 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, although insurance is being promoted as an element of the overall climate change response strategy in some island regions, for example, 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, for example, development in hazard-prone areas (Herweijer et al., 2009; Linnerooth-Bayer et al., 2011; Thomas and Leichenko, 2011; van Nostrand and Nevius, 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 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 (van Aalst et al., 2008; López-Marrero, 2010). Further, some analysts argue that adaptation choices are often subjective in nature and suggest that participatory stakeholder involvement can yield valuable information about the priorities and expectations that communities attach to the sector for which adaptation is being sought.

The point is underscored by Moreno and Becken (2009), whose study of the tourism sector on the Mamanuca islands (Fiji) clearly demonstrates that approaches that 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, and adoption of adaptive management approaches, combined with reduction of GHG 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 increase existing operational costs only 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 (Nunn, 2009; Barnett, 2010). 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; Campbell and Beckford, 2009; Kelman and West, 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 transboundary 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 socioeconomic scenarios and data at the required scale for small islands**. Although some advances have been made (Taylor et al., 2007; Australian Bureau of Meteorology and CSIRO, 2011a,b), much of the work in the

Caribbean, Pacific and Indian Oceans, and Mediterranean islands is focused at the regional scale rather than being country specific. Because most socioeconomic decisions are taken at the local level, there is a need for a more extensive database of simulations of future small island climates and socioeconomic 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. Although 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 transboundary processes are also significant in a small island context. Although some such work has been undertaken for some parts of the Pacific (Australian Bureau of Meteorology and CSIRO, 2011a,b), 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, transfer of 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 and -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 center 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 are poorly known and further research is required to identify such costs, and to determine the economic and societal costs of climate change impacts and the costs of adaptation options to minimize those impacts.

The foregoing list is a sample of the gaps, needs, and research agenda that urgently need to be filled for small islands. Although 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.

References

ADB, 2009: *Natural Catastrophe Risk Insurance Mechanisms for Asia and the Pacific.* Asian Development Bank (ADB), Manila, Philippines, 67 pp.

Adger, W.N. and K. Brown, 2009: Vulnerability and resilience to environmental change: ecological and social perspectives. In: *A Companion to Environmental Geography* [Castree, N., D. Demeritt, D. Liverman, and B. Rhoads (eds.)]. Blackwell Publishing Ltd., Chichester, UK, pp. 109-122.

Adger, W., N. Arnell, and E. Tompkins, 2005: Successful adaptation to climate change across scales. *Global Environmental Change*, **5(2)**, 77-86.

Adger, W., S. Dessai, M. Goulden, M. Hulme, I. Lorenzoni, D. Nelson, L. Naess, J. Wolf, and A. Wreford, 2009: Are there social limits to adaptation to climate change? *Climatic Change*, **93(3)**, 335-354.

Afifi, T., K. Warner, and T. Rosenfeld, 2013: Environmentally induced migration, theoretical and methodological research challenges. In: *The Encyclopedia of Global Human Migration* [Ness, I. (ed.)]. Wiley-Blackwell Publishing Ltd., Chichester, UK, doi:10.1002/9781444351071.wbeghm197.

Agrawala, S. and M. van Aalst, 2008: Adapting development cooperation to adapt to climate change. *Climate Policy*, **8(2)**, 183-193.

Akerlof, K., R. DeBono, P. Berry, A. Leiserowitz, C. Roser-Renouf, K.-L. Clarke, A. Rogaeva, M.C. Nisbet, M.R. Weathers, and E.W. Maibach, 2010: Public perceptions of climate change as a human health risk: surveys of the United States, Canada and Malta. *International Journal of Environmental Research and Public Health*, **7(6)**, 2559-2606.

Albins, M.A. and M.A. Hixon, 2008: Invasive Indo-Pacific lionfish *Pterois volitans* reduce recruitment of Atlantic coral-reef fishes. *Marine Ecology Progress Series*, **367**, 233-238.

Albins, M.A. and M.A. Hixon, 2013: Worst case scenario: potential long-term effects of invasive predatory lionfish (*Pterois volitans*) on Atlantic and Caribbean coral-reef communities. *Environmental Biology of Fishes*, **96(10-11)**, 1151-1157.

Aligizaki, K. and G. Nikolaidis, 2008: Morphological identification of two tropical dinoflagellates of the genera *Gambierdiscus* and *Sinophysis* in the Mediterranean Sea. *Journal of Biological Research-Thessaloniki*, **9**, 75-82.

Al-Jeneid, S., M. Bahnassy, S. Nasr, and M. El Raey, 2008: Vulnerability assessment and adaptation to the impacts of sea level rise on the Kingdom of Bahrain. *Mitigation and Adaptation Strategies for Global Change*, **13(1)**, 87-104.

Alling, A., O. Doherty, H. Logan, L. Feldman, and P. Dustan, 2007: Catastrophic coral mortality in the remote Central Pacific Ocean: Kiribati, Phoenix Islands. *Atoll Research Bulletin*, **551**, 1-19.

Anagnostou, C., P. Antoniou, and G. Hatiris, 2011: Erosion of a depositional coast in NE Rhodos Island (SE Greece) and assessment of the best available measures for coast protection. (Proceedings, 11th International Coastal Symposium, May 9-14, 2011, Szczecin, Poland.) *Journal of Coastal Research*, **(64 SI)**, 1316-1319.

Anderson, M.G., E. Holcombe, J.R. Blake, F. Ghesquire, N. Holm-Nielsen, and T. Fisseha, 2011: Reducing landslide risk in communities: evidence from the Eastern Caribbean. *Applied Geography*, **31(2)**, 590-599.

Angelo, C.L. and C.C. Daehler, 2013: Upward expansion of fire-adapted grasses along a warming tropical elevation gradient. *Ecography*, **36(5)**, 551-559.

Angelucci, F. and P. Conforti, 2010: Risk management and finance along value chains of Small Island Developing States. Evidence from the Caribbean and the Pacific. *Food Policy*, **35(6)**, 565-575.

Anthoff, D., R.J. Nicholls, and R.S.J. Tol, 2010: The economic impact of substantial sea-level rise. *Mitigation and Adaptation Strategies for Global Change*, **15(4)**, 321-335.

Atkinson, C.T. and D.A. LaPointe, 2009: Introduced avian diseases, climate change, and the future of Hawaiian honeycreepers. *Journal of Avian Medicine and Surgery*, **23(1)**, 53-63.

Audefroy, J.F., 2011: Haiti: post-earthquake lessons learned from traditional construction. *Environment and Urbanization*, **23(2)**, 447-462.

Australian Bureau of Meteorology and CSIRO, 2011a: *Climate Change in the Pacific: Scientific Assessment and New Research. Volume 1: Regional Overview*. The Pacific Climate Change Science Program (PCCSP), a key activity under the Australian government's International Climate Change Adaptation Initiative (ICCAI), funded by AusAID, managed by the Australian Department of the Environment (DOE) and delivered by a partnership between the Australian Bureau of Meteorology (BOM) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO), PCCSP, Aspendale, VIC, Australia, 257 pp.

Australian Bureau of Meteorology and CSIRO, 2011b: *Climate Change in the Pacific: Scientific Assessment and New Research. Volume 2: Country Reports Overview*. The Pacific Climate Change Science Program (PCCSP), a key activity under the Australian government's International Climate Change Adaptation Initiative (ICCAI), funded by AusAID, managed by the Australian Department of the Environment (DOE) and delivered by a partnership between the Australian Bureau of Meteorology (BOM) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO), PCCSP, Aspendale, VIC, Australia, 273 pp.

Baider, C. and F.B.V. Florens, 2011: Control of invasive alien weeds averts imminent plant extinction. *Biological Invasions*, **13(12)**, 2641-2646.

Baker, J.L., 2012: *Climate Change, Disaster Risk, and the Urban Poor: Cities Building Resilience for a Changing World.* Urban Development Series, The International Bank for Reconstruction and Development / The World Bank, World Bank Publications, Washington, DC, USA, 297 pp.

Ballu, V., M.-N. Bouin, P. Siméoni, W.C. Crawford, S. Calmant, J.-M. Boré, T. Kanas, and B. Pelletier, 2011: Comparing the role of absolute sea-level rise and vertical tectonic motions in coastal flooding, Torres Islands (Vanuatu). *Proceedings of the National Academy of Sciences of the United States of America*, **108(32)**, 13019-13022.

Banuri, T., 2009: Climate change and sustainable development. *Natural Resources Forum*, **33(4)**, 257-258.

Barnett, J., 2001: Adapting to climate change in Pacific Island Countries: the problem of uncertainty. *World Development*, **29(6)**, 977-993.

Barnett, J., 2010: Climate change science and policy, as if people mattered. In: *Climate Change, Ethics and Human Security* [O'Brien, K., A.L. St. Clair, and B. Kristoffersen (eds.)]. Cambridge University Press, Cambridge, UK, pp. 47-62.

Barnett, J., 2011: Dangerous climate change in the Pacific Islands: food production and food security. *Regional Environmental Change*, **11(1)**, 229-237.

Barnett, J. and J. Campbell, 2010: *Climate Change and Small Island States: Power, Knowledge and the South Pacific.* Earthscan Ltd., London, UK and Washington, DC, USA, 218 pp.

Barnett, J. and N. Chamberlain, 2010: Migration as climate change adaptation: implications for the Pacific. In: *Climate Change and Migration, South Pacific Perspectives* [Burson, B. (ed.)]. Institute of Policy Studies, Victoria University of Wellington, Wellington, New Zealand, pp. 51-60.

Barnett, J. and S.J. O'Neill, 2012: Islands, resettlement and adaptation. *Nature Climate Change*, **2**, 8-10.

Barnett, J. and M. Webber, 2010: *Accommodating Migration to Promote Adaptation to Climate Change.* Policy Research Working Paper No. 5270, Background Paper prepared for the Secretariat of the Swedish Commission on Climate Change and Development and the World Bank World Development Report 2010: Development and Climate Change, The International Bank for Reconstruction and Development / The World Bank, Development Economics Vice Presidency, Washington, DC, USA, 62 pp.

Barnett, J., S. Lambert, and I. Fry, 2008: The hazards of indicators: insights from the environmental vulnerability index. *Annals of the Association of American Geographers*, **98(1)**, 102-119.

Bassiouni, M. and D.S. Oki, 2013: Trends and shifts in streamflow in Hawai'i, 1913-2008. *Hydrological Processes*, **27(10)**, 1484-1500.

Bazilian, M., H. Rogner, M. Howells, S. Hermann, D. Arent, D. Gielen, P. Steduto, A. Mueller, P. Komor, R.S.J. Tol, and K.K. Yumkella, 2011: Considering the energy, water and food nexus: towards an integrated modelling approach. *Energy Policy*, **39(12)**, 7896-7906.

Becker, M., B. Meyssignac, C. Letetrel, W. Llovel, A. Cazenave, and T. Delcroix, 2012: Sea level variations at tropical Pacific islands since 1950. *Global and Planetary Change*, **80-81**, 85-98.

Bedford, R. and C. Bedford, 2010: International migration and climate change: a post-Copenhagen perspective on options for Kiribati and Tuvalu. In: *Climate Change and Migration: South Pacific Perspectives* [Burson, B. (ed.)]. Institute of Policy Studies, Victoria University of Wellington, Wellington, New Zealand, pp. 89-134.

Béguin, A., S. Hales, J. Rocklöv, C. Åström, V.R. Louis, and R. Sauerborn, 2011: The opposing effects of climate change and socio-economic development on the global distribution of malaria. *Global Environmental Change*, **21(4)**, 1209-1214.

Bell, J.D., J.E. Johnson, and A.J. Hobday (eds.), 2011: *Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change.* Secretariat of the Pacific Community, Noumea, New Caledonia, 925 pp.

Bell, J.D., C. Reid, M.J. Batty, P. Lehodey, L. Rodwell, A.J. Hobday, J.E. Johnson, and A. Demmke, 2013: Effects of climate change on oceanic fisheries in the tropical Pacific: implications for economic development and food security. *Climatic Change*, **119(1)**, 199-212.

Benning, T.L., D. LaPointe, C.T. Atkinson, and P.M. Vitousek, 2002: Interactions of climate change with biological invasions and land use in the Hawaiian Islands: modeling the fate of endemic birds using a geographic information system. *Proceedings of the National Academy of Sciences of the United States of America*, **99(22)**, 14246-14249.

Berringer, A.C.S., 2012: Climate change and emigration: comparing "sinking islands" and Jamaica. *Miradas en Movimiento*, **SI:** Naturally Immigrants, January 2012, 106-120.

Biermann, F. and I. Boas, 2010: Preparing for a warmer world: towards a global governance system to protect climate refugees. *Global Environmental Politics*, **10(1)**, 60-88.

