

Chapter 29. Small Islands**Coordinating Lead Authors**

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25 Executive Summary

26

27 **The distinction between *observed* and *projected* impacts of climate change is often not clear in the literature on small islands (*high agreement*).** Many publications deal with both types of impact, often using a recent
28 ‘observed’ impact relating to some extreme weather- climate- or ocean-related event as an analogy to what may
29 happen in the future. Moreover, much of the literature on projected climate change impacts on small islands is not
30 specific about the scenario (s) used, partly because of the difficulty in moving from global-scale scenarios and
31 models to the scale of small islands. [29.4] Consequently, there is *low confidence* in the magnitude of projected
32 impacts in some sectors and systems of small islands. However, there is evidence that this challenge can be partly
33 overcome with continued improvements in downscaling, as is demonstrated by the use of downscaled SRES
34 scenarios in a comprehensive assessment of the vulnerability of fisheries in 22 Pacific island countries. As these and
35 other studies are duplicated elsewhere, confidence in projected impacts of climate change on small islands will
36 increase. [29.3, 29.4.2]
37
38

39 **Many impacts on small islands are generated from processes well beyond the borders of an individual nation or island and generally they have negative effects (*high confidence, robust evidence*).** Trans-boundary impacts
40 on small islands may originate in distant regions including continental countries and high latitudes. Examples of the
41 former include airborne dust from the Sahara and Asia reaching small islands far down-drift from the desert source,
42 and examples of the latter include large ocean swells generated by extra tropical cyclones and high latitude low
43 pressure systems. [29.5.1, 29.5.2] Other trans-boundary impacts result from invasive plant and animal species that
44 reach the warmth of tropical small islands and the spread of aquatic pathogens that may have implications for human
45 health. For island communities the trans-boundary implications of existing and future ‘invasions’ and human health
46 challenges are projected to increase in a changing climate. [29.3.3.2, 29.5.3, 29.5.5]
47
48

49 **For most small islands climate change is just one of a series of multiple stresses that must be coped with, and often it is not the most important one (*medium agreement, medium confidence*).** Increasingly there are arguments
50 that priority in the short-term should be given to addressing immediate development problems such as water supply,
51 waste management, deteriorating ecosystems and food security. [29.3.3] We agree that addressing the critical social,
52 economic and environmental issues of the day will *likely* increase human and environmental resilience to the longer-
53 term impacts of climate change. [29.6.1, 29.6.2.3, Figure 29-5]
54

1
2 **Adaptation and mitigation on small islands are not trade-offs, but can be regarded as complementary**
3 **components in the response to climate change (*medium confidence*).** At least three key areas for adaptation-
4 mitigation inter-linkages in small islands are identified here: energy supply and use, tourism infrastructure and
5 activities, and coastal wetlands. The alignment of these sectors for potential emission reductions together with
6 adaptation needs offers co-benefits and opportunities in small islands. [29.7.2, 29.8] Lessons learned from
7 adaptation and mitigation experiences in one island may offer some guidance to other small island states, though we
8 have *low confidence* in the wholesale transfer of adaptation and mitigation options when the lenses through which
9 they are viewed differ from one island state to the next, based on cultural, socio-economic, ecological and political
10 values. [29.6.2, 29.8]

11
12 **Assistance from the international community is vital for supporting adaptation and mitigation programs in**
13 **small islands, though there is increasing concern that some types of interventions may be maladaptive**
14 **(*medium evidence*).** Caution is needed to ensure that donors are not driving the climate change agenda in small
15 islands, as there is a risk that donor-driven adaptation and mitigation aid may not address the critical challenges
16 confronting island governments and communities, and may not be aligned with the sustainable development goals of
17 small islands (*high agreement*). This may lead to inadequate adaptation or a waste of scarce resources and may
18 unintentionally cause enhanced vulnerability by supporting inappropriate adaptation strategies that are externally
19 derived, rather than optimizing the benefits of local practices that have proven to be efficacious through time. [29.8,
20 Box 29-1, 29.6.2.3, 29.6.3]

21
22 **Island vulnerability to climate change may be related to the experience and perceptions of islanders to both**
23 **climate and non-climate stressors (*medium agreement*).** Islands and islanders are recognized for their long
24 experience of adapting to a range of hazards including extreme weather-climate- and ocean-related events and for
25 their resilience in coping with such hazards. We have *medium confidence* that adaptive capacity is better when the
26 frequency of hazards is greater, but there may be limits to this capacity when small islands are going through rapid
27 socio-economic change. [29.3.3.1, 29.6.1, 29.6.2]

28 29 30 **29.1. Introduction**

31
32 It has long been recognized that greenhouse gas emissions from small islands are negligible in relation to global
33 emissions, but that the threats of climate change and sea-level rise to small islands are very real. Indeed, it has been
34 suggested that the very existence of some atoll nations are threatened by rising sea levels associated with global
35 warming. Whilst such extreme scenarios are not applicable to all small island nations, there is no doubt that on the
36 whole the impacts of climate change on small islands will have serious negative effects especially on socio-
37 economic conditions and bio-physical resources – although impacts will be ameliorated by the extent and
38 effectiveness of adaptation.

39
40 The small islands considered in this chapter are principally sovereign states and territories located within the tropics
41 of the southern and western Pacific Ocean, central and western Indian Ocean, the Caribbean Sea, and the eastern
42 Atlantic off the coast of west Africa, as well as in the more temperate Mediterranean Sea.

43
44 Although these small islands nations are by no means homogenous politically, socially, or culturally, or in terms of
45 physical size and character or economic development, there has been a tendency to generalise about the potential
46 impacts on small islands and their adaptive capacity. In this chapter we attempt to strike a balance between
47 identifying the differences between small islands as well as recognising that small islands tend to share a number of
48 common characteristics that have distinguished them as a particular group in international affairs. Also in this
49 chapter we reiterate some of the frequently voiced and key concerns relating to climate change impacts,
50 vulnerability and adaptation whilst emphasising a number of additional themes that have emerged in the literature on
51 small islands since the IPCC Fourth Assessment. These include the relationship between climate change policy,
52 activities and development issues; externally generated trans-boundary impacts; and the implications of risk in
53 relation to adaptation and the adaptive capacity of small island nations.

29.2. Major Conclusions from Previous Assessments

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

The Second Assessment (SAR) in 1995 confirmed the vulnerable state of small islands, now included in a specific chapter titled ‘Coastal Zones and Small Islands’ (Bijlsma, *et al.*, 1996). However, importantly the SAR recognized that both vulnerability and impacts would be highly variable between small islands and that impacts were ‘likely to be greatest where local environments are already under stress as a result of human activities’ (Bijlsma, *et al.*, 1996: 290-291). The report also summarized results from the application of a common methodology for vulnerability and adaptation analysis that gave new insights into the socio-economic implications of sea-level rise for small islands including: negative impacts on virtually all sectors including tourism, freshwater resources, fisheries and agriculture, human settlements, financial services and human health; protection is likely to be very costly; and, adaptation would involve a series of tradeoffs. It also noted that major constraints to adaptation on small islands included: lack of technology and human resource capacity, serious financial limitations, lack of cultural and social acceptability and uncertain political and legal frameworks. Integrated coastal and island management was seen as a way of overcoming some of these constraints.

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

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

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

1 critical development needs of the present. As a result, it is argued, there is a reduction in resilience that will have
2 serious ramifications for small island adaptation in the future.

5 **29.3. Observed Impacts of Climate Change, including Detection and Attribution**

6
7 The distinction between *observed* impacts of climate change and *projected* impacts is often unclear in the small
8 islands literature and discussions. Publications frequently deal with both aspects of impacts interchangeably, and use
9 observed impacts from, for instance an extreme seasonal event, as an analogy to what may happen in the future due
10 to climate change (e.g. Lo-Yat *et al.*, 2011). The key climate and ocean drivers of change that impact small islands
11 include variations in air and ocean temperatures, ocean chemistry, rainfall, wind strength and direction, sea-levels
12 and wave climate and particularly the extremes such as tropical cyclones, drought and distant storm swell events. All
13 have varying impacts, dependent on the magnitude and frequency and temporal and spatial extent, as well as on the
14 bio-physical nature of the island and its social, economic and political setting.

15
16 [INSERT FIGURE 29-1 HERE

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

24 **29.3.1. Observed Impacts on Island Coasts and Marine Biophysical Systems**

26 *29.3.1.1. Sea Level Rise, Inundation, and Shoreline Change on Small Islands*

27
28 Sea-level rise poses one of the most widely recognized climate change threats to low-lying coastal areas (Church
29 and White 2011; Cazenave and Llovel, 2010; Nicholls and Cazenave, 2010). This is particularly important in small
30 islands where the majority of human communities and infrastructure are located in coastal zones with limited
31 relocation opportunities especially on atoll islands (Woodroffe, 2008) (Figure 29-1). Rates of global average sea-
32 level rise have continued at approximately 3.3 mm yr⁻¹ between 1993 and 2011 and acceleration is detected in
33 longer records since 1870 (Merrifield *et al.*, 2009; Church and White, 2011) (See Chapter 13, Working Group 1).
34 Rates of sea-level rise are however not uniform across the globe and large regional differences have been detected
35 including in the south Indian Ocean and tropical Pacific, where rates have been significantly higher than the global
36 average (Meyssignac *et al.*, 2012). In the tropical western Pacific where a large number of small island communities
37 exist, rates up to four times the global average (approximately 12 mm yr⁻¹) have been reported between 1993 and
38 2009 and are generally thought to describe transient rates associated with natural cyclic climate phenomena such as
39 ENSO (El Niño-Southern Oscillation) (Cazenave and Remy, 2011; Becker *et al.*, 2012). Large interannual
40 variability in sea level has also been demonstrated from the Indian Ocean (e.g Chagos Archipelago, Dunne *et al.*,
41 2012) whilst in the Caribbean Palanisamy *et al.* (2012) found that over the last 60 years the mean rates of sea-level
42 rise in the Caribbean region were similar to the global average ~ 1.8mm yr⁻¹.

43
44 There are few long-term sea level change trends for individual small island locations and the situation is hampered
45 in many sites by the absence of adequate monitoring regimes. Furthermore, sea flooding and inundation is
46 frequently associated with sea level extremes caused by transient phenomena, e.g.; surge, storm wave and routine
47 lunar (tidal) cycles (Vassie *et al.*, 2004; Zahibo *et al.*, 2007; Komar and Allan, 2008; Haigh *et al.*, 2011). For
48 example, high spring tide floods at Fongafale Island, Funafuti Atoll, Tuvalu, have been well publicized and study
49 has shown that areas of the central portion of Fongafale are already below sea-level at high spring tide (Yamano *et al.*,
50 2007). Rates of relative sea level rise at Funafuti between 1950 – 2009 has been approximately three times
51 higher than the global average (Becker *et al.*, 2012) and saline flooding of internal low-lying areas occurs regularly
52 and is expected to become more frequent and extensive over time (Yamano *et al.*, 2007).