Bijlsma, L., C.N. Ehler, R.J.T. Klein, S.M. Kulshrestha, R.F. McLean, N. Mimura, R.J. Nicholls, L.A. Nurse, H. Perez Nieto, E.Z. Stakhiv, R.K. Turner, and R.A. Warrick, 1996: Coastal zones and small islands. In: *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change* [Watson, R.T., M.C. Zinyowera, and R.H. Moss (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 289-324.

Birkmann, J., 2011: First- and second-order adaptation to natural hazards and extreme events in the context of climate change. *Natural Hazards*, **58(2)**, 811-840.

Bishop, M.L., 2012: The political economy of small states: enduring vulnerability? *Review of International Political Economy*, **19(5)**, 942-960.

Black, R., W.N. Adger, N.W. Arnell, S. Dercon, A. Geddes, and D. Thomas, 2011: The effect of environmental change on human migration. *Global Environmental Change*, **21(1 Suppl.)**, S3-S11.

Blackburn, T.M., P. Cassey, R.P. Duncan, K.L. Evans, and K.J. Gaston, 2004: Avian extinction and mammalian introductions on oceanic islands. *Science*, **305(5692)**, 1955-1958.

Blancard, S. and J. Hoarau, 2013: A new sustainable human development indicator for small island developing states: a reappraisal from data envelopment analysis. *Economic Modelling*, **30**, 623-635.

Bokhorst, S., A. Huiskes, P. Convey, and R. Aerts, 2007: The effect of environmental change on vascular plant and cryptogam communities from the Falkland Islands and the Maritime Antarctic. *BMC Ecology*, **7(1)**, 15, doi:10.1186/1472-6785-7-15.

Bokhorst, S., A. Huiskes, P. Convey, P.M. van Bodegom, and R. Aerts, 2008: Climate change effects on soil arthropod communities from the Falkland Islands and the Maritime Antarctic. *Soil Biology and Biochemistry*, **40(7)**, 1547-1556.

Boyd, E., N. Grist, S. Juhola, and V. Nelson, 2009: Exploring development futures in a changing climate: frontiers for development policy and practice. *Development Policy Review*, **27(6)**, 659-674.

Brandt, M.E. and J.W. McManus, 2009: Disease incidence is related to bleaching extent in reef-building corals. *Ecology*, **90(10)**, 2859-2867.

Breckwoldt, A. and H. Seidel, 2012: The need to know what to manage – community-based marine resource monitoring in Fiji. *Current Opinion in Environmental Sustainability*, **4(3)**, 331-337.

Bridges, K.W. and W.C. McClatchey, 2009: Living on the margin: ethnoecological insights from Marshall Islanders at Rongelap atoll. *Global Environmental Change*, **19(2)**, 140-146.

Briguglio, L., G. Cordina, N. Farrugia, and S. Vella, 2009: Economic vulnerability and resilience: concepts, measurements. *Oxford Development Studies*, **37(3)**, 229-247.

Brown, J.N., J.R. Brown, C. Langlais, R. Colman, J. Risbey, B.F. Murphy, A. Moise, A.S. Gupta, I. Smith, and L. Wilson, 2013a: Exploring qualitative regional climate projections: a case study for Nauru. *Climate Research*, **58(2)**, 165-182.

Brown, J.N., A.S. Gupta, J.R. Brown, L.C. Muir, J.S. Risbey, P. Whetton, X. Zhang, A. Ganachaud, B. Murphy, and S.E. Wijffels, 2013b: Implications of CMIP3 model biases and uncertainties for climate projections in the western tropical Pacific. *Climatic Change*, **119(1)**, 147-161.

Bunce, M., L. Mee, L.D. Rodwell, and R. Gibb, 2009: Collapse and recovery in a remote small island – a tale of adaptive cycles or downward spirals? *Global Environmental Change*, **19(2)**, 213-226.

Bush, D.M., W.J. Neal, and C.W. Jackson, 2009: Summary of Puerto Rico's vulnerability to coastal hazards: risk, mitigation, and management with examples. *Geological Society of America Special Papers*, **460**, 149-165.

Buzinde, C.N., D. Manuel-Navarrete, E.E. Yoo, and D. Morais, 2010: Tourists' perceptions in a climate of change: eroding destinations. *Annals of Tourism Research*, **37(2)**, 333-354.

Byravan, S. and S.C. Rajan, 2006: Providing new homes for climate change exiles. *Climate Policy*, **6(2)**, 247-252.

Cahoon, D.R., P. Hensel, J. Rybczyk, K.L. McKee, C.E. Proffitt, and B.C. Perez, 2003: Mass tree mortality leads to mangrove peat collapse at Bay Islands, Honduras after Hurricane Mitch. *Journal of Ecology*, **91(6)**, 1093-1105.

Calado, H., P. Borges, M. Phillips, K. Ng, and F. Alves, 2011: The Azores archipelago, Portugal: improved understanding of small island coastal hazards and mitigation measures. *Natural Hazards*, **58(1)**, 427-444.

Cambers, G., 2009: Caribbean beach changes and climate change adaptation. *Aquatic Ecosystem Health and Management*, **12(2)**, 168-176.

Campbell, D. and C. Beckford, 2009: Negotiating uncertainty: Jamaican small farmers' adaptation and coping strategies, before and after hurricanes – a case study of Hurricane Dean. *Sustainability*, **1(4)**, 1366-1387.

Campbell, J.D., M.A. Taylor, T.S. Stephenson, R.A. Watson, and F.S. Whyte, 2011: Future climate of the Caribbean from a regional climate model. *International Journal of Climatology*, **31(12)**, 1866-1878.

Campbell, J., 2009: Islandness: vulnerability and resilience in Oceania. *Shima: The International Journal of Research into Island Cultures*, **3(1)**, 85-97.

Campbell, J., 2010: Climate change and population movement in Pacific Island Countries. In: *Climate Change and Migration: South Pacific Perspectives* [Burson, B. (ed.)]. Institute of Policy Studies, Victoria University of Wellington, Wellington, New Zealand, pp. 29-50.

Campbell, J.R., M. Goldsmith, and K. Koshy, 2005: *Community Relocation as an Option for Adaptation to the Effects of Climate Change and Climate Variability in Pacific Island Countries (PICs).* Asia-Pacific Network for Global Change Research, Kobe, Japan, 61 pp.

Campbell, S.J., L.J. McKenzie, and S.P. Kerville, 2006: Photosynthetic responses of seven tropical seagrasses to elevated seawater temperature. *Journal of Experimental Marine Biology and Ecology*, **330(2)**, 455-468.

Cantin, N.E., A.N. Cohen, K.B. Karnauskas, A.N. Tarrant, and D.C. McCorkle, 2010: Ocean warming slows coral growth in the central Red Sea. *Science*, **329(5989)**, 322-325.

Cardona, O.D., 2007: *Indicators of Disaster Risk and Risk Management: Program for Latin American and the Caribbean – Summary Report.* Sustainable Development Department, Environment Division, Inter-American Development Bank, Washington, DC, USA, 44 pp.

Carilli, J.E., R.D. Norris, B. Black, S.M. Walsh, and M. McField, 2010: Century-scale records of coral growth rates indicate that local stressors reduce coral thermal tolerance threshold. *Global Change Biology*, **16(4)**, 1247-1257.

Carpenter, R.C. and P.J. Edmunds, 2006: Local and regional scale recovery of *Diadema* promotes recruitment of scleractinian corals. *Ecology Letters*, **9(3)**, 268-277.

Cashman, A., L. Nurse, and J. Charlery, 2010: Climate change in the Caribbean: the water management implications. *Journal of Environment and Development*, **19(1)**, 42-67.

Caujape-Castells, J., A. Tye, D.J. Crawford, A. Santos-Guerra, A. Sakai, K. Beaver, W. Lobin, F. Vincent Florens, M. Moura, and R. Jardim, 2010: Conservation of oceanic island floras: present and future global challenges. *Perspectives in Plant Ecology, Evolution and Systematics*, **12(2)**, 107-129.

Cazenave, A. and W. Llovel, 2010: Contemporary sea level rise. *Annual Review of Marine Science*, **2**, 145-173.

Cazenave, A. and F. Remy, 2011: Sea level and climate: measurements and causes of changes. *Wiley Interdisciplinary Reviews: Climate Change*, **2(5)**, 647-662.

CCRIF, 2008: *The Caribbean Catastrophe Risk Insurance Facility Annual Report 2007-2008.* The Caribbean Catastrophe Risk Insurance Facility (CCRIF), George Town, Grand Cayman, Cayman Islands, 34 pp.

Cervino, J.M., F.L. Thompson, B. Gomez-Gil, E.A. Lorence, T.J. Goreau, R.L. Hayes, K.B. Winiarski-Cervino, G.W. Smith, K. Hughen, and E. Bartels, 2008: The *Vibrio* core group induces yellow band disease in Caribbean and Indo-Pacific reef-building corals. *Journal of Applied Microbiology*, **105(5)**, 1658-1671.

Chadee, D.D., 2009: Dengue cases and *Aedes aegypti* indices in Trinidad, West Indies. *Acta Tropica*, **112(2)**, 174-180.

Chadee, D., B. Shivnauth, S. Rawlins, and A. Chen, 2007: Climate, mosquito indices and the epidemiology of dengue fever in Trinidad (2002-2004). *Annals of Tropical Medicine and Parasitology*, **101(1)**, 69-77.

Chan, W.H., Y.L. Mak, J.J. Wu, L. Jin, W.H. Sit, J.C.W. Lam, Y. Sadovy de Mitcheson, L.L. Chan, P.K.S. Lam, and M.B. Murphy, 2011: Spatial distribution of ciguateric fish in the Republic of Kiribati. *Chemosphere*, **84(1)**, 117-123.

Charlery, J. and L. Nurse, 2010: Areal downscaling of global climate models: an approach that avoids data remodelling. *Climate Research*, **43(3)**, 241-249.

Chaves, L.F. and J.M. Koenraadt, 2010: Climate change and highland malaria: fresh air in a hot debate. *The Quarterly Review of Biology*, **85(1)**, 27-55.

Chen, F., N. Duic, L.M. Alves, and M.d.G. Carvalho, 2007: Renewislands – Renewable energy solutions for islands. *Renewable and Sustainable Energy Reviews*, **8(11)**, 1888-1902.

Chen, I., H.J. Shiu, S. Benedick, J.D. Holloway, V.K. Chey, H.S. Barlow, J.K. Hill, and C.D. Thomas, 2009: Elevation increases in moth assemblages over 42 years on a tropical mountain. *Proceedings of the National Academy of Sciences of the United States of America*, **106(5)**, 1479-1483.

Christenhusz, M.J.M. and T.K. Toivonen, 2008: Giants invading the tropics: the oriental vessel fern, *Angiopteris evecta*. *Biological Invasions*, **10(8)**, 1215-1228.

Church, J.A. and N.J. White, 2011: Sea-level rise from the late 19th to the early 21st century. *Surveys in Geophysics*, **32(4-5)**, 585-602.

Cinner, J.E., T.R. McClanahan, N.A.J. Graham, T.M. Daw, J. Maina, S.M. Stead, A. Wamukota, K. Brown, and Ö. Bodin, 2012: Vulnerability of coastal communities to key impacts of climate change on coral reef fisheries. *Global Environmental Change*, **22(1)**, 12-20.

Cochard, R., S.L. Ranamukhaarachchi, G.P. Shivakoti, O.V. Shipin, P.J. Edwards, and K.T. Seeland, 2008: The 2004 tsunami in Aceh and Southern Thailand: a review on coastal ecosystems, wave hazards and vulnerability. *Perspectives in Plant Ecology Evolution and Systematics*, **10(1)**, 3-40.

Connell, J., 2012: Population resettlement in the Pacific: lessons from a hazardous history? *Australian Geographer*, **43(2)**, 127-142.

Connell, J. and J.P. Lea, 2002: *Urbanisation in the Island Pacific: Towards Sustainable Development.* Routledge, London, UK and New York, NY, USA, 240 pp.

Cooper, A., D. Jackson, and S. Gore, 2013: A groundswell event on the coast of the British Virgin Islands: variability in morphological impact. (Proceedings, 12th International Coastal Symposium, Plymouth, England.) *Journal of Coastal Research*, **(65 SI)**, 696-701.

Coutinho, R., J. Pacheco, N. Wallenstein, A. Pimentel, R. Marques, and R. Silva, 2009: Integrating geological knowledge in planning methods for small islands coastal plans. (Proceedings, 10th International Coastal Symposium, Lisbon, Portugal.) *Journal of Coastal Research*, **(56 SI)**, 1199-1203.

Cronk, Q., 1997: Islands: stability, diversity, conservation. *Biodiversity & Conservation*, **6(3)**, 477-493.

Crump, J., 2008: Snow, sand, ice and sun: climate change and equity in the Arctic and Small Island Developing States. *Sustainable Development Law and Policy*, **8(3)**, 8-13.