1 Documented cases of coastal inundation and erosion often cite extenuating circumstances such as vertical
2 subsidence, engineering works, development activities or beach mining. Three examples can be cited. First, on the
3 Torres Islands, Vanuatu communities have been displaced due to increasing inundation of low-lying settlement areas
4 due to a combination of tectonic subsidence and sea-level rise (Ballu *et al.*, 2011). Second, on Anjouan Island,
5 Comores in the Indian Ocean, Sinane *et al.* (2010) found beach aggregate mining was a major contributing factor
6 influencing rapid beach erosion. Third, the intrinsic exposure of rapidly expanding settlements and agriculture in the
7 low-lying flood prone Rewa Delta, Fiji is shown by Lata and Nunn (2012) to place populations in increasingly
8 severe conditions of vulnerability to flooding and marine inundation.
9

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

21 In many locations changing patterns of human settlement and direct impacts on shoreline processes present
22 immediate erosion challenges in populated islands and coastal zones (Yamano *et al.*, 2007; Storey and Hunter, 2010;
23 Novelo-Casanova and Suarez, 2010) and mask attribution. A study of Majuro atoll (Marshall Islands) found that
24 erosion was widespread but attribution to factors like sea level rise were masked by pervasive anthropogenic
25 impacts to the coastal system (Ford, 2012). Similarly a study of three islands in the Rosario Archipelago (Colombia)
26 reported shoreline retreat over a 50-55 year span and found Grande, Rosario, and Tesoro Islands had lost 6.7, 8.2
27 and 48.7 per cent of their land area respectively. Erosion was largely attributed to management issues on densely
28 settled Grande Island, whilst sea level increase and persistent northeast winds enhanced erosion on uninhabited
29 Rosario, and Tesoro (Restrepo *et al.*, 2012). Likewise, Cambers (2009) reported average beach erosion rates of 0.5
30 m yr⁻¹ in eight Caribbean islands from 1985-2000 and whilst the study could not quantify the extent of attribution it
31 did highlight that greater erosion rates were positively correlated with the number of hurricane events. Alternately,
32 Etienne and Terry (2012) found the net shoreline impacts of a category 4 cyclone which passed within 30 km of
33 Taveuni Island (Fiji) nourished shorelines with fresh coralline sediments despite localized storm damage. These
34 studies contribute to improved understanding of island shoreline processes and change since AR4 though the
35 vulnerability of small island shores and low-lying areas to increasing inundation and erosion in response to sea level
36 rise and other potential climate change stressors provided in AR4, remains unchanged.
37
38

39 29.3.1.2. Coastal Ecosystem Change on Small Islands: Coral Reefs and Coastal Wetlands

40
41 Coral reefs are an important resource in small tropical islands and the culture and wellbeing of island communities is
42 linked to their on-going function and productivity. They play a significant role in supplying sediment to island
43 shores and in mediating wave energy this reducing potential at-shore erosion. They also provide habitat for a host of
44 marine species upon which many island communities are dependent for subsistence diets as well as underpinning
45 beach and reef-based touristic economic activity (Bell *et al.*, 2011; Perch-Nielsen, 2010). The documented
46 sensitivity of coral reef ecosystems to climate change is summarized elsewhere (see Box CC-CR).
47

48 Increased coral bleaching due to thermal stress and reduced calcification rates due to increasing CO₂ concentration
49 are expected to affect the function and viability of living reef systems (Hoegh-Guldberg *et al.*, 2007; Eakin *et al.*,
50 2009) and some studies are starting to observe impacts consistent with regional reef decline (De'ath *et al.*, 2009;
51 Tanzil *et al.*, 2009; Cantin *et al.*, 2010). Unprecedented bleaching events in small islands have been recorded in the
52 remote Phoenix Group (Kiribati) where there had been near 100 per cent coral mortality in the lagoon environment
53 and 62 per cent mortality on the outer leeward slopes of the otherwise pristine reefs of Kanton Atoll during 2002 /
54 2003 (Alling *et al.*, 2007). Similar patterns of mortality were observed in four other atolls in the Phoenix group and

1 temperature-induced coral bleaching was also recorded in isolated and unpopulated Palmyra Atoll during the 2009
2 ENSO event (Williams *et al.*, 2010). In 2005 extensive bleaching was recorded at 22 sites around Rodrigues Island
3 in the western Indian Ocean with up to 75% of the dominant species affected in some areas (Hardman *et al.*, 2007).
4 Studies of the severe 1998 El Niño bleaching event in the tropical Indian Ocean showed reefs in the Maldives,
5 Seychelles and Chagos Islands were among the most impacted (Cinner *et al.*, 2012; Tkachenko, 2012). In 2005 a
6 reef survey around Barbados following a Caribbean regional bleaching event revealed the most severe bleaching
7 ever recorded with approximately 70% of corals impacted (Oxenford *et al.*, 2008). Globally, the incidence and
8 implications of temperature-related coral bleaching in small islands is well documented and the synergistic effect of
9 increasing ocean acidification can be considered a threat to the long-term persistence of island coral reef ecosystems
10 (see Box CC-OA).

11
12 Island reefs have limited defences against thermal stress and acidification. However studies such as Cinner *et al.*
13 (2012) and Tkachenko (2012) highlight that whilst recovery from bleaching is variable, some reefs show greater
14 resilience that has important implications for reef protection and management regimes. Additionally, there is
15 evidence that coral reef resilience is enhanced in the absence of other environmental stresses such as declining water
16 quality. In Belize chronologies of growth rates in massive corals *Montastraea faveolata* over the past 75–150 years
17 show that the bleaching event in 1998 was unprecedented but that the severity of the response also appeared to stem
18 from reduced thermal tolerance resulting from the direct effect of human coastal development (Carilli *et al.*, 2010).
19 Likewise a study over a 40 year period (1960's – 2008) in the Grand Recif of Tulear, Madagascar concluded that
20 severe degradation was mostly ascribed to direct anthropogenic disturbance of the near shore marine environment,
21 despite an average 1°C increase in temperature over this period (Harris *et al.*, 2010). Coral recovery following the
22 2004 bleaching event in the central Pacific atolls Tarawa and Abaiang (Kiribati) was also noted to likely be
23 improved in the absence of direct human impacts (Donner *et al.*, 2010).

24
25 The loss of coral reef habitat has dire implications to coastal fisheries (Pratchett *et al.*, 2009) in small islands where
26 reef based subsistence and tourism activities are often critical to the wellbeing and economies of islands (Bell *et al.*,
27 2011). In Kimbe Bay, Papua New Guinea 65% of coastal fish are dependent on living reefs at some stage in their
28 life cycles and that there is a decline in fish abundance following reef degradation (Jones *et al.*, 2004). Even where
29 coral reef recovery occurs following bleaching, reef associated species composition may not recover to its original
30 state (Pratchett *et al.*, 2009; Donner *et al.*, 2010). In reefs where bleaching has not been an immediate threat, SST
31 anomaly events like that reported by Lo-Yat *et al.*, (2011) between 1996 and 2000, showed an associated lag in
32 larval supply of coral reef fishes of Rangiroa Atoll, French Polynesia. Higher temperatures have also been
33 implicated in negative affects to spawning of adult reef species (Munday *et al.*, 2009; Donelson *et al.*, 2010).

34
35 Like coral reefs, mangroves and sea grass environments provide a range of ecosystem goods and services (Polidoro
36 *et al.*, 2010 and Waycott *et al.*, 2009) and both habitats play a significant role in the wellbeing of small island
37 communities. Mangroves in particular perform a host of commercial and subsistence uses as well as providing
38 natural coastal protection from erosion and storm events (Ellison, 2009; Krauss *et al.*, 2010; Waycott *et al.*, 2011).

39
40 Sea-level rise is reported as the most significant climate change threat to the survival of mangroves (McKee *et al.*,
41 2007; Waycott *et al.*, 2011) and the loss of seaward edge of mangroves at Hungry Bay, Bermuda has been recorded
42 by Ellison (1993) who attributes this to ongoing sea-level rise and the inability of mangroves to tolerate the
43 increased inundation at the seaward margin. Elsewhere in the Caribbean and tropical Pacific observations vary in
44 regards to the potential for sedimentation rates in mangroves forests to keep pace with sea-level rise (McKee *et al.*,
45 2007; Krauss *et al.*, 2003). In Kosrae and Pohnpei Islands (Federated States of Micronesia), Krauss *et al.*, (2010)
46 found significant variability in mangrove average soil elevation changes due to deposition from a deficit of 4.95 mm
47 y⁻¹ to a surplus of 3.28 mm y⁻¹ relative to their sea-level rise estimates. This depositional potential is mostly reported
48 from high island studies via the addition of terrigenous sediment inputs. However, Rankey's (2011) study of
49 shoreline change in atolls in Kiribati also noted natural seaward migration (up to 40m) of some mangrove areas
50 between 1969 and 2009 suggesting sediment accretion can also occur in the absence of terrigenous inputs.
51 Otherwise, in the absence of vertical accretion landward migration may occur where accommodation space permits
52 (Gilman *et al.*, 2008) though in small islands accommodation space is seldom extensive as illustrated by Martinique
53 in the Caribbean (Schleupner, 2008).

1 The response of sea grass to climate change stress is also likely to be complex, regionally variable and manifest in
2 quite different ways. A study of seven species of sea grasses from tropical Green Island, Australia highlighted the
3 variability in response to heat and light stress (Campbell *et al.*, 2006). Light reduction may be a limiting factor to sea
4 grass growth due to increased depth (Ralph *et al.*, 2007) and Ogston and Field (2010) observed that a 20 cm rise in
5 sea level may double suspended sediment loads and turbidity in shallow waters on Hawaii's Molokai Island's
6 fringing reefs, with negative implications to photosynthetic species such as seagrass. Otherwise, temperature stress
7 is most commonly reported as the main expected climate change impact on sea grass (e.g. Marbá and Duarte 2010;
8 Campbell *et al.*, 2006; Waycott *et al.*, 2011). Literature on seagrass diebacks in small islands is scarce but research
9 in the Balearic Islands (Western Mediterranean) has shown that over a six-year study, sea grass shoot mortality and
10 recruitment rates were negatively influenced by higher temperature (Marbá and Duarte, 2010).

13 **29.3.2. Observed Impacts on Terrestrial Systems: Island Biodiversity and Water Resources**

15 Climate change impacts on terrestrial biodiversity on islands, frequently interacting with several other drivers
16 (Blackburn *et al.*, 2004; Didham *et al.*, 2005), fall into three general categories namely: (a) ecosystem and species
17 horizontal shifts and range decline; (b) altitudinal species range shifts and decline mainly due to temperature
18 increase on high islands; and (c) exotic and pest species range increase and invasions mainly due to temperature
19 increase in high latitude islands. Due to the limited area and isolated nature of most islands, these effects are
20 generally magnified compared to continental areas and may cause species loss especially in tropical islands high in
21 endemics. For example, decline in the long-term persistence of freshwater-dependent ecosystems within two low-
22 lying Caribbean carbonate islands in the Bahamas have been attributed to the synergistic impacts of increasing sea
23 level and reduced rainfall. Greaver and Sternberg (2010) found that during periods of reduced rainfall the shallow
24 freshwater lens subsides and contracts landward and ocean water infiltrates further inland below coastal strand
25 vegetation. The combination of drier conditions and saline incursion in deeper soils negatively impacts vegetation
26 formerly reliant on deeper freshwater reserves. Sea level rise has been observed to threaten the long-term persistence
27 of freshwater-dependent ecosystems within low-lying islands in the Florida Keys in the northern end of the
28 Caribbean (Goodman *et al.*, 2012). On Sugarloaf Key, Ross *et al.* (2009) found pine forest area declined from 88 to
29 30 h from 1935 to 1991 due to increasing salinization and rising ground water, with vegetation transitioning to more
30 saline tolerant species such as mangroves.

32 Whilst there are many studies that report observations associated with temperature increases in mid- and high-
33 latitude islands, such as the Falkland Islands and Marion Islands in the south Atlantic and south Indian ocean
34 respectively (Bokhorst *et al.*, 2007; 2008; (Le Roux *et al.*, 2005) and Svalbard in the Arctic (Webb *et al.*, 1998)
35 there are few equivalent studies in tropical small islands. One exception is a recent study of the tropical bird species
36 the Mauritius kestrel that indicates changing rainfall conditions in the island of Mauritius over the last 50 years has
37 resulted in this species having reduced reproductive success due to a mismatch between the timing of breeding and
38 peak food abundance (Senapathi *et al.*, 2011).

40 Increasing global temperatures also lead to altitudinal species range shifts and contractions within high islands with
41 an upward creep of the tree line and associated faunal species (Benning *et al.*, 2002). Comparative vegetation
42 distribution and composition studies in sub-Antarctic Marion Island, found an altitudinal shift of 3.4 m per year for
43 plant species (Parolo and Rossi 2008). Comparative effects also occur in the tropics such as the Hawaii Volcano
44 National Park where comparison of sample plots over a 40 year period from 1966-67 to 2008 show climate change
45 attributed adaptation of fire adapted grasses upward in elevation (Angelo and Daehler, 2012). Reduction in the
46 numbers and sizes of endemic populations caused by such habitat constriction and changes in species composition in
47 mountain systems may result in demise and possibly extinction of endemic species (Chen *et al.*, 2009; Pauli *et al.*,
48 2007; Sekercioglu *et al.*, 2008). Altitudinal temperature change has also been reported to influence the distribution
49 for disease vectors such as mosquitoes potentially threatening biota unaccustomed to such vectors (Freed *et al.*,
50 2005).

52 Freshwater supply in small island environments has always presented challenges and has been an issue raised in all
53 previous IPCC reports. On high volcanic and granitic islands small and steep river catchments respond rapidly to
54 rainfall events and watersheds generally have restricted storage capacity. On porous limestone and low atoll islands

1 surface runoff is minimal and water rapidly passes through the substrate into the ground water lens. Rainwater
2 harvesting is also an important contribution to freshwater access and alternatives like desalination have mixed
3 success in small island settings due to operational costs (White and Falkland, 2010).

4
5 Rapidly growing demand, land use change, urbanisation and tourism are already placing significant strain on the
6 limited freshwater reserves in small island environments (Cashman *et al.*, 2010; Emmanuel and Spence, 2009;
7 White and Falkland, 2010). In the Caribbean where there is considerable variation in the types of freshwater supplies
8 utilised concern over the status of freshwater availability has been expressed for at least the past 30 years (Cashman
9 *et al.*, 2010). There have also been economic and management failures in the water sector not only in the Caribbean
10 (Mycoo, 2007) but also in small islands in the Indian (Payet and Agricole, 2006) and Pacific oceans (Moglia *et al.*,
11 2008a; 2008b; White *et al.*, 2007) .

12
13 These issues also occur on a background of decreasing rainfall and increasing temperature. Rainfall records
14 averaged over the Caribbean region for 100 years (1900-2000) show a consistent 0.18 mm/year reduction in rainfall,
15 a trend that is projected to continue (Jury and Winter, 2010). In contrast, analysis of rainfall data over the past
16 100years from the Seychelles has shown substantial variability related to ENSO though an increase in average
17 rainfall from 1959 to 1997 and an increase in temperature of ~ 0.25 °C per decade has occurred (Payet and Agricole,
18 2006). Detection of long-term statistical change in precipitation is one prerequisite to understanding the impacts of
19 climate change in small island hydrology and water resources.

20
21 Much recent literature has focussed on saline (sea-water) intrusion into fresh groundwater reserves on atoll islands
22 which is frequently attributed to incremental sea-level rise though there is a paucity of empirical evidence to support
23 this premise (e.g. Rozell and Wong, 2010). White and Falkland's (2010) review of existing small island studies
24 indicates that a sea level increase of up to 1 m would have negligible salinity impacts on atoll island groundwater
25 lenses so long as there is adequate vertical accommodation space, island shores remain intact, rainfall patterns do not
26 change and direct human impacts are managed. However, wave overtopping and wash over can be expected to
27 become more frequent with sea level rise and this has been shown to impact freshwater lenses dramatically. On
28 Pukapuka Atoll, Cook Islands storm surge over-wash occurred in 2005 and caused the fresh water lenses to become
29 immediately brackish and took some 11 months to recover to conductivity levels appropriate for human use (Terry
30 and Falkland, 2010). The ability of freshwater lens' to float upwards within the matrix of the island in step with
31 incremental sea level rise also means that in low-lying and central areas of many atolls the lens may pond at the
32 surface. This phenomenon already occurs in very low-lying central areas of Fongafale Island, Tuvalu, and during
33 extreme high 'king' tides large areas of the inner part of the island become inundated with brackish waters (Yamano
34 *et al.*, 2007; Locke, 2009).

35 36 37 **29.3.3. Observed Impacts on Human Systems of Small Islands**

38 39 **29.3.3.1. Observed Impacts on Island Settlements and Tourism**

40
41 Whilst traditional settlements on high islands were often located inland, the move to coastal locations was
42 encouraged by colonial and religious authorities and more recently through the development of tourism. Now the
43 majority of settlements, infrastructure and development is located on low-lands along the coastal fringe of small
44 islands. In the case of atoll islands, all development and settlement is essentially coastal. It follows that populations,
45 infrastructure, agricultural areas and fresh groundwater supplies are all vulnerable to extreme tides, wave and surge
46 events and sea level rise (Walsh *et al.*, 2012). Population drift from outer islands or from inland, together with rapid
47 population growth in main centers and lack of accommodation space drives growing populations into ever more
48 vulnerable locations. Additionally, without adequate resources and planning, engineering solutions such as shoreline
49 reclamation also place communities and infrastructure in positions of increased risk (Schleupner, 2008; Yamano *et*
50 *al.*, 2007).

51
52 Many of the environmental issues that the media raise relating to Tuvalu, the Marshall Islands and Maldives are in
53 fact only relevant to the major center and its surrounds, that is Funafuti, Majuro and Male respectively. As an
54 example Storey and Hunter (2010) indicate the 'Kiribati' problem does not refer to the whole of Kiribati but rather

1 to the southern part of Tarawa atoll where preexisting issues of severe overcrowding, proliferation of informal
2 housing and unplanned settlement, inadequate water supply, poor sanitation and solid waste disposal, pollution and
3 conflict over land ownership are of concern. They argue that these problems require immediate resolution if the
4 vulnerability of the South Tarawa community to the ‘real and alarming threat’ of climate change is to be managed
5 effectively (Storey and Hunter, 2010).

6
7 On Majuro atoll, rapid urban development and the abandonment of traditional settlement patterns has resulted in
8 movement from less vulnerable to more vulnerable locations on the island (Spennemann, 1996). Likewise,
9 geophysical studies of Fongafale Island, the capital of Tuvalu, show that engineering works during World War II,
10 and rapid development and population growth since independence, has led to the settlement of inappropriate
11 shoreline and swampland areas leaving communities in heightened conditions of vulnerability (e.g. Yamano *et al.*,
12 2007). Ascribing direct climate change impacts in such disturbed environments is problematic due to the existing
13 multiple lines of stress on the island’s biophysical and social systems. However, it is clear that such pre-existing
14 conditions of vulnerability add to the threat of climate change in such locations.

15
16 The issue of ‘coastal squeeze’ remains a concern for many small islands as there is a constant struggle to manage the
17 requirements for physical development against the need to maintain ecological balance (Fish *et al.*, 2008; Sano *et al.*,
18 2010; Gero *et al.*, 2011; Mycoo, 2011). Martinique in the Caribbean exemplifies the point, where physical
19 infrastructure prevents the beach and wetlands from retreating landward as a spontaneous adaptation response to
20 increased rates of coastal erosion (Schleupner, 2008). Moreover, intensive coastal development in the limited coastal
21 zone combined with population growth and tourism have placed great stress on the coast and has resulted in dense
22 aggregations of infrastructure and people in potentially vulnerable conditions.

23
24 Tourism is an important sector on many small islands. Linkages between weather, climate and tourism in small
25 islands have been assessed on several occasions, including in IPCC assessments. There is currently no evidence that
26 observed climatic changes in small island destinations or source markets have altered patterns of demand for tourism
27 to small islands (Scott *et al.*, 2012a). There is also no systematic analysis of how recent extreme storm events have
28 impacted tourism operations (costs of evacuations, damages, recovery interruption, insurance) in small islands
29 (UNWTO, 2010).