Cruz, M., R. Aguiar, A. Correia, T. Tavares, J. Pereira, and F. Santos, 2009: Impacts of climate change on the terrestrial ecosystems of Madeira. *International Journal of Design and Nature and Ecodynamics*, **4(4)**, 413-422.

Cummins, J.D. and O. Mahul, 2009: *Catastrophe Risk Financing in Developing Countries: Principles for Public Intervention.* The International Bank for Reconstruction and Development / The World Bank, World Bank Publications, Washington, DC, USA, 268 pp.

Danovaro, R., S.F. Umani, and A. Pusceddu, 2009: Climate Change and the potential spreading of marine mucilage and microbial pathogens in the Mediterranean Sea. *PLoS ONE*, **4(9)**, e7006, doi:10.1371/journal.pone.0007006.

Dawson, J.L. and S.G. Smithers, 2010: Shoreline and beach volume change between 1967 and 2007 at Raine Island, Great Barrier Reef, Australia. *Global and Planetary Change*, **72(3)**, 141-154.

de Haas, H., 2011: Mediterranean migration futures: patterns, drivers and scenarios. *Global Environmental Change*, **21(1 Suppl.)**, S59-S69.

de Scally, F.A., 2008: Historical tropical cyclone activity and impacts in the Cook Islands. *Pacific Science*, **62(4)**, 443-459.

De'ath, G., J.M. Lough, and K.C. Fabricius, 2009: Declining coral calcification on the Great Barrier Reef. *Science*, **323(5910)**, 116-119.

Dema, B., 2012: Sea level rise and the freely associated states: addressing environmental migration under the compacts of free association. *Columbia Journal of Environmental Law*, **37(1)**, 177-204.

Didham, R.K., J.M. Tylianakis, M.A. Hutchison, R.M. Ewers, and N.J. Gemmell, 2005: Are invasive species the drivers of ecological change? *Trends in Ecology and Evolution*, **20(9)**, 470-474.

Donelson, J.M., P.L. Munday, M.I. McCormick, N.W. Pankhurst, and P.M. Pankhurst, 2010: Effects of elevated water temperature and food availability on the reproductive performance of a coral reef fish. *Marine Ecology Progress Series*, **401**, 233-243.

Donn, W.L. and W.T. McGuinness, 1959: Barbados storm swell. *Journal of Geophysical Research*, **64(12)**, 2341-2349.

Donner, S.D., 2009: Coping with commitment: projected thermal stress on coral reefs under different future scenarios. *PLoS ONE*, **4(6)**, e5712, doi:10.1371/journal.pone.0005712.

Donner, S.D., T. Kirata, and C. Vieux, 2010: Recovery from the 2004 coral bleaching event in the Gilbert Islands, Kiribati. *Atoll Research Bulletin*, **587**, 1-25.

Dornan, M., 2009: Methods for assessing the contribution of renewable technologies to energy security: the electricity sector of Fiji. *Pacific Economic Bulletin*, **24(3)**, 71-91.

Dornan, M., 2011: Solar-based rural electrification policy design: the Renewable Energy Service Company (RESCO) model in Fiji. *Renewable Energy*, **36(2)**, 797-803.

Dorville, J.-F. and N. Zahibo, 2010: Hurricane Omar waves impact on the west coast of the Guadeloupe Island, October 2008. *The Open Oceanography Journal*, **4**, 83-91.

Dulal, H.B., K.U. Shah, and N. Ahmad, 2009: Social equity considerations in the implementation of Caribbean climate change adaptation policies. *Sustainability*, **1(3)**, 363-383.

Dumaru, P., 2010: Community-based adaptation: enhancing community adaptive capacity in Druadrua Island, Fiji. *Wiley Interdisciplinary Reviews: Climate Change*, **1(5)**, 751-763.

Dunne, R.P., S.M. Barbosa, and P.L. Woodworth, 2012: Contemporary sea level in the Chagos Archipelago, central Indian Ocean. *Global and Planetary Change*, **82-83**, 25-37.

Dupon, J.-F., 1987: Les atolls et le risque cyclonique: le cas des Tuamotu [The atolls and the potential cyclone: the case of the Tuamotu Islands]. *Cahiers des Sciences Humaines*, **23(3-4)**, 567-599 (in French).

Duvat, V., 2009: Beach erosion management in small island developing states: Indian Ocean case studies. In: *Coastal Processes* [Brebbia, C.A., G. Benassai, and G.R. Rodriguez (eds.)]. Proceedings of the International Conference on Physical Coastal Processes, Management and Engineering, September 14-16, Malta, WIT Press, Southampton, UK, pp. 149-160.

Duvat, V., 2013: Coastal protection structures in Tarawa Atoll, Republic of Kiribati. *Sustainability Science*, **8(3)**, 363-379.

Eakin, C.M., J.M. Lough, and S.F. Heron, 2009: Climate variability and change: monitoring data and evidence for increased coral bleaching stress. In: *Coral Bleaching: Patterns, Processes, Causes and Consequences* [van Oppen, M.J.H. and J.M. Lough (eds.)]. Ecological Studies, Vol. 205, Springer-Verlag, Berlin, Germany, pp. 41-67.

Ellison, J.C., 1993: Mangrove retreat with rising sea-level, Bermuda. *Estuarine, Coastal and Shelf Science*, **37(1)**, 75-87.

Ellison, J.C., 2009: Wetlands of the Pacific Island region. *Wetlands Ecology and Management*, **17(3)**, 169-206.

Emmanuel, K. and B. Spence, 2009: Climate change implications for water resource management in Caribbean tourism. *Worldwide Hospitality and Tourism Themes*, **1(3)**, 252-268.

Englund, R.A., 2008: Invasive species threats to native aquatic insect biodiversity and conservation measures in Hawai'i and French Polynesia. *Journal of Insect Conservation*, **12(3-4)**, 415-428.

ESCAP and UNISDR, 2010: The Asia-Pacific disaster report, 2010. In: *Protecting Development Gains: Reducing Disaster Vulnerability and Building Resilience in Asia and the Pacific*. ESCAP and UNISDR, Bangkok, Thailand, 129 pp.

Etienne, S., 2012: Marine inundation hazards in French Polynesia: geomorphic impacts of Tropical Cyclone Oli in February 2010. In: *Natural Hazards in the Asia – Pacific Region: Recent Advances and Emerging Concepts* [Terry, J.P. and J. Goff (eds.)]. Geological Society Special Publication No. 361, The Geological Society Publishing House, Bath, UK, pp. 21-39.

Etienne, S. and J.P. Terry, 2012: Coral boulders, gravel tongues and sand sheets: features of coastal accretion and sediment nourishment by Cyclone Tomas (March 2010) on Taveuni Island, Fiji. *Geomorphology*, **175-176**, 54-65.

Fazey, I., N. Pettorelli, J. Kenter, D. Wagatora, and D. Schuett, 2011: Maladaptive trajectories of change in Makira, Solomon Islands. *Global Environmental Change*, **21(4)**, 1275-1289.

Feagin, R.A., N. Mukherjee, K. Shanker, A.H. Baird, J. Cinner, A.M. Kerr, N. Koedam, A. Sridhar, R. Arthur, L.P. Jayatissa, D. Lo Seen, M. Menon, S. Rodriguez, M. Shamsuddoha, and F. Dahdouh-Guebas, 2010: Shelter from the storm? Use and misuse of coastal vegetation bioshields for managing natural disasters. *Conservation Letters*, **3(1)**, 1-11.

Ferdinand, I., G. O'Brien, P. O'Keefe, and J. Jayawickrama, 2012: The double bind of poverty and community disaster risk reduction: a case study from the Caribbean. *International Journal of Disaster Risk Reduction*, **2**, 84-94.

Figueroa, J., 2008: The need to strengthen malaria control in the Caribbean in the era of HIV/AIDS. *West Indian Medical Journal*, **57(5)**, 425-426.

Fish, M.R., I.M. Cote, J.A. Horrocks, B. Mulligan, A.R. Watkinson, and A.P. Jones, 2008: Construction setback regulations and sea-level rise: mitigating sea turtle nesting beach loss. *Ocean and Coastal Management*, **51(4)**, 330-341.

Fletcher, C.H., C. Bochicchio, C. Conger, M. Engels, F. Feirstein, N. Frazer, C. Glenn, R.W. Grigg, E.E. Grossman, and J.N. Harvey, 2008: Geology of Hawaii reefs. In: *Coral Reefs of the USA* [Riegl, B.M. and R.E. Dodge (eds.)]. Coral Reefs of the World, Vol. 1, Springer Science, Dordrecht, Netherlands, pp. 435-487.

Forbes, D.L., T.S. James, M. Sutherland, and S.E. Nichols, 2013: Physical basis of coastal adaptation on tropical small islands. *Sustainability Science*, **8(3)**, 327-344.

Ford, M., 2012: Shoreline changes on an urban atoll in the central Pacific Ocean: Majuro Atoll, Marshall Islands. *Journal of Coastal Research*, **28(1)**, 11-22.

Ford, M., 2013: Shoreline changes interpreted from multi-temporal aerial photographs and high resolution satellite images: Wotje Atoll, Marshall Islands. *Remote Sensing of Environment*, **135**, 130-140.

Forster, J., P.W. Schuhmann, I.R. Lake, A.R. Watkinson, and J.A. Gill, 2012: The influence of hurricane risk on tourist destination choice in the Caribbean. *Climatic Change*, **114(3-4)**, 745-768.

Fox, J.C., C.K. Yosi, P. Nimiago, F. Oavika, J.N. Pokana, K. Lavong, and R.J. Keenan, 2010: Assessment of aboveground carbon in primary and selectively harvested tropical forest in Papua New Guinea. *Biotropica*, **42(4)**, 410-419.

Freed, L.A., R.L. Cann, M.L. Goff, W.A. Kuntz, and G.R. Bodner, 2005: Increase in avian malaria at upper elevations in Hawaii. *The Condor*, **107(4)**, 753-764.

Frieler, K., M. Meinshausen, A. Golly, M. Mengel, K. Lebek, S.D. Donner, and O. Hoegh-Guldberg, 2013: Limiting global warming to 2°C is unlikely to save most coral reefs. *Nature Climate Change*, **3**, 165-170.

Gaigher, R., M. Samways, J. Henwood, and K. Jolliffe, 2011: Impact of a mutualism between an invasive ant and honeydew-producing insects on a functionally important tree on a tropical island. *Biological Invasions*, **13(8)**, 1717-1721.

Gamble, D.W., D. Campbell, T.L. Allen, D. Barker, S. Curtis, D. McGregor, and J. Popke, 2010: Climate change, drought, and Jamaican agriculture: local knowledge and the climate record. *Annals of the Association of American Geographers*, **100(4)**, 880-893.

Game, E.T., G. Lipsett-Moore, R. Hamilton, N. Peterson, J. Kereseka, W. Atu, M. Watts, and H. Possingham, 2011: Informed opportunism for conservation planning in the Solomon Islands. *Conservation Letters*, **4(1)**, 38-46.

Garrison, V., W. Foreman, S. Genualdi, D. Griffin, C. Kellogg, M. Majewski, A. Mohammed, A. Ramsubhag, E. Shinn, and S. Simonich, 2006: Saharan dust – a carrier of persistent organic pollutants, metals and microbes to the Caribbean? *Revista de Biología Tropical*, **54(3 Suppl.)**, 9-21.

Gemenne, F., 2011: Climate-induced population displacements in a 4°C world. *Philosophical Transactions of the Royal Society A*, **369(1934)**, 182-195.

Gero, A., K. Méheux, and D. Dominey-Howes, 2011: Integrating community based disaster risk reduction and climate change adaptation: examples from the Pacific. *Natural Hazards and Earth System Sciences*, **11(1)**, 101-113.

Gillespie, T.W., J. Chu, and S. Pau, 2008: Non-native plant invasion of the Hawaiian Islands. *Geography Compass*, **2(5)**, 1241-1265.

Gilman, E.L., J. Ellison, N.C. Duke, and C. Field, 2008: Threats to mangroves from climate change and adaptation options: a review. *Aquatic Botany*, **89(2)**, 237-250.

Gilmour, J.P., L.D. Smith, A.J. Heyward, A.H. Baird, and M.S. Pratchett, 2013: Recovery of an isolated coral reef system following severe disturbance. *Science*, **340(6128)**, 69-71.

Goodman, J., J. Maschinski, P. Hughes, J. McAuliffe, J. Roncal, D. Powell, and L.O. Sternberg, 2012: Differential response to soil salinity in endangered key tree cactus: implications for survival in a changing climate. *PLoS ONE*, **7(3)**, e32528, doi:10.1371/journal.pone.0032528.

Gordon-Clark, M., 2012: Paradise lost? Pacific island archives threatened by climate change. *Archival Science*, **12(1)**, 51-67.

Gössling, S. and K.P. Schumacher, 2010: Implementing carbon neutral destination policies: issues from the Seychelles. *Journal of Sustainable Tourism*, **18(3)**, 377-391.