30
31 Climate can also impact directly on environmental resources that are major tourism attractions in small islands.
32 Beach erosion is widespread and has been found to negatively impact destination attractiveness and accommodation
33 prices (Houston 2002, Cowell *et al.*, 2006, Buzinde *et al.*, 2010a, 2010b, Hamilton 2007). Erosion caused by
34 Hurricane *Wilma* in 2005 at renowned coastal tourism destinations in Mexico is indicated of these impacts. Tourist
35 perceptions of the beach erosion and restoration ranged from aesthetically unpleasant and feeling deceived by
36 marketing of extensive beaches to focusing on new recreational opportunities provided by the erosion control
37 structures in the water (Buzinde *et al.*, 2010a, 2010b). Visitation at Cancun declined roughly 50% in the year
38 following the erosion, but as beach restoration continued, arrivals recovered to pre-erosion levels in 2007 (Scott *et al.*,
39 2012b). It is unclear whether the extent of this recovery would have occurred without the extensive investment
40 in beach restoration.

41
42 Higher surface water temperatures continue to cause coral bleaching near many small islands. Severe bleaching
43 caused several marine parks and dive sites in Southeast Asia and the Indian Ocean to close during 2010, in an
44 attempt to try and reduce further damage (Sarnsamak, 2011). Studies reveal dive tourists are well aware of coral
45 bleaching, particularly the experienced diver segment (Cesar, 2000; Westmacott *et al.*, 2000, Ngazy *et al.*, 2005,
46 Gössling *et al.*, 2008, Kragt *et al.*, 2009, Klint *et al.*, 2012a, 2012b, Klinthong 2012), and therefore more acute
47 impacts occur among tourism operators and resorts that cater to these markets. No information is available on how
48 changes in marine ecology are influencing the sport fishing industry of small islands (Scott *et al.*, 2012b).
49 The availability of freshwater is limited on many small islands, and changes in the availability or quality during
50 drought events linked to climate change have adverse impacts on tourism operations (Gössling *et al.*, 2012,
51 UNWTO 2012). One aspect of this that cruise ships may cease coming to an island where there is not sufficient
52 freshwater to restock their supplies. Tourism is a seasonally significant water user in many island destinations and in
53 times of drought, concerns over limited supply for residents and other economic activities become heightened
54 (Tapper *et al.*, 2011, Gössling *et al.*, 2012). As a consequence, some islands are investing in coral reef restoration,

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

7 29.3.3.2. *Observed Impacts on Human Health of Island Populations*

9 Globally, the effects of climate change on human health will be both direct and indirect, and are expected to
10 exacerbate existing health risks, especially in the most vulnerable communities where the burden of disease is
11 already high (refer to Chapter 11.3, 11.5 and 11.6.1, this volume). Many small island states currently suffer from
12 climate-sensitive health outcomes, including morbidity and mortality from extreme weather events, certain vector-
13 and food- and water-borne diseases (Barnett and Campbell, 2010; Cashman *et al.*, 2010; Pulwarty *et al.*, 2010;
14 McMichael and Lindgren, 2011). Extreme weather and climate events such as tropical cyclones, storm surges,
15 flooding, and drought can have both short- and long-term effects on human health, including drowning, injuries,
16 increased disease transmission, and health problems associated with deterioration of water quality and quantity.
17 Most small island nations are in tropical areas with weather conducive to the transmission of diseases such as
18 malaria, dengue, filariasis, and schistosomiasis.

19
20 The linkages between human health, climate variability and seasonal weather have been demonstrated in several
21 recent studies. The Caribbean has been identified as a ‘highly endemic zone for leptospirosis’ with Guadeloupe,
22 Barbados, and Jamaica representing the highest annual incidence (13 to 7.8 per 100,000 population) in the world
23 with only the Seychelles being higher (43.2 per 100,000 population) (Pappas *et al.*, 2008). Studies conducted in
24 Guadeloupe demonstrated a link between El Niño occurrence and leptospirosis incidence with rates increasing to 13
25 per 100,00 population in El Niño years as opposed to 4.5 cases per 100,00 inhabitants in La Niña and neutral years
26 (Herrmann-Stock *et al.*, 2008). In addition, epidemiological studies conducted in Trinidad reviewed the incidence of
27 leptospirosis during the period 1996-2007 and showed seasonal patterns in the occurrence of confirmed leptospirosis
28 cases, with significantly ($P < 0.001$) more cases or 75% of all cases occurring in the wet season, May to November
29 (193 cases), than during the dry season, December to May (66 cases) (Mohan *et al.*, 2009). Recently changes in the
30 epidemiology of leptospirosis have been detected especially in tropical islands with the main factors being climatic
31 and anthropogenic (Pappas *et al.*, 2008) that are likely to be enhanced with increases in ambient temperature and
32 changes in precipitation, vegetation and water availability as a consequence of climate change (Russell, 2009).

33
34 In Pacific islands the incidence of diseases such as malaria and dengue fever has been increasing, especially
35 endemic dengue in Samoa, Tonga and Kiribati (Russell, 2009). While studies conducted so far in the Pacific have
36 only established a direct link between malaria, dengue and climate variability, these and other health risks including
37 from cholera, are projected to increase as a consequence of climate change (Russell, 2009; refer also to Chapter
38 11.2.4 and 11.2.5 this volume, for detailed discussion on the link between climate change and projected increases in
39 the outbreak of dengue and cholera). Dengue incidence is also a major health concern in other small island
40 countries, including Trinidad and Tobago, Singapore, Cape Verde, Comoros and Mauritius (Chadee *et al.*, 2007;
41 Chadee 2009; Koh *et al.*, 2008; Van Kleef *et al.*, 2010; Teles, 2011). In the specific cases of Trinidad and Tobago,
42 the outbreaks have been significantly correlated with rainfall and temperature, respectively (Chadee *et al.*, 2007;
43 Chadee 2009; Koh *et al.*, 2008).

44
45 Previous IPCC assessments have consistently shown that human health on islands can be seriously compromised by
46 lack of access to adequate, safe, fresh water and adequate nutrition (Nurse *et al.*, 2001; Mimura *et al.*, 2007). Lovell
47 (2011) notes that in the Pacific many of the anticipated health effects of climate change are expected to be indirect,
48 connected to the increased stress and declining well-being that comes with property damage, loss of economic
49 livelihood and threatened communities. There is also a growing concern in island communities in the Caribbean,
50 Pacific and Indian Ocean, that fresh water scarcity, more intense droughts and storms could lead to a deterioration in
51 standards of sanitation and hygiene (Cashman *et al.*, 2010; McMichael and Lindgren, 2011). In such circumstances,
52 increased exposure to a range of health risks including communicable diseases would be a distinct possibility.

1 Ciguatera fish poisoning (CFP) occurs in tropical regions and is the most common non-bacterial food-borne illness
2 associated with consumption of fish. Distribution and abundance of the organisms that produce these toxins, chiefly
3 dinoflagellates of the genus *Gambierdiscus*, are reported to correlate positively with water temperature.
4 Consequently, there is growing concern that increasing temperatures associated with climate change could increase
5 the incidence of CFP in the island regions of the Caribbean (Morrison *et al.*, 2008; Tester *et al.*, 2010), Pacific
6 (Llewellyn, 2010; Rongo and van Woesik, 2011; Chan *et al.*, 2011) and the Mediterranean (Aligizaki and Nikolaidis,
7 2008; refer also to section 29.5.4). One of the objectives of the Caribbean study was to characterize the relationships
8 between sea surface temperatures (SSTs) and CFP incidence rates. This was done in tandem with a series of
9 experiments designed to determine the effects of temperature on the growth rate of organisms responsible for CFP.
10 High rates in the Lesser Antilles occur in areas which experience the warmest water temperatures and which show
11 the least temperature variability. There are also high rates in the Pacific in Tokelau, Tuvalu, Kiribati, Cook Islands
12 and Vanuatu.

13
14 The influence of climatic factors on malaria vector density and parasite development is well established (Beguin *et al.*
15 *et al.*, 2011; Chaves and Koenraadt, 2010). Previous studies have assessed the potential influence of climate change on
16 malaria, using deterministic or statistical models (Hay *et al.*, 2009; Martens *et al.*, 1999; Parham and Michael, 2010;
17 Pascual *et al.*, 2006). While the present incidence of malaria on small islands is not reported to be high, favourable
18 environmental and social circumstances for the spread of the disease are present in some island regions, and are
19 expected to be enhanced under projected changes in climate in Papua New Guinea, Guyana, Suriname and French
20 Guyana (Michon *et al.*, 2007; Rawlins *et al.*, 2008; Figueroa, 2008). In the Caribbean, the occurrence of
21 autochthonous malaria in non-endemic island countries in the last ten years, suggests that all of the essential malaria
22 transmission conditions now exist, and Rawlins *et al.* (2008) call for enhanced surveillance, recognizing the possible
23 impact of climate change on the spread of anopheles and malaria transmission.

24 25 26 29.3.3.3. *Observed Impacts of Climate Change on Relocation and Migration*

27
28 Empirical evidence of human migration as a response to climate change is scarce for small islands – in terms of a
29 lack of studies showing the direct impacts of climate change on human settlements, and how these impacts lead to
30 changes in migration and resettlement attitudes and behaviours. Several authors highlight this lack of empirical
31 studies of the effect of climate drivers such as sea level rise, on island migration (Lilleor and Van den Broeck, 2011:
32 s78, Mortreux and Barnett, 2009). Further there is no evidence of any government policy that allows for climate
33 ‘refugees’ from islands to be accepted into another country (Bedford and Bedford, 2010). This surprising finding
34 contrasts with the early desk-based estimates of migration under climate change such as the work of Myers (2002).
35 These early studies have been criticised as they fail to acknowledge: the reality of climate impacts on islands, the
36 capacity of islands and islanders to adapt, or the actual drivers of migration (Barnett and O'Neill, 2012).

37
38 The majority of studies on island migration reveal that the key drivers are economic or cultural and not climatic. For
39 example when looking at historical process of migration within the Mediterranean it appears that rising levels of
40 income, coupled with a decreased dependence on subsistence agriculture has left the Mediterranean less vulnerable
41 to all environmental stressors, resulting in a reduced need for mobility to cope with environmental or climatic
42 change (de Haas, 2011). Studies from the Pacific have also shown that culture, lifestyle and a connection to place
43 are more significant drivers of migration than climate (Mortreux and Barnett, 2009, Barnett and Webber, 2010). For
44 example a Pacific Access Category of migration has been agreed between New Zealand and Tuvalu that permits 75
45 Tuvaluans to migrate to New Zealand every year (Kravchenko, 2008). Instead of enabling climate driven migration,
46 this agreement is designed to facilitate economic and social migration as part of the Pacific island lifestyle (Shen and
47 Gemenne, 2011). Thus, there is no evidence *yet* that reveals that migration from islands is being driven by climate
48 change.

49
50 Nonetheless there is recognition that environmental change affects land use and land rights, which in turn are drivers
51 of migration (Bedford and Bedford, 2010). In a survey of 86 case studies of community relocations in Pacific
52 islands, Campbell *et al.* (2005) found that environmental variability and natural hazards accounted for 37
53 communities relocating. In the Pacific, where land rights are a source of conflict, climate change could increase
54 levels of stress associated with land rights, and impact on migration (Campbell, 2010; Weir and Virani, 2011).

1 While there is not yet a climate fingerprint on migration and resettlement patterns in small islands, it is clear that
2 there is the potential for human movement as a response to climate change. To better understand the impact of
3 climate change on migration there is an urgent need for robust methods to identify and measure the effects of the
4 drivers of migration on migration and resettlement.
5
6

7 *29.3.3.4. Observed Impacts on Island Economies*

8

9 The economic and environmental vulnerabilities of small island states are well documented (Briguglio *et al.*, 2009,
10 Bishop, 2012). Such vulnerabilities, which render the states at risk of being harmed by economic and environmental
11 conditions, stem from intrinsic features of these states, and are not governance induced (although poor governance
12 in this regard may aggravate the harm).
13

14 Economic vulnerability is the result of a high degree of exposure to economic conditions often outside the control of
15 small island states, exacerbated by dependence on a narrow range of exports and a high degree of dependence on
16 strategic imports, such as food and fuel (Briguglio *et al.*, 2009). This leads to economic volatility, a condition that is
17 harmful for the economy of the islands (Guillaumont, 2010).
18

19 There are other economic downsides associated with small size and insularity. Small size leads to high overhead
20 cost per capita, particularly in infrastructural outlays. This is of major relevance to climate change adaptation as this
21 often requires upgrades and redesign of island infrastructure. Insularity leads to high cost of transport per unit,
22 associated with purchases of raw materials and industrial supplies in small quantities, as well as high cost of storing
23 and warehousing to ensure adequate supply of production inputs and consumer goods. These disadvantages are
24 associated with the inability of small islands to reap the benefits of economies of scale resulting in a high cost of
25 doing business in small islands (Winters and Martins, 2004).
26

27 The environmental vulnerability of small island states stems from various intrinsic features, including the high ratio
28 of coastline to land mass, rendering these states highly exposed to ocean borne hazards and to sea-level rise (Barnett
29 and Campbell, 2010, Nicholls and Cazenave, 2010). Small island states are also highly prone to natural disasters
30 (Pедуzzi *et al.*, 2009; Turvey, 2007). Other environmental problems associated with small territory size relate to the
31 high population densities of many small island states, which leads to a high per capita cost of waste management,
32 traffic congestion, relatively high degree of biodiversity loss, heavy strain on water resources and other
33 environmental harm associated with population pressure.
34

35 These economic and environmental problems are exacerbated by climate change, particularly because government
36 funds have to be diverted from the normal budget outlays to cover additional expenditures associated with
37 mitigation and adaptation to climate change. In addition, a large proportion of economic activity of many small
38 island states, particularly those associated with tourism and fisheries, are located right on the coastline and these are
39 likely to be affected by sea-level rise and extreme weather events.
40
41

42 *29.3.4. Detection and Attribution of Observed Impacts of Climate Change on Small Islands*

43

44 While exceptional vulnerability of many small islands to future climate change is widely accepted, the foregoing
45 analysis indicates that scientific literature on observed impacts is quite limited. Detection of past and recent climate
46 change impacts is challenging due to the presence of other anthropogenic drivers, especially in the constrained
47 environments of small islands. Attribution is further challenged by the strong influence of natural climate variability
48 compared to incremental change of climate drivers. Notwithstanding these limitations we have prepared a summary
49 of the relationship between detection and attribution to climate change of several of the phenomena described in the
50 above sections. Figure 29-2 reflects our degree of confidence in the linkage between observed changes in several
51 components of the coastal, terrestrial and human systems of small islands and the drivers of climate change.
52
53

1 [INSERT FIGURE 29-2 HERE

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

12 **29.4. Projected Integrated Climate Change Impacts**

13
14 Small islands face many challenges in using climate change projections for policy development and decision-
15 making. Primary among these is the absence of credible regional socio-economic scenarios relevant at the scale at
16 which most decisions are taken. Scenarios are an important tool to help decision makers disaggregate vulnerability
17 to the direct physical impacts of the climate signal from the vulnerability associated with socio-economic conditions
18 and governance. Before building socio-economic scenarios to aid decision making, there has to be scientifically
19 credible simulation of future small island climates. In this regard, there is a serious problem in generating climate
20 scenarios at the scale of small islands since they are generally much smaller than the resolution of the global models.
21 This is because the grid squares in the Global Circulation Models (GCMs) used in the SRES scenarios over the last
22 decade, were between 200 and 600 km², which provides inadequate resolution over the land areas of virtually all
23 small islands.

24
25 The scale problem has been usually addressed by the implementation of statistical downscaling models that relate
26 GCM output to the historical climate of a local small island data point. The limitation of this approach is the need
27 for observed data ideally for at least three decades for a number of representative points on the island, in order to
28 establish the statistical relationships between GCM data and observations. In most small islands long-term quality-
29 controlled climate data is generally sparse, so that in widely dispersed islands such as in the Pacific, observational
30 records are usually supplemented with satellite observations combined with computer models (Australian Bureau of
31 Meteorology and CSIRO, 2011a; Keener *et al.*, 2012). However where adequate local data is available for several
32 stations for at least 30 years, downscaling techniques have demonstrated that they can respond to the guidance of the
33 GCMs to closely match the local domain and that they require less computational demand (e.g. Charlery and Nurse,
34 2010). Even so, most projected changes in climate for the Caribbean, Pacific, Indian Ocean and Mediterranean
35 islands, generally apply to the region as a whole and this may be adequate to determine general trends in regions
36 where islands are close together.

39 **29.4.1. Non-Formal Scenario-Based Projected Impacts**

40
41 Scenarios are often constructed by using a qualitative climate projections approach based on expected changes in
42 some physical climate signal from literature review rather than direct modelling. Sometimes this is proposed as a
43 ‘what if’ question which is then quantified using a numerical method. For example, in the Caribbean, sea level
44 projections superimposed on topographic maps have been used to estimate that 49-60% of resort properties would
45 be damaged with a one metre sea-level rise, potentially transforming the competitive position and sustainability of
46 coastal tourism destinations in the region (Scott *et al.*, 2012c). Another example of qualitative modelling from the
47 Pacific is a case study from Nauru which uses local data and knowledge of climate to assess the GCM projections. It
48 suggests that Nauru should plan for continued ENSO variability in the future with dry years during La Niña and an
49 overall increase in mean rainfall and extreme rainfall events. Climate adaptation concerns which arise include water
50 security and potential changes in extreme wet events which affect infrastructure and human health (Brown *et al.*,
51 *submitted*).

29.4.2. Projected Impacts for Islands based on Existing SRES Scenarios

Another approach to scenario development is to use the SRES projections more directly. The broad synthesis in the AR4 of climate scenario projections and impacts on small island regions (e.g. Mimura *et al.*, 2007) remains valid (see new RCP Projections in Figure 29-3). For example, Table 29-1 shows that in general for the SRES A1B more balanced medium emissions scenario, the projections suggest about a 2°C increase in temperature in the Caribbean, Indian Ocean and Pacific Ocean small islands regions by 2100 with an overall annual decrease in precipitation of about 12% in the Caribbean (see also AR5 WG I, 14.7.4) and a 3-5% increase in the Indian and Pacific Oceans small island regions. There are important spatial differences however as for example among the more dispersed Pacific islands where the more equatorial regions are likely to get wetter and the sub-tropical high pressure belts drier as reported by AR5 WG I, however, in regions directly affected by the SPCZ and western portion of the ITCZ, the rainfall outlook is uncertain (AR5 WG I, 14.7.13). The Mediterranean islands also have differences from the tropical small island pattern. Throughout the Mediterranean region, the length, frequency, and/or intensity of warm spells or heat waves are very likely to increase to the year 2100 (AR5 WG I, 14.7.6).

[INSERT TABLE 29-1 HERE]

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

In the main regions in which most tropical or sub-tropical small island states are located, there are few independent peer reviewed scientific publications providing downscaled climate data projections, and virtually none illustrating the experience gained from their use for policy making. A projected 2°C temperature increase by the year 2100 has potential far reaching consequences for sentinel ecosystems such as coral reefs that are important to tropical islands (see Chapter 6.2.2.4.4.). This is because ‘Degree Heating Months’ (DHM) >2 °C-month are the determined threshold for severe coral bleaching (Donner, 2009). For example Donner (2009) in a study of sea surface temperature (SST) across all coral reef regions using GCM ensemble projections forced with five different SRES future emissions scenarios, concluded that even warming in the future from the current accumulation of greenhouse gases in the atmosphere could cause over half of the world’s coral reefs to experience harmfully frequent thermal stress by 2080. Further, this timeline could be brought forward to as early as 2030 under the A1B medium emissions scenario. He further states that thermal adaptation of 1.5 °C would only delay the thermal stress forecast by 50–80 years. Donner (2009) also estimated the year of likelihood of a severe mass coral bleaching event due more than once every 5 years, to be 2074 in the Caribbean, 2074 in the western Indian Ocean, 2082 in the central Indian Ocean, 2065 in Micronesia, 2057 in the central Pacific, 2094 in Polynesia and 2073 in the eastern Pacific small islands regions.