Gössling, S., O. Lindén, J. Helmersson, J. Liljenberg, and S. Quarm, 2012a: Diving and global environmental change: a Mauritius case study. In: *New Frontiers in Marine Tourism: Diving Experiences, Management and Sustainability* [Garrod, B. and S. Gössling (eds.)]. Elsevier, Amsterdam, Netherlands, 67 pp.

Gössling, S., P. Peeters, C.M. Hall, J.-P. Ceron, G. Dubois, L.V. Lehmann, and D. Scott, 2012b: Tourism and water use: supply, demand, and security. An international review. *Tourism Management*, **33(1)**, 1-15.

Gravelle, G. and N. Mimura, 2008: Vulnerability assessment of sea-level rise in Viti Levu, Fiji Islands. *Sustainability Science*, **3(2)**, 171-180.

Greaver, T.L. and L.S.L. Sternberg, 2010: Decreased precipitation exacerbates the effects of sea level on coastal dune ecosystems in open ocean islands. *Global Change Biology*, **16(6)**, 1860-1869.

Green, S.J., J.L. Akins, and I.M. Côté, 2011: Foraging behaviour and prey consumption in the Indo-Pacific lionfish on Bahamian coral reefs. *Marine Ecology Progress Series*, **433**, 159-167.

Green, S.J., J.L. Akins, A. Maljković, and I.M. Côté, 2012: Invasive lionfish drive Atlantic coral reef fish declines. *PLoS ONE*, **7(3)**, e32596, doi:10.1371/journal.pone.0032596.

Griffin, D.W., 2007: Atmospheric movement of microorganisms in clouds of desert dust and implications for human health. *Clinical Microbiology Reviews*, **20(3)**, 459-477.

Gritti, E., B. Smith, and M. Sykes, 2006: Vulnerability of Mediterranean Basin ecosystems to climate change and invasion by exotic plant species. *Journal of Biogeography*, **33(1)**, 145-157.

Guillaumont, P., 2010: Assessing the economic vulnerability of small island developing states and the least developed countries. *The Journal of Development Studies*, **46(5)**, 828-854.

Haigh, I.D., M. Eliot, and C. Pattiaratchi, 2011: Global influences of the 18.61 year nodal cycle and 8.85 year cycle of lunar perigee on high tidal levels. *Journal of Geophysical Research: Oceans*, **116(C6)**, C06025, doi:10.1029/2010JC006645.

Hansen, L., J. Hoffman, C. Drews, and E. Mielbrecht, 2010: Designing climate-smart conservation: guidance and case studies. *Conservation Biology*, **24(1)**, 63-69.

Harangozo, S.A., 1992: Flooding in the Maldives and its implications for the global sea level rise debate. In: *Sea Level Changes: Determination and Effects* [Woodworth, P.L., D.T. Pugh, J.G. DeRonde, R.G. Warrick, and J. Hannah (eds.)]. Geophysical Monograph Series, 69, International Union of Geodesy and Geophysics and the American Geophysical Union, Washington, DC, USA, pp. 95-99.

Hardman, E.R., N.S. Stampfli, L. Hunt, S. Perrine, A. Perry, and J.S.J. Raffin, 2007: The impacts of coral bleaching in Rodrigues, Western Indian Ocean. *Atoll Research Bulletin*, **555**, 1-10.

Hare, W.L., W. Cramer, M. Schaeffer, A. Battaglini, and C.C. Jaeger, 2011: Climate hotspots: key vulnerable regions, climate change and limits to warming. *Regional Environmental Change*, **11(1 Suppl.)**, S1-S13.

Harmsen, E.W., N.L. Miller, N.J. Schlegel, and J.E. Gonzalez, 2009: Seasonal climate change impacts on evapotranspiration, precipitation deficit and crop yield in Puerto Rico. *Agricultural Water Management*, **96(7)**, 1085-1095.

Harp, E.L., M.E. Reid, J.P. McKenna, and J.A. Michael, 2009: Mapping of hazard from rainfall-triggered landslides in developing countries: examples from Honduras and Micronesia. *Engineering Geology*, **104(3-4)**, 295-311.

Harris, A., G. Manahira, A. Sheppard, C. Gough, and C. Sheppard, 2010: Demise of Madagascar's once great barrier reef: changes in coral reef conditions over 40 years. *Atoll Research Bulletin*, **574**, 1-16.

Hay, J.E., 2013: Small island developing states: coastal systems, global change and sustainability. *Sustainability Science*, **8(3)**, 309-326.

Hay, J.E. and N. Mimura, 2013: Vulnerability, risk and adaptation assessment methods in the Pacific Islands region: past approaches, and considerations for the future. *Sustainability Science*, **8(3)**, 391-405.

Hay, S.I., C.A. Guerra, P.W. Gething, A.P. Patil, A.J. Tatem, A.M. Noor, C.W. Kabaria, B.H. Manh, I.R.F. Elyazar, S. Brooker, D.L. Smith, R.A. Moyeed, and R.W. Snow, 2009: A world malaria map: *Plasmodium falciparum* endemicity in 2007. *PLoS Medicine*, **6(3)**, e1000048, doi:10.1371/journal.pmed.1000048.

Heger, M., A. Julca, and O. Paddison, 2008: Analysing the impact of natural hazards in small economies: the Caribbean case. UNU-WIDER Research Paper No. 2008/25, United Nations, University World Institute for Development Economics Research (UNU-WIDER), Helsinki, Finland, 27 pp.

Heltberg, R., P.B. Siegel, and S.L. Jorgensen, 2009: Addressing human vulnerability to climate change: toward a 'no-regrets' approach. *Global Environmental Change*, **19(1)**, 89-99.

Hemer, M.A., Y. Fan, N. Mori, A. Semedo, and X.L. Wang, 2013: Projected changes in wave climate from multi-model ensemble. *Nature Climate Change*, **3(5)**, 471-476.

Herrmann-Storck, C., D. Postic, I. Lamaury, and J.M. Perez, 2008: Changes in epidemiology of leptospirosis in 2003-2004, a two El Niño – Southern Oscillation period, Guadeloupe archipelago, French West Indies. *Epidemiology and Infection*, **136(10)**, 1407-1415.

Herweijer, C., N. Ranger, and R.E.T. Ward, 2009: Adaptation to climate change: threats and opportunities for the insurance industry. *The Geneva Papers on Risk and Insurance – Issues and Practice*, **34(3)**, 360-380.

Hoegh-Guldberg, O., P.J. Mumby, A.J. Hooten, R.S. Steneck, P. Greenfield, E. Gomez, C.D. Harvell, P.F.H. Sale, A. Dubi, and M.E. Hatziolos, 2007: Coral reefs under rapid climate change and ocean acidification. *Science*, **318(5857)**, 1737-1742.

Hoeke, R.K., K.L. McInnes, J. Kruger, R. McNaught, J. Hunter, and S. Smithers, 2013: Widespread inundation of Pacific islands by distant-source wind-waves. *Global Environmental Change*, **108**, 128-138.

Hornidge, A. and F. Scholtes, 2011: Climate change and everyday life in Toineke Village, West Timor: uncertainties, knowledge and adaptation. *Sociologus*, **61(2)**, 151-175.

Houston, J.R., 2002: The economic value of beaches – a 2002 update. *Shore and Beach*, **70(1)**, 9-12.

Howard, G., K. Charles, K. Pond, A. Brookshaw, R. Hossain, and J. Bartram, 2010: Securing 2020 vision for 2030: climate change and ensuring resilience in water and sanitation services. *Journal of Water and Climate Change*, **1(1)**, 2-16.

Hughes, S., A. Yau, L. Max, N. Petrovic, F. Davenport, M. Marshall, T.R. McClanahan, E.H. Allison, and J.E. Cinner, 2012: A framework to assess national level vulnerability from the perspective of food security: the case of coral reef fisheries. *Environmental Science & Policy*, **23**, 95-108.

Hughes, T.P., A.H. Baird, D.R. Bellwood, M. Card, S.R. Connolly, C. Folke, R. Grosberg, O. Hoegh-Guldberg, J.B.C. Jackson, J. Kleypas, J.M. Lough, P. Marshall, M. Nyström, S.R. Palumbi, J.M. Pandolfi, B. Rosen, and J. Roughgarden, 2003: Climate change, human impacts, and the resilience of coral reefs. *Science*, **301(5635)**, 929-933.

Hübner, A. and S. Gössling, 2012: Tourist perceptions of extreme weather events in Martinique. *Journal of Destination Marketing & Management*, **1(1-2)**, 47-55.

Idjadi, J.A., R.N. Haring, and W.F. Precht, 2010: Recovery of the sea urchin *Diadema antillarum* promotes scleractinian coral growth and survivorship on shallow Jamaican reefs. *Marine Ecology Progress Series*, **403**, 91-100.

IPCC, 2007: *Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Metz, B., O.R. Davidson, P.R. Bosch, R. Dave, and L.A. Meyer (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, 851 pp.

IPCC, 2011: *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, and C. von Stechow (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, 1075 pp.

Jarvis, R., 2010: Sinking nations and climate change adaptation strategies. *Seattle Journal of Social Justice*, **9(1)**, 447-486.

Joe, S.M. and C.C. Daehler, 2008: Invasive slugs as under-appreciated obstacles to rare plant restoration: evidence from the Hawaiian Islands. *Biological Invasions*, **10(2)**, 245-255.

Jones, G.P., M.I. McCormick, M. Srinivasan, and J.V. Eagle, 2004: Coral decline threatens fish biodiversity in marine reserves. *Proceedings of the National Academy of Sciences of the United States of America*, **101(21)**, 8251-8253.

Jones, P., 2005: Managing urban development in the Pacific. *Australian Planner*, **42(1)**, 39-46.

Jump, A.S., T.-J. Huang, and C.-H. Chou, 2012: Rapid altitudinal migration of mountain plants in Taiwan and its implications for high altitude biodiversity. *Ecography*, **35**, 204-210.

Jury, M.R. and A. Winter, 2010: Warming of an elevated layer over the Caribbean. *Climatic Change*, **99(1-2)**, 247-259.

Kaldellis, J.K., 2008: Integrated electrification solution for autonomous electrical networks on the basis of RES and energy storage configurations. *Energy Conversion and Management*, **49(12)**, 3708-3720.

Kaldellis, J.K., D. Zafirakis, E.L. Kaldelli, and K. Kavadias, 2009: Cost benefit analysis of a photovoltaic-energy storage electrification solution for remote islands. *Renewable Energy*, **34(5)**, 1299-1311.

Keener, V., J.J. Marra, M.L. Finucane, D. Spooner, and M.H. Smith, 2012: *Climate Change and Pacific Islands: Indicators and Impacts: Report for the 2012 Pacific Islands Regional Climate Assessment.* Island Press, Washington, DC, USA, 170 pp.

Kelman, I., 2010: Introduction to climate, disasters and international development. *Journal of International Development*, **22(2)**, 208-217.

Kelman, I. and J. West, 2009: Climate change and Small Island Developing States: a critical review. *Ecological and Environmental Anthropology*, **5(1)**, 1-16.

Kelman, I., J. Lewis, J.C. Gaillard, and J. Mercer, 2011: Participatory action research for dealing with disasters on islands. *Island Studies Journal*, **6(1)**, 59-86.

Kenis, M., M.-A. Auger-Rozenberg, A. Roques, L. Timms, C. Péré, M.J.W. Cock, J. Settele, S. Augustin, and C. Lopez-Vaamonde, 2009: Ecological effects of invasive alien insects. *Biological Invasions*, **11(1)**, 21-45.

Kingsford, R., J. Watson, C. Lundquist, O. Venter, L. Hughes, E. Johnston, J. Atherton, M. Gawel, D. Keith, B. Mackey, C. Morley, H.B. Possingham, B. Raynor, H.F. Recher, and K.A. Wilson, 2009: Major conservation policy issues for biodiversity in Oceania. *Conservation Biology*, **23(4)**, 834-840.

Klein, R., S. Ericksen, L. Ness, A. Hammill, T. Tanner, C. Robledo, and K. O'Brien, 2007: Portfolio screening to support the mainstreaming of adaptation to climate change into development assistance. *Climatic Change*, **84(1)**, 23-44.

Klint, L.M., M. Jiang, A. Law, T. Delacy, S. Filep, E. Calgaro, D. Dominey-Howes, and D. Harrison, 2012: Dive tourism in Luganville, Vanuatu: shocks, stressors, and vulnerability to climate change. *Tourism in Marine Environments*, **8(1-2)**, 91-109.

Koh, B.K., L.C. Ng, Y. Kita, C.S. Tang, L.W. Ang, K.Y. Wong, L. James, and K.T. Goh, 2008: The 2005 dengue epidemic in Singapore: epidemiology, prevention and control. *Annals, of the Academy of Medicine, Singapore (AAMS)*, **37(7)**, 538-545.