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

In the Caribbean, downscaled climate projections have been generated for some Caribbean islands using the Hadley Centre PRECIS regional model (Taylor *et al.*, 2007, Stephenson *et al.*, 2008). For the SRES A2 and B2 scenarios the PRECIS regional climate model projects an increase in temperature across the Caribbean of 1–4 °C with increasing rainfall during the latter part of the wet season from November–January, in the northern Caribbean (i.e. north of 22°N) and drier conditions in the southern Caribbean with a strong tendency to drying in the traditional wet season from June–October (Whyte *et al.*, 2008, Campbell *et al.*, 2011, Taylor *et al.*, 2013). Projected lengthening

1 seasonal dry periods, and increasing frequency of drought periods are expected to increase demand for water
2 throughout the region under the SRES A1B scenario (Cashman *et al.*, 2010). Decrease in crop yield is also projected
3 in Puerto Rico for the SRES B1 (low), A2 (mid-high) and A1F1 scenarios during September although increased
4 crop yield is suggested during February (Harmsen *et al.*, 2009). Using a tourism demand model linked to the SRES
5 A1F1 A2 B1 and B2 scenarios, the projected climate change heating and drying impacts are also linked to potential
6 aesthetic, physical and thermal effects that are estimated to cause a change in total regional tourist expenditure of
7 about +321, +356, -118 and -146 million US dollars from the least to the most severe emissions scenario
8 respectively (Moore, 2010).
9

10 In the Indian Ocean, representative downscaled projections have been generated for Australia's two Indian Ocean
11 territories the Cocos (Keeling) Islands and Christmas Island using the CSIRO Mark 3.0 climate model with the
12 SRES A2 high emissions scenario (Maunsell Australia Pty Ltd., 2009). Future climate change projections for the
13 two islands for 2070 include a 1.8°C increase in air temperature by 2070, probable drier dry seasons and wet
14 seasons, a 40 cm rise in sea level and a decrease in intense tropical cyclones.
15

16 In the western tropical Pacific, extensive climate projections have been made for 15 small islands based on
17 downscaling from an ensemble of 15 GCMs (Australian Bureau of Meteorology and CSIRO, 2011b). The
18 temperature projections in this region dominated by oceans seem less than those seen globally ranging from +1.5 to
19 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
20 relative to a 20 year period centred on 1990. Notably there is a expected trend of increasing rainfall as indicated by a
21 projected increase in 20 year extreme rainfall events to an average of seven times per year, by 2090 under the A2
22 (high emissions) scenario (Australian Bureau of Meteorology and CSIRO, 2011b). In the tropical Pacific Ocean,
23 another comprehensive assessment of the vulnerability of the fisheries and aquaculture sectors to climate change in
24 22 Pacific island countries and territories focussed on two future time-frames (2030 and 2100) and two SRES
25 emissions scenarios, B1 (low emissions) and A2 (high emissions) (Bell *et al.*, 2011). The results are not very
26 different from the IPCC AR4 projections with projected temperature increases of about +1.0 to 1.5 °C by 2100 and
27 an increase in rainfall of 10-20% in equatorial regions. Estimates of the resulting projected changes in habitat area
28 (mangroves, seagrasses, freshwater fish) coral reef cover, demersal fish production, skipjack and bigeye tuna for the
29 two SRES scenarios are given in Table 29-2.
30

31 [INSERT TABLE 29-2 HERE

32 Table 29-2: Preliminary projected percentage changes in tuna catches relative to the 20 year average (1980-2000)
33 and estimated percentage change to government revenue resulting from projected changes in the catch of skipjack
34 tuna in 2030 and 2100 (Bell *et al.*, 2011).]
35

36 Most anticipated changes in habitat and resource availability such as the commercial tuna catch are negative, with
37 implications for government revenue and island food security (Bell *et al.*, 2011, Bell *et al.*, 2013).
38

39 In the Mediterranean islands of Mallorca, Corsica, Sardinia, Crete and Lesvos, Gritti *et al.* (2006) simulated the
40 terrestrial vegetation biogeography and distribution dynamics under the SRES A1F1 and B1 scenarios. The
41 simulations indicate that the effects of climate change are expected to be negligible within most ecosystems except
42 for mountainous areas that are projected to be eventually occupied by exotic vegetation types from warmer, drier
43 conditions. Cruz *et al.* (2009) report similar results for the terrestrial ecosystems of Madeira Island in the
44 Mediterranean. Downscaled SRES A2 and B2 scenarios for the periods 2040 – 2069 and 2070 – 2099 suggest that
45 the higher altitude native humid forest called the Laurissilva, may expand upwards in altitude, which could lead to a
46 severe reduction of the heath woodland which because it has little upward area to shift may reduce in range or
47 disappear at high altitudes resulting in the loss of rare and endemic species within this ecosystem.
48
49

50 **29.4.3. RCP Projections and Implications for Small Islands**

51

52 Utilizing updated historical greenhouse gas emissions data the scientific community has produced future projections
53 for four plausible new global Representative Concentration Pathways (RCPs) in order to explore a range of global
54 climate signals up to the year 2100 and beyond (e.g. Moss *et al.*, 2010; van Vuuren *et al.*, 2010). The RCPs are

1 named according to their global warming potential (e.g. RCP 4.5 W/m²) and in an ongoing process are matched to a
2 global socio-economic scenario storyline (SSP) such that each RCP can respond to more than one SSP. Scientists
3 have strongly cautioned against the specification of detailed sub-global conditions and local trends based on these
4 coarser global datasets and models. With these caveats in mind, typical representations of RCP projections for
5 temperature and precipitation for similar times of the year in some small island regions are presented in Figure 29-3
6 adapted from Annex I WGI AR5. Highlighted in Figure 29-3 is the output of one model that is the mid-projection
7 representation of each RCP model ensemble. A more comprehensive compilation of global RCP projections can be
8 found in Annex I of the WGI AR5 Report.

9
10 [INSERT FIGURE 29-3 HERE

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

13
14 Small Island Developing States (SIDS) advocated that the Global Mean Surface Temperature (GMST) increase
15 should be limited to ‘well below’ 1.5°C above pre-industrial levels (Hare *et al.*, 2011; Riedy and McGregor, 2011).
16 Inspection of column 1 in Figure 29-3 suggests that for Caribbean, Indian Ocean and Pacific SIDS in the tropics,
17 that is only plausible under RCP 2.6 that in each case yields about a 1°C regional increase by 2100. RCP 2.6 also
18 suggests no significant change in mean rainfall in the Caribbean with a slight increase for Indian and Pacific Ocean
19 SIDS. In the mid-latitude Mediterranean Sea region RCP 2.6 yields about a 2°C increase in temperature by 2100 and
20 no apparent change in rainfall.

21
22 By comparison with regard to temperature, RCP 4.5 in Figure 29-3 suggest a probable less than 2°C but not less than
23 1.5°C temperature increase in Caribbean, Indian Ocean and Pacific SIDS by 2100 and about a 3°C increase in the
24 Mediterranean. Associated with this, the Caribbean and Mediterranean regions may experience a decrease in mean
25 rainfall while the Indian and Pacific Ocean SIDS may experience increased rainfall. These trends accelerate
26 moderately for RCP 6.0 and steeply for RCP 8.5.

27 28 29 **29.5. Inter- and Intra-Regional Trans-Boundary Impacts on Small Islands**

30
31 Many impacts on small islands are generated by processes originating in another region or continent well beyond the
32 borders of an individual archipelagic nation or small island. These are inter-regional trans-boundary impacts. Intra-
33 regional trans-boundary impacts originate from a within-region source (e.g. within the Caribbean). Some trans-
34 boundary processes may have positive effects on the receiving small island or nation, though most that are reported
35 have negative impacts. Deciphering a climate change signal in inter- and intra-regional trans-boundary impacts on
36 small islands is not easy and usually involves a chain of linkages tracing back from island-impact to a distant climate
37 or climate-related bio-physical or human process. Some examples are given below.

38 39 40 **29.5.1. Large Ocean Waves from Distant Sources**

41
42 Unusually large deep ocean swells, generated from far distant sources in the mid- and high-latitudes by Extra-
43 Tropical Cyclones (ETC) cause considerable damage on the coasts of small islands thousands of kilometers away in
44 the tropics. Impacts include sea-flooding and inundation of settlements, infrastructure and tourism facilities as well
45 as severe erosion of beaches. Examples from small islands in the Pacific and Caribbean are common though perhaps
46 the most significant instance, in terms of a harbinger of climate change and sea-level rise, occurred in the Maldives
47 in April 1987 when long period swells originating from the Southern Ocean some 6000 km away caused major
48 flooding, damage to property, destruction of sea defences and erosion of reclaimed land and islands (Harangozo,
49 1992). The Maldives and several other island groups in the Indian Ocean have been subject to similar ocean swell
50 events more recently, most notably in May 2007 (Department of Meteorology, 2007).

51
52 In the Caribbean northerly swells affecting the coasts of islands have been recognized as a significant coastal hazard
53 ever since the 1950s (Donn and McGuinness, 1959). They cause considerable seasonal damage to beaches, marine
54 ecosystems and coastal infrastructure throughout the Caribbean (Cambers, 2009; Bush *et al.*, 2009). These high-

1 energy events manifest themselves as long period, high-amplitude waves generated by extra-tropical cyclones and
2 high latitude lows originating thousands of kilometers away in the North Atlantic. They occur during the northern
3 hemisphere winter and often impact the normally sheltered, low-energy leeward coasts of the islands (Bush *et al.*,
4 2009; Cambers, 2009). Such swells have even reached the shores of Guyana on the South American mainland as
5 illustrated by a swell event in October 2005 that caused widespread flooding and overtopping and destruction of sea
6 defences (van Ledden *et al.*, 2009).

7
8 Distant origin swells differ from the ‘normal’ wave climate conditions experienced in the Caribbean, particularly
9 with respect to direction of wave approach, wave height and periodicity. Based on statistical analysis of wave data
10 from voluntary observer ships (VOS), Gulev and Grigorieva (2006) suggest that significant wave heights have
11 increased by between 10 – 40 cm/decade in both the North Atlantic and North Pacific, during the period 1958-2002.
12 While significant wave height has been observed to increase in some regions, current model simulations project
13 enhanced wave heights only in the Southern Ocean and the tropical South Pacific, and decreases in all other ocean
14 basins (See AR5-WG1, 13.7.3.2). This may however be related to the challenge of downscaling ‘future wind states
15 from coarse resolution climate models into regional and global wave model projections’ (AR5-WG1, 13.7.3).

16
17 Swell events of similar origin and characteristics also occur in the Pacific the best documented being in the
18 Hawaiian island where there is evidence of damage to coral growth by swell from the north Pacific, especially
19 during years with a strong El Nino signal (Fletcher *et al.*, 2008). Hoeke *et al.* (submitted) describe inundation from
20 mid-high latitude north and south Pacific waves respectively at Majuro (Marshall Islands) in November and
21 December 1979 and along the Coral Coast (Fiji) in May 2011. They also describe in detail an inundation event in
22 December 2008 that was widespread throughout the western and central Pacific and resulted in waves surging across
23 low-lying islands causing severe damage to housing and infrastructure and key natural resources that affected about
24 100,00 people across the region. The proximate cause of this event was swell generated in mid-latitudes of the north
25 Pacific Ocean, more than 4000 km from the furthest affected island (Hoeke *et al.*, submitted).

26
27 Whereas the origin of the long period ocean swells that impact small islands in the tropical regions come from the
28 mid- and high-latitudes in the Pacific, Indian and Atlantic oceans, there are also instances of unusually large waves
29 generated from tropical cyclones that spread into the mid- and high- latitudes. One example occurred during 1999
30 when tide gauges at Ascension and St. Helena Islands in the central south Atlantic recorded unusually large deep-
31 ocean swell generated from distant Hurricane Irene (Vassie *et al.*, (2004). The impacts of increasing incidence or
32 severity of storms or cyclones is generally considered from the perspective of direct landfall of such systems,
33 whereas all of these instances serve to show ‘the potential importance of swells to communities on distant, low-lying
34 coasts, particularly if the climatology of swells is modified under future climate change’ (Vassie *et al.*, 2004: 1095).
35 From the perspective of those islands that suffer damage from this coastal hazard on an annual basis, this is an area
36 that warrants further investigation.

37
38 Deep ocean swell waves and elevated sea-levels resulting from ETCs are examples of *inter-regional* trans-boundary
39 processes; locally generated Tropical Cyclones (TCs) provide examples of *intra-regional* trans-boundary processes.
40 Whilst hurricane force winds, heavy rainfall and turbulent seas associated with TCs can cause massive damage to
41 both land and coastal systems in tropical small islands, the impacts of sea waves and inundation associated with far
42 distant ETCs are limited to the coastal margins. Nevertheless both storm types result in a range of impacts covering
43 island morphology, natural and ecological systems, island economies, settlements and human well-being (see Figure
44 29-4).

45
46 [INSERT FIGURE 29-4 HERE

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

50 1a. Society Islands, French Polynesia, February 2010 (Etienne, 2012); 1b. Maldives, April 1987 (Harangozo,
51 1992); 2a. Taveuni (Fiji) March 2010 (Etienne and Terry, 2012); 2b. Funafuti atoll, Tuvalu, October 1972 (Baines *et al.*, 1974);
52 3a. Society and Australes Islands, French Polynesia, February 2010 (Etienne, 2012); 3b. Maldives, April
53 1987 (Harangozo, 1992); 4a. Viti Levu, Fiji, March 1997 (Terry, *et al.*, 2002); 5a. Society Islands, French Polynesia,
54 February 2010 (Etienne, 2012); 6a. Curacao, Bonaire, Netherlands Antilles, November 1999 (Scheffers and

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

13 **29.5.2. *Trans-Continental Dust Clouds and their Impact***

15 The transport of airborne Saharan dust across the Atlantic and into the Caribbean has engaged the attention of
16 researchers for some time. The resulting dust clouds are known to carry pollen, microbes, insects, bacteria, fungal
17 spores and various chemicals (Prospero *et al.*, 2005; Middleton *et al.*, 2008; Monteil, 2008). During major events,
18 dust concentrations can exceed $100 \mu\text{g m}^{-3}$ (Prospero, 2006; Griffin, 2007). Independent studies using different
19 methodologies have all found a strong positive correlation between dust levels in the Caribbean and periods of
20 drought in the Sahara, while concentrations show a marked decrease during periods of higher rainfall. Consequently,
21 it is argued that higher dust emissions due to increasing aridity in the Sahel and other arid areas could enhance
22 climate change effects over large areas, including the eastern Caribbean and the Mediterranean (Prospero and Lamb,
23 2003). Similar findings have been reported at Cape Verde where dust emission levels were found to be a factor of
24 nine lower during the decade of the 1950s when rainfall was at or above normal, when compared to the 1980s, a
25 period of intense drought in the Sahel region (Nicoll *et al.*, 2011). Dust from the Sahara has also long been known to
26 reach into the eastern Mediterranean (e.g., Santese *et al.*, 2010) whilst dust from Asia has been transported across
27 the Pacific and Atlantic oceans and around the world (Uno *et al.*, 2009).

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

38 **29.5.3. *Movement and Impact of Introduced and Invasive Species across Boundaries***

40 Invasive species are colonizer species that establish populations outside their normal distribution ranges and spread
41 into natural or local areas. The spread of invasive alien species is regarded as a significant trans-boundary threat to
42 the health of biodiversity and ecosystems, and has emerged as a major factor in species decline, extinction and loss
43 of biodiversity goods and services worldwide. This is particularly true of islands, where both endemism and
44 vulnerability to introduced species tend to be high (Kenis *et al.*, 2009; Reaser *et al.*, 2007; Westphal *et al.*, 2008;
45 Rocha *et al.*, 2009; Kueffer *et al.*, 2010). The extent to which alien invasive species successfully establish
46 themselves at new locations in a changing climate will be dependent on many variables, but non-climate factors
47 such as ease of access to migration pathways, suitability of the destination, ability to compete and adapt to new
48 environments, and susceptibility to invasion of host ecosystems are deemed to be critical. This is borne out for
49 example by Le Roux *et al.* (2008) who studied the effect of the invasive weed *Miconia calvescens* in New
50 Caledonia, Society Islands and Marquesas islands, by Gillespie and Pau (2008) in an analysis of the spread of
51 *Leucaena leucocephala*, *Miconia calvescens*, *Psidium sp.* and *Schinus terebinthifolius* in the Hawaiian islands; and
52 by Christenhusz and Toivonen (2008) who showed the potential for rapid spread and establishment of the oriental
53 vessel fern, *Angiopteris evecta*, from the South Pacific throughout the tropics. Mutualism between an invasive ant

1 and locally honeydew-producing insects has been strongly associated with damage to the native and functionally
2 important tree species, *Pisonia grandis* on Cousine island, Seychelles (Gaigher, *et al.*, 2011).

3
4 Whilst invasive alien species constitute a major threat to biodiversity in small islands, the removal of such species
5 can result in recovery and return to species richness. . This has been demonstrated in Mauritius by Baider and
6 Florens, 2011) where some forested areas were weeded of alien plants and after a decade the forest had recovered
7 close to its initial condition,. They concluded, given the severity of alien plant invasion in Mauritius, that their
8 example can ‘be seen as a relevant model for a whole swath of other island nations and territories around the world
9 particularly in the Pacific and Indian Oceans’ (Baider and Florens, 2011).

10
11 The movement of aquatic and terrestrial invasive fauna within and across regions will almost certainly exacerbate
12 the threat posed by climate change in island regions, and could impose significant environmental, economic and
13 social costs. Recent research has shown that the invasion of the Caribbean Sea by the Indo-Pacific lionfish (*Pterois*
14 *volitans*), a highly efficient and successful predator, is a major contributor to observed increases in algal dominance
15 in coral and sponge communities in the Bahamas and elsewhere in the region. The consequential damage to these
16 ecosystems has been attributed to a significant decline in herbivores due to predation by lionfish (Schofield, 2010;
17 Albins and Hixon, 2008; Lesser and Slattery, 2011; Green *et al.*, 2011). While there is no evidence that the lionfish
18 invasion is climate-related, the concern is that when combined with pre-existing stress factors the natural resilience
19 of Caribbean reef communities would decrease (Albins and Hixon, 2011; Green *et al.*, 2012), making them more
20 susceptible to climate change effects such as bleaching. Englund (2008) has documented the negative effects of
21 invasive species on native aquatic insects on Hawai’i and French Polynesia, and their potential role in the extirpation
22 of native aquatic invertebrates in the Pacific. Similarly, there is evidence that on the island of Oahu introduced slugs
23 appear to be ‘skewing species abundance in favour of certain non-native and native plants’, by altering the ‘rank
24 order of seedling survival rates’, thereby undermining the ability of preferred species (e.g. the endangered *C.*
25 *Superba*) to compete effectively (Joe and Daehler, 2008).

26 27 28 **29.5.4. Spread of Aquatic Pathogens within Island Regions**

29
30 The mass mortality of the black sea urchin, *Diadema antillarum*, in the Caribbean basin during the early 1980s
31 demonstrates the ease with which ecological threats in one part of a region can be disseminated to other jurisdictions
32 thousands of kilometres away. The die-off was first observed in the waters off Panama around January 1983, and
33 within 13 months the disease epidemic had spread rapidly through the Caribbean Sea affecting practically all island
34 reefs, as far away as Tobago some 2000 km to the south and Bermuda, some 4000 km to the east. The diadema
35 population in the wider Caribbean declined between 90-95 per cent as a consequence of this single episode (Lessios,
36 1988, 1995; Rotjan and Lewis, 2008; Alvarez-Filip *et al.*, 2009; Croquer and Weil, 2009a, 2009b). As *D. antillarum*
37 is one of the principal grazers that removes macroalgae from reefs and thus promotes juvenile coral recruitment, the
38 collateral damage was severe, as the region’s corals suffered from high morbidity and mortality for decades
39 thereafter (Carpenter and Edmunds, 2006; Myhre and Acevedo-Gutierrez, 2007; Idjadi *et al.*, 2010).

40
41 There are other climate-sensitive diseases such as yellow, white and black band, white plague and white pox that
42 travel across national boundaries and infect coral reefs directly. This is variously supported by examples from the
43 Indo-Pacific relating to the role of bacterial infections in white syndrome and yellow band disease (Piskorska *et al.*,
44 2007; Cervino *et al.*, 2008), the impact of microbial pathogens as stressors on benthic communities in the
45 Mediterranean associated with warming seawater (Ainsworth *et al.*, 2007; Danovaro *et al.*, 2009; Rosenberg *et al.*,
46 2009), and an increasing evidence of white, yellow and black band disease associated with Caribbean and Atlantic
47 reefs (Rosenberg *et al.*, 2009; Brandt and McManus, 2009; Miller *et al.*, 2009; Weil and Croquer, 2009;
48 McClanahan *et al.*, 2009; Weil and Rogers, 2011).