Kolmannskog, V. and L. Trebbi, 2010: Climate change, natural disasters and displacement: a multi-track approach to filling the protection gaps. *International Review of the Red Cross*, **92(879)**, 713-730.

Komar, P.D. and J.C. Allan, 2008: Increasing hurricane-generated wave heights along the US East Coast and their climate controls. *Journal of Coastal Research*, **24(2)**, 479-488.

Krajačić, G., N. Duić, B.V. Mathiesen, and M.d.G. Carvalho, 2010: Smart energy storages for integration of renewables in 100% independent energy systems. (PRES 2010, 13th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction, August 28-September 1, 2010, Prague, Czech Republic.) *Chemical Engineering Transactions*, **21**, 391-396, doi:10.3303/CET1021066.

Krauss, K.W., J.A. Allen, and D.R. Cahoon, 2003: Differential rates of vertical accretion and elevation change among aerial root types in Micronesian mangrove forests. *Estuarine, Coastal and Shelf Science*, **56(2)**, 251-259.

Krauss, K.W., D.R. Cahoon, J.A. Allen, K.C. Ewel, J.C. Lynch, and N. Cormier, 2010: Surface elevation change and susceptibility of different mangrove zones to sea-level rise on Pacific high islands of Micronesia. *Ecosystems*, **13(1)**, 129-143.

Kravchenko, S., 2008: Right to carbon or right to life: human rights approaches to climate change. *Vermont Journal of Environmental Law*, **9(3)**, 513-547.

Krishnamurthy, P.K., 2012: Disaster-induced migration: assessing the impact of extreme weather events on livelihoods. *Environmental Hazards*, **11(2)**, 96-111.

Krushelnycky, P.D., L.L. Loope, T.W. Giambelluca, F. Starr, K. Starr, D.R. Drake, A.D. Taylor, and R.H. Robichaux, 2013: Climate-associated population declines reverse recovery and threaten future of an iconic high-elevation plant. *Global Change Biology*, **19(3)**, 911-922.

Kueffer, C., C.C. Daehler, C.W. Torres-Santana, C. Lavergne, J.-Y. Meyer, R. Otto, and L. Silva, 2010: A global comparison of plant invasions on oceanic islands. *Perspectives in Plant Ecology Evolution and Systematics*, **12(2)**, 145-161.

Kumar, V.S., V.R. Babu, M. Babu, G. Dhinakaran, and G. Rajamanickam, 2008: Assessment of storm surge disaster potential for the Andaman Islands. *Journal of Coastal Research*, **24(2B)**, 171-177.

Kuruppu, N., 2009: Adapting water resources to climate change in Kiribati: the importance of cultural values and meanings. *Environmental Science & Policy*, **12(7)**, 799-809.

Kuruppu, N. and D. Liverman, 2011: Mental preparation for climate adaptation: the role of cognition and culture in enhancing adaptive capacity of water management in Kiribati. *Global Environmental Change*, **21(2)**, 657-669.

Laczko, F. and C. Aghazarm, 2009: *Migration, Environment and Climate Change: Assessing the Evidence.* International Organization for Migration (IOM), Geneva, Switzerland, 441 pp.

Lata, S. and P. Nunn, 2012: Misperceptions of climate-change risk as barriers to climate-change adaptation: a case study from the Rewa Delta, Fiji. *Climatic Change*, **110(1-2)**, 169-186.

Lauer, M. and S. Aswani, 2010: Indigenous knowledge and long-term ecological change: detection, interpretation, and responses to changing ecological conditions in Pacific Island Communities. *Environmental Management*, **45(5)**, 985-997.

Lazrus, H., 2012: Sea change: island communities and climate change. *Annual Review of Anthropology*, **41(1)**, 285-301.

Le Masson, V. and I. Kelman, 2011: Disaster risk reduction on non-sovereign islands: La Réunion and Mayotte, France. *Natural Hazards*, **56(1)**, 251-273.

Le Roux, J.J., A.M. Wieczorek, and J.-Y. Meyer, 2008: Genetic diversity and structure of the invasive tree *Miconia calvescens* in Pacific islands. *Diversity and Distributions*, **14(6)**, 935-948.

Le Roux, P.C., M.A. McGeoch, M.J. Nyakatya, and S.L. Chown, 2005: Effects of a short-term climate change experiment on a sub-Antarctic keystone plant species. *Global Change Biology*, **11(10)**, 1628-1639.

Lefale, P.F., 2010: *Ua 'afa le Aso* Stormy weather today: traditional ecological knowledge of weather and climate. The Samoa experience. *Climatic Change*, **100(2)**, 317-335.

Lesser, M.P. and M. Slattery, 2011: Phase shift to algal dominated communities at mesophotic depths associated with lionfish (*Pterois volitans*) invasion on a Bahamian coral reef. *Biological Invasions*, **13(8)**, 1855-1868.

Lessios, H.A., 1988: Mass mortality of *Diadema antillarum* in the Caribbean: what have we learned? *Annual Review of Ecology and Systematics*, **19(1)**, 371-393.

Lessios, H.A., 1995: *Diadema antillarum* 10 years after mass mortality: still rare, despite help from a competitor. *Proceedings of the Royal Society B*, **259(1356)**, 331-337.

Lilleør, H.B. and K. Van den Broeck, 2011: Economic drivers of migration and climate change in LDCs. *Global Environmental Change*, **21(1 Suppl.)**, S70-S81.

Limalevu, L., B. Aalsbersberg, P. Dumaru, and T. Weir, 2010: Adaptation on a small island. *Tiempo*, **77**, 16-19.

Linnerooth-Bayer, J. and R. Mechler, 2009: *Insurance against Losses from Natural Disasters in Developing Countries.* ST/ESA/2009/DWP/85, DESA Working Paper No. 85, United Nations Department of Economic and Social Affairs (UN DESA), New York, NY, USA, 35 pp.

Linnerooth-Bayer, J., R. Mechler, and S. Hochrainer, 2011: Insurance against losses from natural disasters in developing countries. Evidence, gaps and the way forward. *Journal of Integrated Disaster Risk Management (IDRiM)*, **1(1)**, 59-81.

Llewellyn, L.E., 2010: Revisiting the association between sea surface temperature and the epidemiology of fish poisoning in the South Pacific: reassessing the link between ciguatera and climate change. *Toxicon*, **56(5)**, 691-697.

Locke, J.T., 2009: Climate change-induced migration in the Pacific region: sudden crisis and long-term developments. *The Geographical Journal*, **175(3)**, 171-180.

López-Marrero, T., 2010: An integrative approach to study and promote natural hazards adaptive capacity: a case study of two flood-prone communities in Puerto Rico. *Geographical Journal*, **176(2)**, 150-163.

López-Marrero, T. and B. Yarnal, 2010: Putting adaptive capacity into the context of people's lives: a case study of two flood-prone communities in Puerto Rico. *Natural Hazards*, **52(2)**, 277-297.

López-Villarrubia, E., F. Ballester, C. Iñiguez, and N. Peral, 2010: Air pollution and mortality in the Canary Islands: a time-series analysis. *Environmental Health*, **9**, 8, doi:10.1186/1476-069X-9-8.

Loughry, M. and J. McAdam, 2008: Kiribati – relocation and adaptation. *Forced Migration Review*, **31**, 51-52.

Lovell, S., 2011: Health governance and the impact of climate change on Pacific small island developing states. *IHDP Update: Magazine of the International Human Dimensions Programme on Global Environmental Change*, **2011(1)**, 50-55.

Lozano, M.A., 2006: Riesgos catastróficos en las Islas Canarias. Una visión geográfica [Catastrophic hazards in the Canary Islands. A geographic vision]. *Anales de Geografía*, **26**, 167-194 (in Spanish).

Lo-Yat, A., S.D. Simpson, M. Meekan, D. Lecchini, E. Martinez, and R. Galzin, 2011: Extreme climatic events reduce ocean productivity and larval supply in a tropical reef ecosystem. *Global Change Biology*, **17(4)**, 1695-1702.

Maina, J., T.R. McClanahan, V. Venus, M. Ateweberhan, and J. Madin, 2011: Global gradients of coral exposure to environmental stresses and implications for local management. *PLoS ONE*, **6(8)**, e23064, doi:10.1371/journal.pone.0023064.

Maldives Department of Meteorology, 2007: *The Unusually Strong Tidal Waves Hit Maldives*, *15-18 May.* Department of Meteorology, Malé, Republic of Maldives, 15 pp.

Maniku, H.A., 1990: *Changes in the Topography of the Maldives.* Forum of Writers on Environment (Maldives), Malé, Republic of Maldives, 91 pp.

Marba, N. and C.M. Duarte, 2010: Mediterranean warming triggers seagrass (*Posidonia oceanica*) shoot mortality. *Global Change Biology*, **16(8)**, 2366-2375.

Martens, P., R.S. Kovats, S. Nijof, P. de Vries, M.T.J. Livermore, D.J. Bradley, J. Cox, and A.J. McMichael, 1999: Climate change and future populations at risk of malaria. *Global Environmental Change*, **9(1 Suppl.)**, S89-S107.

Martins, P., J. Rosado-Pinto, M. do Céu Teixeira, N. Neuparth, O. Silva, H. Tavares, J.L. Spencer, D. Mascarenhas, A.L. Papoila, N. Khaltaev, and I. Annesi-Maesano, 2009: Under-report and underdiagnosis of chronic respiratory diseases in an African country. *Allergy*, **64(7)**, 1061-1067.

Maunsell Australia Pty Ltd., 2009: *Climate Change Risk Assessment for the Australian Indian Ocean Territories: Cocos (Keeling) Islands and Christmas Island.* Document No. 60046031-FD, Prepared for the Commonwealth Attorney-General's Department by P. Mackay, G. Prudent-Richard, and L. Hoekstra-Fokkink, Maunsell Australia Pty Ltd., in association with the Commonwealth Scientific and Industrial Research Organization (CSIRO) and Coastal Zone Management (CZM) Pty Ltd., Canberra, ACT, Australia, 93 pp.

McClanahan, T., J. Cinner, J. Maina, N. Graham, T. Daw, S. Stead, A. Wamukota, K. Brown, M. Ateweberhan, and V. Venus, 2008: Conservation action in a changing climate. *Conservation Letters*, **1(2)**, 53-59.

McGranahan, G., D. Balk, and B. Anderson, 2007: The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. *Environment and Urbanization*, **19(1)**, 17-37.

McGray, H., A. Hammil, and R. Bradley, 2007: *Weathering the Storm: Options for Framing Adaptation and Development.* World Resources Institute (WRI), Washington, DC, USA, 57 pp.

McKee, K.L., D.R. Cahoon, and I.C. Feller, 2007: Caribbean mangroves adjust to rising sea level through biotic controls on change in soil elevation. *Global Ecology and Biogeography*, **16(5)**, 545-556, doi:10.1111/j.1466-8238.2007.00317.x.

McLeman, R.A., 2011: Settlement abandonment in the context of global environmental change. *Global Environmental Change*, **21(1 Suppl.)**, S108-S120.

McLeman, R.A. and L.M. Hunter, 2010: Migration in the context of vulnerability and adaptation to climate change: insights from analogues. *Wiley Interdisciplinary Reviews: Climate Change*, **1(3)**, 450-461.

McLeod, E., R. Salm, A. Green, and J. Almany, 2009: Designing marine protected area networks to address the impacts of climate change. *Frontiers in Ecology and the Environment*, **7(7)**, 362-370.

McMichael, A.J. and E. Lindgren, 2011: Climate change: present and future risks to health, and necessary responses. *Journal of Internal Medicine*, **270(5)**, 401-413.

McMichael, C., J. Barnett, and A.J. McMichael, 2012: An ill wind? Climate change, migration, and health. *Environmental Health Perspectives*, **120(5)**, 646-654.

McNamara, K.E. and C. Gibson, 2009: 'We do not want to leave our land': Pacific ambassadors at the United Nations resist the category of 'climate refugees'. *Geoforum*, **40(3)**, 475-483.

McNamara, K.E. and R. Westoby, 2011: Local knowledge and climate change adaptation on Erub Island, Torres Strait. *Local Environment*, **16(9)**, 887-901.

Mercer, J., D. Dominey-Howes, I. Kelman, and K. Lloyd, 2007: The potential for combining indigenous and western knowledge in reducing vulnerability to environmental hazards in small island developing states. *Environmental Hazards*, **7(4)**, 245-256.

Merrifield, M., S. Merrifield, and G. Mitchum, 2009: An anomalous recent acceleration of global sea level rise. *Journal of Climate*, **22(21)**, 5772-5781.

Mertz, O., K. Halsnæs, J.E. Olesen, and K. Rasmussen, 2009: Adaptation to climate change in developing countries. *Environmental Management*, **43(5)**, 743-752.

Mertz, O., T.B. Bruun, B. Fog, K. Rasmussen, and J. Agergaard, 2010: Sustainable land use in Tikopia: food production and consumption in an isolated agricultural system. *Singapore Journal of Tropical Geography*, **31(1)**, 10-26.

Meyer III, W.M., K.A. Hayes, and A.L. Meyer, 2008: Giant African snail, *Achatina fulica*, as a snail predator. *American Malacological Bulletin*, **24(1-2)**, 117-119.

Meyssignac, B., M. Becker, W. Llovel, and A. Cazenave, 2012: An assessment of two-dimensional past sea level recontructions over 1950-2009 based on tide-gauge data and different input sea level grids. *Surveys in Geophysics*, **33(5)**, 945-972.

Michon, P., J.L. Cole-Tobian, E. Dabod, S. Schoepflin, J. Igu, M. Susapu, N. Tarongka, P.A. Zimmerman, J.C. Reeder, and J.G. Beeson, 2007: The risk of malarial infections and disease in Papua New Guinean children. *The American Journal of Tropical Medicine and Hygiene*, **76(6)**, 997-1008.

Middleton, N., P. Yiallouros, S. Kleanthous, O. Kolokotroni, J. Schwartz, D.W. Dockery, P. Demokritou, and P. Koutrakis, 2008: A 10-year time-series analysis of respiratory and cardiovascular morbidity in Nicosia, Cyprus: the effect of short-term changes in air pollution and dust storms. *Environmental Health*, **7**, 39, doi:10.1186/1476-069X-7-39.

Miller, J., E. Muller, C. Rogers, R. Waara, A. Atkinson, K.R.T. Whelan, M. Patterson, and B. Witcher, 2009: Coral disease following massive bleaching in 2005 causes 60% decline in coral cover on reefs in the US Virgin Islands. *Coral Reefs*, **28(4)**, 925-937.

Miller, S., T. Brewer, and N. Harris, 2009: Rainfall thresholding and susceptibility assessment of rainfall-induced landslides: application to landslide management in St. Thomas, Jamaica. *Bulletin of Engineering Geology and the Environment*, **68(4)**, 539-550.

Mills, M., R.L. Pressey, R. Weeks, S. Foale, and N.C. Ban, 2010: A mismatch of scales: challenges in planning for implementation of marine protected areas in the Coral Triangle. *Conservation Letters*, **3(5)**, 291-303.

Mimura, N., L.A. Nurse, R.F. McLean, J. Agard, L. Briguglio, P. Lefale, R. Payet, and G. Sem, 2007: Small islands. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 687-716.

Moglia, M., P. Perez, and S. Burn, 2008a: Urbanization and water development in the Pacific Islands. *Development*, **51(1)**, 49-55.

Moglia, M., P. Perez, and S. Burn, 2008b: Water troubles in a Pacific atoll town. *Water Policy*, **10(6)**, 613-637.

Mohan, A., A. Cumberbatch, A. Adesiyun, and D.D. Chadee, 2009: Epidemiology of human leptospirosis in Trinidad and Tobago, 1996-2000: a retrospective study. *Acta Tropica*, **112(3)**, 260-265.

Mohanty, M., 2012: New renewable energy sources, green energy development and climate change: implications to Pacific Island countries. *Management of Environmental Quality: An International Journal*, **23(3)**, 264-274.

Monteil, M., 2008: Saharan dust clouds and human health in the English-speaking Caribbean: what we know and don't know. *Environmental Geochemistry and Health*, **30(4)**, 339-343.

Monteil, M. and R. Antoine, 2009: African dust and asthma in the Caribbean: medical and statistical perspectives. *International Journal of Biometeorology*, **53(5)**, 379-381.

Moore, W.R., 2010: The impact of climate change on Caribbean tourism demand. *Current Issues in Tourism*, **13(5)**, 495-505.

Moreno, A. and S. Becken, 2009: A climate change vulnerability assessment methodology for coastal tourism. *Journal of Sustainable Tourism*, **17(4)**, 473-488.

Morrison, K., P.A. Prieto, A.C. Domínguez, D. Waltner-Toews, and J. FitzGibbon, 2008: Ciguatera fish poisoning in La Habana, Cuba: a study of local social-ecological resilience. *Ecohealth*, **5(3)**, 346-359.

Mortreux, C. and J. Barnett, 2009: Climate change, migration and adaptation in Funafuti, Tuvalu. *Global Environmental Change*, **19(1)**, 105-112.

Moss, R.H., J.A. Edmonds, K.A. Hibbard, M.R. Manning, S.K. Rose, D.P. van Vuuren, T.R. Carter, S. Emori, M. Kainuma, T. Kram, G.A. Meehl, J.F.B. Mitchell, N. Nakicenovic, K. Riahi, S.J. Smith, R.J. Stouffer, A.M. Thomson, J.P. Weyant, and T.J. Wilbanks, 2010: The next generation of scenarios for climate change research and assessment. *Nature*, **463(7282)**, 747-756.

Munday, P.L., J.M. Leis, J.M. Lough, C.B. Paris, M.J. Kingsford, M.L. Berumen, and J. Lambrechts, 2009: Climate change and coral reef connectivity. *Coral Reefs*, **28(2)**, 379-395.

Mycoo, M., 2007: Diagnosis of Trinidad's water problems (mid-1980s to mid-1990s). *Water Policy*, **9(1)**, 73-86.

Mycoo, M., 2011: Natural hazard risk reduction: making St. Lucia safe in an era of increased hurricanes and associated events. *Natural Hazards Review*, **12(1)**, 37-45.

Mycoo, M. and A. Chadwick, 2012: Adaptation to climate change: the coastal zone of Barbados. *Proceedings of the Institution of Civil Engineers (ICE) - Maritime Engineering*, **165(4)**, 159-168.

Myers, N., 2002: Environmental refugees: a growing phenomenon of the 21st century. *Philosophical Transactions of the Royal Society B*, **357(1420)**, 609-613.

Nelson, D.R., 2011: Adaptation and resilience: responding to a changing climate. *Wiley Interdisciplinary Reviews: Climate Change*, **2(1)**, 113-120.

Nicholls, R.J. and A. Cazenave, 2010: Sea-level rise and its impact on coastal zones. *Science*, **328(5985)**, 1517-1520.

Nicholls, R.J. and R.S.J. Tol, 2006: Impacts and responses to sea-level rise: a global analysis of the SRES scenarios over the twenty-first century. *Philosophical Transactions of the Royal Society A*, **364(1841)**, 1073-1095.

Nicholls, R.J., N. Marinova, J.A. Lowe, S. Brown, P. Vellinga, D. de Gusmao, J. Hinkel, and R.S.J. Tol, 2011: Sea-level rise and its possible impacts given a 'beyond 4°C world' in the twenty-first century. *Philosophical Transactions of the Royal Society A*, **369(1934)**, 161-181.

Nicoll, K.A., R.G. Harrison, and Z. Ulanowski, 2011: Observation of Saharan dust electrification. *Environmental Research Letters*, **6(1)**, 014001, doi:10.1088/1748-9326/6/1/014001.

Novelo-Casanova, D.A. and G. Suarez, 2010: Natural and man-made hazards in the Cayman Islands. *Natural Hazards*, **55(2)**, 441-466.

Nunn, P.D., 2007: *Climate, Environment, and Society in the Pacific during the Last Millennium*. Developments in Earth and Environmental Sciences, Vol. 6, Elsevier, Amsterdam, Netherlands, 316 pp.

Nunn, P.D., 2009: Responding to the challenges of climate change in the Pacific Islands: management and technological imperatives. *Climate Research*, **40(2-3)**, 211-231.

Nunn, P.D., W. Aalbersberg, S. Lata, and M. Gwilliam, 2013: Beyond the core: community governance for climate-change adaptation in peripheral parts of Pacific Island Countries. *Regional Environmental Change* (in press), doi: 10.1007/s10113-013-0486-7.

Nurse, L.A., G. Sem, J.E. Hay, A.G. Suarez, P.P. Wong, L. Briguglio, and S. Ragoonaden, 2001: Small island states. In: *Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment of the Intergovernmental Panel on Climate Change* [McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 843-876.

OECS, 2004: *Grenada: Macro-Socio-Economic Assessment of the Damages Caused by Hurricane Ivan, September 7th 2004.* Organisation of East Caribbean States (OECS), OECS Secretariat, Castries, St. Lucia, 126 pp.

Ogston, A.S. and M.E. Field, 2010: Predictions of turbidity due to enhanced sediment resuspension resulting from sea-level rise on a fringing coral reef: evidence from Molokai, Hawaii. *Journal of Coastal Research*, **26(6)**, 1027-1037.

Otero, P., S. Pérez, A. Alfonso, C. Vale, P. Rodríguez, Neide N. Gouveia, Nuno Gouveia, J. Delgado, P. Vale, M. Hirama, Y. Ishihara, J. Molgó, and L.M. Botana, 2010: First toxin profile of ciguateric fish in Madeira Arquipelago (Europe). *Analytical Chemistry*, **82(14)**, 6032-6039.

Oxenford, H.A., R. Roach, A. Brathwaite, L. Nurse, R. Goodridge, F. Hinds, K. Baldwin, and C. Finney, 2008: Quantitative observations of a major coral bleaching event in Barbados, southeastern Caribbean. *Climatic Change*, **87(3-4)**, 435-449.

Palanisamy, H., M. Becker, B. Meyssignac, O. Henry, and A. Cazenave, 2012: Regional sea level change and variability in the Caribbean Sea since 1950. *Journal of Geodetic Science*, **2(2)**, 125-133.

Pappas, G., P. Papadimitriou, V. Siozopoulou, L. Christou, and N. Akritidis, 2008: The globalization of leptospirosis: worldwide incidence trends. *International Journal of Infectious Diseases*, **12(4)**, 351-357.

Parham, P.E. and E. Michael, 2010: Modelling the effects of weather and climate change on malaria transmission. *Environmental Health Perspectives*, **118(5)**, 620-626.

Park, S., N. Marshall, E. Jakku, A. Dowd, S. Howden, E. Mendham, and A. Fleming, 2012: Informing adaptation responses to climate change through theories of transformation. *Global Environmental Change*, **22(1)**, 115-126.

Parks, B.C. and J.T. Roberts, 2006: Globalization, vulnerability to climate change, and perceived injustice. *Society and Natural Resources*, **19(4)**, 337-355.

Pascual, M., J.A. Ahumada, L.F. Chaves, X. Rodo, and M. Bouma, 2006: Malaria resurgence in the East African highlands: temperature trends revisited. *Proceedings of the National Academy of Sciences of the United States of America*, **103(15)**, 5829-5834.

Pauli, H., M. Gottfried, K. Reiter, C. Klettner, and G. Grabherr, 2007: Signals of range expansions and contractions of vascular plants in the high Alps: observations (1994-2004) at the GLORIA master site Schrankogel, Tyrol, Austria. *Global Change Biology*, **13(1)**, 147-156.

Payet, R. and W. Agricole, 2006: Climate change in the Seychelles: implications for water and coral reefs. *AMBIO: A Journal of the Human Environment*, **35(4)**, 182-189.

Peduzzi, P., H. Dao, C. Herold, and F. Mouton, 2009: Assessing global exposure and vulnerability towards natural hazards: the Disaster Risk Index. *Natural Hazards and Earth System Sciences*, **9(4)**, 1149-1159.

Pelling, M., 2011: Urban governance and disaster risk reduction in the Caribbean: the experiences of Oxfam GB. *Environment and Urbanization*, **23(2)**, 383-400.

Pelling, M. and J.I. Uitto, 2001: Small island developing states: natural disaster vulnerability and global change. *Global Environmental Change Part B: Environmental Hazards*, **3(2)**, 49-62.

Perch-Nielsen, S.L., 2010: The vulnerability of beach tourism to climate change – an index approach. *Climatic Change*, **100(3-4)**, 579-606.

Pérez-Arellano, J., O.P. Luzardo, A.P. Brito, M.H. Cabrera, M. Zumbado, C. Carranza, A. Angel-Moreno, R.W. Dickey, and L.D. Boada, 2005: Ciguatera fish poisoning, Canary Islands. *Emerging Infectious Diseases*, **11(12)**, 1981-1982.

Peters, G.P., R.M. Andrew, T. Boden, J.G. Canadell, P. Ciais, C. Le Quéré, G. Marland, M.R. Raupach, and C. Wilson, 2013: The challenge to keep global warming below 2°C. *Nature Climate Change*, **3**, 4-6.

Piskorska, M., G. Smith, and E. Weil, 2007: Bacteria associated with the coral *Echinopora lamellosa* (Esper 1795) in the Indian Ocean-Zanzibar Region. *African Journal of Environmental Science and Technology*, **1(5)**, 93-98.

Polidoro, B.A., K.E. Carpenter, L. Collins, N.C. Duke, A.M. Ellison, J.C. Ellison, E.J. Farnsworth, E.S. Fernando, K. Kathiresan, N.E. Koedam, S.R. Livingstone, T. Miyagi, G.E. Moore, V.N. Nam, J.E. Ong, J.H. Primavera, S.G. Salmo III, J.C. Sanciangco, S. Sukardjo, Y. Wang, and J.W.H. Yong, 2010: The loss of species: mangrove extinction risk and geographic areas of global concern. *PLoS ONE*, **5(4)**, e10095, doi:10.1371/journal.pone.0010095.

Polovina, J.J., J.P. Dunne, P.A. Woodworth, and E.A. Howell, 2011: Projected expansion of the subtropical biome and contraction of the temperate and equatorial upwelling biomes in the North Pacific under global warming. *International Council for the Exploration of the Sea (ICES) Journal of Marine Science*, **68(6)**, 986-995.

Praene, J.P., M. David, F. Sinama, D. Morau, and O. Marc, 2012: Renewable energy: progressing towards a net zero energy island, the case of Reunion Island. *Renewable and Sustainable Energy Reviews*, **16(1)**, 426-442.

Prasad, B.C., 2008: Institutions, good governance and economic growth in the Pacific Island countries. *International Journal of Social Economics*, **35(12)**, 904-918.

Pratchett, M.S., S.K. Wilson, A.J. Graham, P.L. Munday, G.P. Jones, and N.V.C. Polunin, 2009: Coral bleaching and consequences for motile reef organisms: past, present and uncertain future effects. In: *Coral Bleaching: Patterns, Processes, Causes and Consequences* [van Oppen, M.J.H. and J.M. Lough (eds.)]. Ecological Studies, Vol. 205, Springer-Verlag, Berlin, Germany, pp. 139-158.

Prevatt, D., L. Dupigny-Giroux, and F. Masters, 2010: Engineering perspectives on reducing hurricane damage to housing in CARICOM Caribbean Islands. *Natural Hazards Review*, **11(4)**, 140-150.

Prospero, J.M., 2006: Case study: Saharan dust impacts and climate change. *Oceanography*, **19(2)**, 59-61.

Prospero, J.M. and P.J. Lamb, 2003: African droughts and dust transport to the Caribbean: climate change implications. *Science*, **302(5647)**, 1024-1027.

Prospero, J.M., E. Blades, G. Mathison, and R. Naidu, 2005: Interhemispheric transport of viable fungi and bacteria from Africa to the Caribbean with soil dust. *Aerobiologia*, **21(1)**, 1-19.

Prospero, J.M., E. Blades, R. Naidu, G. Mathison, H. Thani, and M. Lavoie, 2008: Relationship between African dust carried in the Atlantic trade winds and surges in pediatric asthma attendances in the Caribbean. *International Journal of Biometeorology*, **52(8)**, 823-832.

Pulwarty, R.S., L.A. Nurse, and U.O. Trotz, 2010: Caribbean Islands in a changing climate. *Environment: Science and Policy for Sustainable Development*, **52(6)**, 16-27.

Ralph, P.J., M.J. Durako, S. Enriquez, C.J. Collier, and M.A. Doblin, 2007: Impact of light limitation on seagrasses. *Journal of Experimental Marine Biology and Ecology*, **350(1-2)**, 176-193.

Rankey, E.C., 2011: Nature and stability of atoll island shorelines: Gilbert Island chain, Kiribati, equatorial Pacific. *Sedimentology*, **58(7)**, 1831-1859.

Rasmussen, K., W. May, T. Birk, M. Mataki, O. Mertz, and D. Yee, 2009: Climate change on three Polynesian outliers in the Solomon Islands: impacts, vulnerability and adaptation. *Geografisk Tidsskrift-Danish Journal of Geography*, **109(1)**, 1-13.

Rasmussen, K., W. May, T. Birk, M. Mataki, and O. Mertz, 2011: Prospects for climate change on three Polynesian outliers in Solomon Islands: exposure, sensitivity and adaptive capacity. *Geografisk Tidsskrift-Danish Journal of Geography*, **111(1)**, 43-57.

Rawlins, S.C., A. Hinds, and J.M. Rawlins, 2008: Malaria and its vectors in the Caribbean: the continuing challenge of the disease forty-five years after eradication from the islands. *West Indian Medical Journal*, **57(5)**, 462-469.

Reaser, J.K., L.A. Meyerson, Q. Cronk, M. De Poorter, L.G. Eldrege, E. Green, M. Kairo, P. Latasi, R.N. Mack, J. Mauremootoo, D. O'Dowd, W. Orapa, S. Sastroutomo, A. Saunders, C. Shine, S. Thrainsson, and L. Vaiutu, 2007: Ecological and socioeconomic impacts of invasive alien species in island ecosystems. *Environmental Conservation*, **34(02)**, 98-111.

Reenberg, A., T. Birch-Thomsen, O. Mertz, B. Fog, and S. Christiansen, 2008: Adaptation of human coping strategies in a small island society in the SW Pacific – 50 years of change in the coupled human-environment system on Bellona, Solomon Islands. *Human Ecology*, **36(6)**, 807-819.

Restrepo, J.C., L. Otero, A.C. Casas, A. Henao, and J. Gutiérrez, 2012: Shoreline changes between 1954 and 2007 in the marine protected area of the Rosario Island Archipelago (Caribbean of Colombia). *Ocean & Coastal Management*, **69**, 133-142.

Richmond, N. and B.K. Sovacool, 2012: Bolstering resilience in the coconut kingdom: improving adaptive capacity to climate change in Vanuatu. *Energy Policy*, **50**, 843-848.

Riedy, C. and I. McGregor, 2011: Climate governance is failing us: we all need to respond. *PORTAL Journal of Multidisciplinary International Studies*, **8(3 SI)**, http://epress.lib.uts.edu.au/journals/index.php/portal/issue/view/171.

Rocha, S., I. Ineich, and J. Harris, 2009: Cryptic variation and recent bipolar range expansion within the Stumped-Toed Gecko *Gehyra mutilata* across Indian and Pacific Ocean islands. *Contributions to Zoology*, **78(1)**, 1-8.

Rogers, T., K. Chmutina, and L.L. Moseley, 2012: The potential of PV installations in SIDS – an example in the island of Barbados. *Management of Environmental Quality: An International Journal*, **23(3)**, 284-290.

Romine, B.M. and C.H. Fletcher, 2013: A summary of historical shoreline changes on beaches of Kauai, Oahu, and Maui, Hawaii. *Journal of Coastal Research*, **29(3)**, 605-614.

Rongo, T. and R. van Woesik, 2011: Ciguatera poisoning in Rarotonga, southern Cook Islands. *Harmful Algae*, **10(4)**, 345-355.

Rosenberg, E., A. Kushmaro, E. Kramarsky-Winter, E. Banin, and L. Yossi, 2009: The role of microorganisms in coral bleaching. *The International Society for Microbial Ecology (ISME) Journal*, **3(2)**, 139-146.

Ross, M.S., J.J. O'Brien, R.G. Ford, K. Zhang, and A. Morkill, 2009: Disturbance and the rising tide: the challenge of biodiversity management on low-island ecosystems. *Frontiers in Ecology and the Environment*, **7(9)**, 471-478.

Rozell, D.J. and T.F. Wong, 2010: Effects of climate change on groundwater resources at Shelter Island, New York State, USA. *Hydrogeology Journal*, **18(7)**, 1657-1665.

Rudiak-Gould, P., 2012: Promiscuous corroboration and climate change translation: a case study from the Marshall Islands. *Global Environmental Change*, **22(1)**, 46-54.

Russell, L., 2009: *Poverty, Climate Change and Health in Pacific Island Countries.* Menzies Centre for Health Policy, University of Sydney, Sydney, NSW, Australia, 55 pp.

Santese, M., M.R. Perrone, A.S. Zakey, F. De Tomasi, and F. Giorgi, 2010: Modeling of Saharan dust outbreaks over the Mediterranean by RegCM3: case studies. *Atmospheric Chemistry and Physics*, **10(1)**, 133-156.

Sax, D.F. and S.D. Gaines, 2008: Species invasions and extinction: the future of native biodiversity on islands. *Proceedings of the National Academy of Sciences of the United States of America*, **105(1 Suppl.)**, 11490-11497.

Scheffers, A. and S. Scheffers, 2006: Documentation of the impact of Hurricane Ivan on the coastline of Bonaire (Netherlands Antilles). *Journal of Coastal Research*, **22(6)**, 1437-1450.

Schipper, L. and M. Pelling, 2006: Disaster risk, climate change and international development: scope for, and challenges to, integration. *Disasters*, **30(1 SI)**, 19-38.

Schleupner, C., 2008: Evaluation of coastal squeeze and its consequences for the Caribbean island Martinique. *Ocean & Coastal Management*, **51(5)**, 383-390.

Schofield, P.J., 2010: Update on geographic spread of invasive lionfishes (*Pterois volitans* [Linnaeus, 1758] and *P. miles* [Bennett, 1828]) in the western North Atlantic Ocean, Caribbean Sea and Gulf of Mexico. *Aquatic Invasions*, **5(1 Suppl.)**, S117-S122.

Schwarz, A., C. Béné, G. Bennett, D. Boso, Z. Hilly, C. Paul, R. Posala, S. Sibiti, and N. Andrew, 2011: Vulnerability and resilience of remote rural communities to shocks and global changes: empirical analysis from Solomon Islands. *Global Environmental Change*, **21(3)**, 1128-1140.

Scott, D., S. Gössling, and C.M. Hall, 2012a: International tourism and climate change. *Wiley Interdisciplinary Reviews: Climate Change*, **3(3)**, 213-232.

Scott, D., S. Gössling, and C.M. Hall, 2012b: *Climate Change and Tourism: Impacts, Adaptation and Mitigation.* Routledge, Abingdon, UK and New York, NY, USA, 437 pp.

Scott, D., M.C. Simpson, and R. Sim, 2012c: The vulnerability of Caribbean coastal tourism to scenarios of climate change related sea level rise. *Journal of Sustainable Tourism*, **20(6)**, 883-898.

Şekercioglu, C.H., S.H. Schneider, J.P. Fay, and S.R. Loarie, 2008: Climate change, elevational range shifts, and bird extinctions. *Conservation Biology*, **22(1)**, 140-150.

Senapathi, D., M.A.C. Nicoll, C. Teplitsky, C.G. Jones, and K. Norris, 2011: Climate change and the risks associated with delayed breeding in a tropical wild bird population. *Proceedings of the Royal Society B*, **278(1722)**, 3184-3190.

Shen, S. and F. Gemenne, 2011: Contrasted views on environmental change and migration: the case of Tuvaluan migration to New Zealand. *International Migration*, **49(s1 Suppl.)**, e224-e242.

Sinane, K., G. David, G. Pennober, and R. Troadec, 2010: Fragilisation et modification des formations littorales meubles sur l'île d'Anjouan (Comores): quand l'érosion d'origine anthropique se conjugue au changement climatique. *VertigO*, *La Revue Électronique en Sciences de l'Environnement*, **10(3)** (in French), http://vertigo.revues.org/10528?lang=en.

Solomon, S.M. and D.L. Forbes, 1999: Coastal hazards and associated management issues on South Pacific Islands. *Ocean & Coastal Management*, **42(6)**, 523-554.

Sovacool, B.K., 2012: Expert views of climate change adaptation in the Maldives. *Climatic Change*, **114(2)**, 295-300.

Spennemann, D.H.R., 1996: Nontraditional settlement patterns and typhoon hazard on contemporary Majuro Atoll, Republic of Marshall Islands. *Environmental Management*, **20(3)**, 337-348.

Srinivasan, U.T., 2010: Economics of climate change: risk and responsibility by world region. *Climate Policy*, **10(3)**, 298-316.

Steinberger, J.K., J. van Niel, and D. Bourg, 2009: Profiting from negawatts: Reducing absolute consumption and emissions through a performance-based energy economy. *Energy Policy*, **37(1)**, 361-370.

Stephenson, T.S., A.A. Chen, and M.A. Taylor, 2008: Toward the development of prediction models for the primary Caribbean dry season. *Theoretical and Applied Climatology*, **92(1-2)**, 87-101.

Storey, D. and S. Hunter, 2010: Kiribati: an environmental 'perfect storm'. *Australian Geographer*, **41(2)**, 167-181.

Stuart, E.K., 2006: Energizing the island community: a review of policy standpoints for energy in small island states and territories. *Sustainable Development*, **14(2)**, 139-147.

Swart, R. and F. Raes, 2007: Making integration of adaptation and mitigation work: mainstreaming into sustainable development policies. *Climate Policy*, **7(4)**, 288-303.

Tabucanon, G.M. and B. Opeskin, 2011: The resettlement of Nauruans in Australia: an early case of failed environmental migration. *The Journal of Pacific History*, **46(3)**, 337-356.

Takasaki, Y., 2011: Do the commons help augment mutual insurance among the poor? *World Development*, **39(3)**, 429-438.

Tanzil, J.T.I., B.E. Brown, and A.W. Tudhope, 2009: Decline in skeletal growth of the coral *Porites lutea* from the Andaman Sea, South Thailand between 1984 and 2005. *Coral Reefs*, **28(2)**, 519-528.

Taylor, M.A., A. Centella, J. Charlery, I. Borrajero, A. Benzanilla, J. Campbell, R. Rivero, T.S. Stephenson, F. Whyte, and R. Watson, 2007: *Glimpses of the Future: A Briefing from the PRECIS Caribbean Climate Change Project.* Published by the Climate Studies Group, Mona, for the Caribbean Community Climate Change Centre (CCCCC), Belmopan, Belize, 24 pp.

Taylor, M.A., F.S. Whyte, T.S. Stephenson, and J.D. Campbell, 2013: Why dry? Investigating the future evolution of the Caribbean Low Level Jet to explain projected Caribbean drying. *International Journal of Climatology*, **33(3)**, 784-792.

Techera, E., 2008: Customary law and community based conservation of marine areas in Fiji. In: *Beyond the Global Village. Environmental Challenges Inspiring Global Citizenship* [Hillerbrand, R. and R. Karlsson (eds.)]. Proceedings of the 6th Global Conference on Environmental Justice and Global Citizenship 2007 held by Inter-Disciplinary Net at Mansfield College, Oxford, UK, 2-5 July 2007, eBook, Interdisciplinary Press, Oxford, UK, pp. 107-121.

Tegart, W.J.M., G.W. Sheldon, and D.C. Griffiths, 1990: Policymakers' summary. In: *Climate Change: The IPCC Impacts Assessment. Contribution of Working Group II to the First Assessment Report of the Intergovernmental Panel on Climate Change* [Tegart, W.J.M., G.W. Sheldon, and D.C. Griffiths (eds.)]. Australian Government Publishing Service, Canberra, ACT, Australia, pp. 1-5.

Teles, F.R., 2011: Update on dengue in Africa. *Dengue Bulletin*, **35**, 35-51.

Terry, J.P. and A.C. Falkland, 2010: Responses of atoll freshwater lenses to storm-surge overwash in the northern Cook Islands. *Hydrogeology Journal*, **18(3)**, 749-759.

Terry, J.P., S. Garimella, and R.A. Kostaschuk, 2002: Rates of floodplain accretion in a tropical island river system impacted by cyclones and large floods. *Geomorphology*, **42(3-4)**, 171-182.

Tester, P.A., R.L. Feldman, A.W. Nau, S.R. Kibler, and R. Wayne Litaker, 2010: Ciguatera fish poisoning and sea surface temperatures in the Caribbean Sea and the West Indies. *Toxicon*, **56(5)**, 698-710.

Thiengo, S.C., A. Maldonado, E.M. Mota, E.J.L. Torres, R. Caldeira, O.S. Carvalho, A.P.M. Oliveira, R.O. Simoes, M.A. Fernandez, and R.M. Lanfredi, 2010: The giant African snail *Achatina fulica* as natural intermediate host of *Angiostrongylus cantonensis* in Pernambuco, northeast Brazil. *Acta Tropica*, **115(3)**, 194-199.

Thomas, A. and R. Leichenko, 2011: Adaptation through insurance: lessons from the NFIP. *International Journal of Climate Change Strategies and Management*, **3(3)**, 250-263.

Thomas-Hope, E. and A. Jardine-Comrie, 2007: Valuation of environmental resources for tourism in small island developing states: implications for planning in Jamaica. *International Development Planning Review*, **29(1)**, 93-112.

Tkachenko, K.S., 2012: The northernmost coral frontier of the Maldives: the coral reefs of Ihavandippolu Atoll under long-term environmental change. *Marine Environmental Research*, **82**, 40-48.

Tompkins, E.L., M.C. Lemos, and E. Boyd, 2008: A less disastrous disaster: managing response to climate-driven hazards in the Cayman Islands and NE Brazil. *Global Environmental Change*, **18(4)**, 736-745.

Tompkins, E.L., L. Hurlston, and W. Poortinga, 2009: Foreignness as a constraint on learning: the impact of migrants on disaster resilience in small islands. *Environmental Hazards*, **8(4)**, 263-277.

Tompkins, E.L., W.N. Adger, E. Boyd, S. Nicholson-Cole, K. Weatherhead, and N. Arnell, 2010: Observed adaptation to climate change: UK evidence of transition to a well-adapting society. *Global Environmental Change*, **20(4)**, 627-635.

Tsyban, A., J.T. Everett, and J. Titus, 1990: World oceans and coastal zones. In: *Climate Change: The IPCC Impacts Assessment. Report prepared for Intergovernmental Panel on Climate Change by Working Group II* [Tegart, W.J. McG., G.W. Sheldon, and D.C. Griffiths (eds.)]. Australian Government Publishing Service, Canberra, ACT, Australia, pp. 6-1 to 6-28.

Uno, I., K. Eguchi, K. Yumimoto, T. Takemura, A. Shimizu, M. Uematsu, Z. Liu, Z. Wang, Y. Hara, and N. Sugimoto, 2009: Asian dust transported one full circuit around the globe. *Nature Geoscience*, **2**, 557-560.

UNWTO, 2012: *Challenges and Opportunities for Tourism Development in Small Island Developing States*. United Nations World Tourism Organization (UNWTO), Madrid, Spain, 122 pp.

Uyarra, M.C., I.M. Cote, J.A. Gill, R.R.T. Tinch, D. Viner, and A.R. Watkinson, 2005: Island-specific preferences of tourists for environmental features: implications of climate change for tourism-dependent states. *Environmental Conservation*, **32(1)**, 11-19.

van Aalst, M.K., T. Cannon, and I. Burton, 2008: Community level adaptation to climate change: the potential role of participatory community risk assessment. *Global Environmental Change*, **18(1)**, 165-179.

van Alphen, K., H.S. Kunz, and M.P. Hekkert, 2008: Policy measures to promote the widespread utilization of renewable energy technologies for electricity generation in the Maldives. *Renewable and Sustainable Energy Reviews*, **12(7)**, 1959-1973.

van der Werf, G.R., D.C. Morton, R.S. DeFries, J.G.J. Olivier, P.S. Kasibhatla, R.B. Jackson, G.J. Collatz, and J.T. Randerson, 2009: CO_2 emissions from forest loss. *Nature Geoscience*, **2**, 737-738.

van Hooidonk, R., J. Maynard, and S. Planes, 2013: Temporary refugia for coral reefs in a warming world. *Nature Climate Change*, **3**, 508-511.

Van Kleef, E., H. Bambrick, and S. Hales, 2010: The geographic distribution of dengue fever and the potential influence of global climate change. *TropIKA.Net*, http://journal.tropika.net/pdf/tropika/2010nahead/a01v2n1.pdf.

van Ledden, M., G. Vaughn, J. Lansen, F. Wiersma, and M. Amsterdam, 2009: Extreme wave event along the Guyana coastline in October 2005. *Continental Shelf Research*, **29(1)**, 352-361.

Van Nostrand, J.M. and J.G. Nevius, 2011: Parametric insurance: using objective measures to address the impacts of natural disasters and climate change. *Environmental Claims Journal*, **23(3-4)**, 227-237.

Vassie, J.M., P.L. Woodworth, and M.W. Holt, 2004: An example of North Atlantic deep-ocean swell impacting ascension and St. Helena Islands in the central South Atlantic. *Journal of Atmospheric and Oceanic Technology*, **21(7)**, 1095-1103.

Voccia, A., 2012: Climate change: what future for small, vulnerable states? *International Journal of Sustainable Development & World Ecology*, **19(2)**, 101-115.

Walsh, K.J.E., K.L. McInnes, and J.L. McBride, 2012: Climate change impacts on tropical cyclones and extreme sea levels in the South Pacific – a regional assessment. *Global and Planetary Change*, **80-81**, 149-164.

Warrick, O., 2009: Ethics and methods in research for community-based adaptation: reflections from rural Vanuatu. *Participatory Learning and Action*, **60**, 76-87.

Waycott, M., C.M. Duarte, T.J.B. Carruthers, R.J. Orth, W.C. Dennison, S. Olyarnik, A. Calladine, J.W. Fourqurean, K.L. Heck, A.R. Hughes, G.A. Kendrick, W.J. Kenworthy, F.T. Short, and S.L. Williams, 2009: Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences of the United States of America*, **106(30)**, 12377-12381.

Waycott, M., L.J. McKenzie, J.E. Mellors, J.C. Ellison, M.T. Sheaves, C. Collier, A.M. Schwarz, A. Webb, J.E. Johnson, and C.E. Payri, 2011: Vulnerability of mangroves, seagrasses and intertidal flats in the tropical Pacific to climate change. In: *Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change* [Bell, D., J.E. Johnson, and J.A. Hobday (eds.)]. Secretariat of the Pacific Community, Noumea, New Caledonia, pp. 297-368.

Webb, A.P., and P.S. Kench, 2010: The dynamic response of reef islands to sea-level rise: evidence from multi-decadal analysis of island change in the central Pacific. *Global and Planetary Change*, **72(3)**, 234-246.

Webb, N.R., S.J. Coulson, I.D. Hodkinson, W. Block, J.S. Bale, and A.T. Strathdee, 1998: The effects of experimental temperature elevation on populations of cryptostigmatic mites in high Arctic soils. *Pedobiologia*, **42(4)**, 298-308.

Weil, E. and A. Cróquer, 2009: Spatial variability in distribution and prevalence of Caribbean scleractinian coral and octocoral diseases. I. Community-level analysis. *Diseases of Aquatic Organisms*, **83(3)**, 195-208.

Weil, E. and C.S. Rogers, 2011: Coral reef diseases in the Atlantic-Caribbean. In: *Coral Reefs: An Ecosystem in Transition* [Dubinsky, Z. and N. Stambler (eds.)]. Springer, Dordrecht, Netherlands, pp. 465-491.

Weir, T. and Z. Virani, 2011: Three linked risks for development in the Pacific Islands: climate change, disasters and conflict. *Climate and Development*, **3(3)**, 193-208.

Westphal, M., M. Browne, K. MacKinnon, and I. Noble, 2008: The link between international trade and the global distribution of invasive alien species. *Biological Invasions*, **10(4)**, 391-398.

Wetzel, F.T., H. Beissmann, D.J. Penn, and W. Jetz, 2013: Vulnerability of terrestrial island vertebrates to projected sea-level rise. *Global Change Biology*, **19(7)**, 2058-2070.

Wheeler, D., 2011: *Quantifying Vulnerability to Climate Change: Implications for Adaptation Assistance.* CGD Working Paper 240, Center for Global Development (CGD), Washington, DC, USA, 49 pp.

White, I. and T. Falkland, 2010: Management of freshwater lenses in small Pacific islands. *Hydrogeology Journal*, **18(1)**, 227-246.

White, I., T. Falkland, P. Perez, A. Dray, T. Metutera, E. Metai, and M. Overmars, 2007: Challenges in freshwater management in low coral atolls. *Journal of Cleaner Production*, **15(16)**, 1522-1528.

Whyte, F.S., M.A. Taylor, T.S. Stephenson, and J.D. Campbell, 2008: Features of the Caribbean Low Level Jet. *International Journal of Climatology*, **28(1)**, 119-128.

Williams, G.J., I.S. Knapp, J.E. Maragos, and S.K. Davy, 2010: Modelling patterns of coral bleaching at a remote Pacific atoll. *Marine Pollution Bulletin*, **60(9)**, 1467-1476.

Willis, J.K. and J.A. Church, 2012: Regional sea-level projection. *Science*, **336(6081)**, 550-551.

Winters, L.A. and P.M. Martins, 2004: When comparative advantage is not enough: business costs in small remote economies. *World Trade Review*, **3(3)**, 347-383.

Woodroffe, C.D., 2008: Reef-island topography and the vulnerability of atolls to sea-level rise. *Global and Planetary Change*, **62(1-2)**, 77-96.

Yamamoto, L. and M. Esteban, 2010: Vanishing island states and sovereignty. *Ocean & Coastal Management*, **53(1)**, 1-9.

Yamano, H., H. Kayanne, T. Yamaguchi, Y. Kuwahara, H. Yokoki, H. Shimazaki, and M. Chicamori, 2007: Atoll island vulnerability to flooding and inundation revealed by historical reconstruction: Fongafale Islet, Funafuti Atoll, Tuvalu. *Global and Planetary Change*, **57(3-4)**, 407-416.

Yates, M.L., G. Le Cozannet, M. Garcin, E. Salaï, and P. Walker, 2013: Multidecadal atoll shoreline change on Manihi and Manuae, French Polynesia. *Journal of Coastal Research*, **29(4)**, 870-882.

Zahibo, N., E. Pelinovsky, T. Talipova, A. Rabinovich, A. Kurkin, and I. Nikolkina, 2007: Statistical analysis of cyclone hazard for Guadeloupe, Lesser Antilles. *Atmospheric Research*, **84(1)**, 13-29.