49 50 51 **29.5.5. Trans-Boundary Movements and Human Health**

52
53 For island communities the trans-boundary implications of existing and future human health challenges are
54 projected to increase in a changing climate. For instance, the aggressive spread of the invasive giant African snail,

1 *Achatina fulica*, throughout the Caribbean, Indo-Pacific islands and Hawaii is not only assessed to be a severe threat
2 to native snails and other fauna (e.g. native gastropods), flora and crop agriculture, but is also identified as a vector
3 for certain human diseases such as meningitis (Reaser *et al.*, 2007; Meyer *et al.*, 2008; Thiengo *et al.*, 2010).
4

5 Like other aquatic pathogens ciguatoxins, that cause ciguatera fish poisoning, may be readily dispersed by currents
6 across and within boundaries in tropical and sub-tropical waters. Ciguatoxins are known to be highly temperature-
7 sensitive and may flourish when certain sea water temperature thresholds are reached, as has been noted in the South
8 Pacific (Llewellyn, 2010), Cook Islands (Rongo and van Woesik, 2011), Kiribati (Chan *et al.*, 2011), the Caribbean
9 and Atlantic (Morrison *et al.*, 2008; Otero *et al.*, 2010; Tester *et al.*, 2010) and Mediterranean (Aligizaki and
10 Nikolaidis, 2008) (see also 29.3.3.3).
11
12

13 **29.6. Adaptation and Management of Risks**

14

15 For most islands, there is limited empirical evidence of changes in risk associated with climate change, largely due
16 to: poor regional projections e.g. of sea level rise (Willis and Church, 2012), and a lack of long term baseline
17 monitoring of changes in climatic risk (Voccia, 2012), such as risk of saline intrusion, risk of invasive species, risk
18 of biodiversity loss, risk of large ocean waves, or risk of sea-level rise. Island adaptation studies therefore rely on
19 analogues of responses to past and present weather extremes and climatic change, or assumed impacts of climate
20 change based on island type, see Table 29-3. Until climate risks are better identified for islands, our ability to
21 identify effective adaptations remains constrained.
22

23 [INSERT TABLE 29-3 HERE

24 Table 29-3. Type of island in the Pacific region and implications for hydro-meteorological hazards.]
25
26

27 **29.6.1. Addressing Current Vulnerabilities and Adaptation Gaps on Small Islands**

28

29 There is medium evidence of generic vulnerability of small islands to climate change, with some disagreement about
30 the costs of adapting in small islands, and ultimately the potential need for migration from small islands (Nicholls *et al.*,
31 2011, Gemenne, 2011, Biermann and Boas, 2010, Voccia 2012). Islands are heterogeneous in geomorphology,
32 culture, ecosystems, populations and hence also in their vulnerability to climate change (Wheeler, 2011).

33 Vulnerabilities and adaptation needs are as diverse as the variety of islands between regions and even within nation
34 states such as the Solomon Islands (see for example Rasmussen *et al.*, 2011).
35

36 Generic indices of national level vulnerability continue to emerge (Cardona, 2007) with a minority focused on small
37 islands (e.g. Blancard and Hoarau, 2013). Many indicators suffer from lack of data, for example, Peduzzi *et al.*
38 (2009) note that 18 small island states in the Pacific, Caribbean and Indian oceans are not included in their Disaster
39 Risk Index due to lack of data. Other generic indices use indicators that are not relevant in all islands (Barnett and
40 Campbell, 2010), or use data of limited quality for islands, such as sea level rise (as used in Wheeler, 2010). Park *et al.*
41 (2012) attempt to produce relevant indicators of climate vulnerability and adaptive capacity for the Pacific
42 Islands by adopting a three-stage participatory approach linking scientific knowledge with local visions of
43 vulnerability. Their study concludes that all Pacific Island nations will be vulnerable to climate change in the next 40
44 years.
45

46 Following Smit *et al.* (2000), Brooks *et al.* (2005), and Yamano *et al.* (2007), Barnett and Campbell (2010) reinforce
47 the point that island vulnerability to climate change is often a function of four key stressors: socio-economic, geo-
48 physical, and socio-ecological vulnerabilities, as well as the climate stressor. Socio-economic vulnerabilities are
49 related to on-going challenges of managing urbanisation, pollution and sanitation, both in small island states and
50 non-sovereign islands as highlighted by Storey and Hunter (2010) in Kiribati, López-Marrero and Yarnal (2010) in
51 Puerto Rico, and in Mayotte (France) (Le Masson and Kelman, 2011). Geo-physical characteristics of islands are
52 varied, some low-lying atolls, some oceanic, some volcanic islands (see Table 29-3; Figure 29-1), each of which
53 creates different vulnerabilities, for example the Azores (Portugal) face seismic, landslide and tsunami risks
54 (Coutinho *et al.*, 2009). Socio-ecological stresses, such as habitat loss and degradation, invasive species (described

1 in Sax and Gaines, 2008), overexploitation, pollution, human encroachment and disease can harm biodiversity
2 (Caujape-Castells *et al.*, 2010; Kingsford *et al.*, 2009), and reduce the ability of socio-ecological systems to bounce
3 back after shocks. To understand climate vulnerability on islands, the impact of each of these non-climate stresses
4 needs to be first understood and then integrated into climate vulnerability assessments (Rasmussen *et al.*, 2011). For
5 example, with individual ecosystems, such as coral reef ecosystems – those already under stress from non-climate
6 factors are more at risk from climate change than those that are unstressed (Maina *et al.*, 2011, Hughes *et al.*, 2003).
7 Evidence is starting to emerge that shows the same applies at the island scale. In Majuro (Marshall Islands), 34-37
8 years of aerial photography indicates that rural areas have experienced lower rates of erosion than urban areas (Ford,
9 2012). This could suggest that either the eroding urban coastal areas were initially more exposed, or that human
10 activity in coastal areas and interventions in coastal ecosystems are exacerbating erosion associated with sea level
11 rise. Additional empirical evidence is needed to confirm which explanation is accurate. In short, all aspects of
12 vulnerability and climate risk assessment remain under-researched in islands; for most islands it is not possible to
13 answer the key vulnerability questions unequivocally, i.e. who is at risk of what, where, and when?
14
15

16 **29.6.2. Practical Experiences of Adaptation on Small Islands**

17
18 Islands are often assumed to be generically vulnerable to climate change (Parks and Roberts, 2006, Myers, 2002).
19 Yet islands and islanders are also recognized for their long experience of adapting to weather variability and climate
20 hazards and for their resilience in the face of hydro-meteorological hazards (Barnett, 2001). Their resilience appears
21 to come from both a belief in their own capacity (Kuruppu and Liverman, 2011; Adger and Brown, 2009), and a
22 familiarity with their environment and understanding of what is needed to adapt (Tompkins *et al.*, 2009; Le Masson
23 and Kelman, 2011). For example, compared to communities in the larger countries of Madagascar, Tanzania and
24 Kenya, the Indian Ocean islands – the Seychelles and Mauritius – were found to have comparatively high adaptive
25 capacity (Cinner *et al.*, 2012). Adaptive capacity was assessed as: capacity to anticipate change and prepare
26 strategies, self-awareness of human impact on environment; willingness to change occupation; livelihood diversity;
27 social capital; material assets; access to technology and infrastructure. These studies all point to the importance of
28 self-belief as well as culturally communicated knowledge of current risks and how to respond to them.
29

30 There are many ways in which climate adaptation can be undertaken: reducing socio-economic vulnerabilities,
31 building adaptive capacity, enhancing disaster risk reduction, or building longer term climate resilience (e.g. see
32 McGray *et al.*, 2007, Eakin *et al.*, 2009). Figure 29-5 highlights the potential benefits and risks associated with the
33 various options. Not all adaptations will be equally appropriate in all contexts. Understanding the baseline
34 conditions and stresses (both climate and other) are important in understanding which climate change adaptation
35 option will generate the greatest benefits. On small islands where resources are often limited, recognising the
36 starting point for action is critical to maximising the benefits from adaptation. The following section considers the
37 benefits of pursuing the various options.
38

39 [INSERT FIGURE 29-5 HERE

40 Figure 29-5. Potential benefits and risks associated with alternative climate change adaptation actions or policies.]
41
42

43 **29.6.2.1. Building Adaptive Capacity on Small Islands**

44
45 Capacity to adapt to current risks on islands may be correlated to ability to adapt to future climate change, but there
46 is limited evidence for this (such as Lefale, 2010). Consequently, this section can only assess evidence of adaptive
47 capacity that: reduces vulnerability to existing stressors, enables adaptation to current stresses, or supports current
48 disaster risk management, much of this relates to traditional practices.
49

50 As in previous IPCC Assessments, there is continuing strong support for the incorporation of indigenous knowledge
51 into adaptation planning. For example, Samoans have their own seasonal calendar based on observations of local
52 environmental and weather changes. Their ability to forecast the onset of extreme weather and climate events
53 relying predominantly on local environmental changes are tools that could be incorporated in the formulation of
54 climate change adaptation strategies (Lefale, 2010). Two discrete studies from the Solomon Islands highlight the

1 importance of traditional patterns of social organization within communities to support food security under social
2 and environmental change (Reenberg *et al.*, 2008, Mertz *et al.*, 2010). In both studies the strategy of relying on
3 traditional systems of organization for farming and land use management have been shown to work effectively –
4 largely as there has been little cultural and demographic change. Evidence is inconclusive on the local capacity to
5 observe long-term climate change. In the Solomon Islands, Lauer and Aswani (2010) found mixed ability to detect
6 change in spatial cover of seagrass meadows. In Jamaica, Gamble *et al.* (2010) reported a high level of agreement
7 between farmers’ perception of increasing drought incidence and statistical analysis of precipitation and vegetation
8 data for the area. In this case farmers perceptions clearly validated the observational data and vice versa. Despite
9 some claims that the vulnerability of indigenous groups in small islands may be best tackled by combining
10 indigenous and Western knowledge in a culturally compatible and sustainable manner (Mercer *et al.*, 2007), given
11 the small number of studies in this area, there is not sufficient evidence to determine the benefits and limits to the
12 use of traditional knowledge in building adaptive capacity to climate change on small islands.
13

14 There is a growing literature, but a lack of agreement on the role of traditional technologies and skills for climate
15 adaptation. In coastal Samoa participatory village consultation and capacity building that take into account
16 traditional practices, can be vital to the success of adaptation initiatives in island communities (Daly, 2010).
17 Campbell (2009) identified that traditional disaster reduction measures used in Pacific islands focussed around
18 maintaining food security, building community cooperation, and protecting settlements and inhabitants. Examples of
19 actions to maintain food security include: the production and storage of food surpluses – such as yam and breadfruit
20 buried in leaf-lined pits to ferment; high levels of agricultural diversity to minimise specific damage to any one crop;
21 and the growth of robust famine crops – unused in times of plenty which could be used in emergencies (Campbell,
22 2009). Nonetheless there are physical and cultural limits to the ability to store surplus production on atoll islands.
23 On Rongelap in the Marshall Islands, surpluses are avoided, or are redistributed to support community bonds
24 (Bridges and McClatchey, 2009). Further, traditional approaches that Pacific island communities have used for
25 survival for millennia (such as building elevated settlements and resilient structures; and working collectively), have
26 been abandoned or forgotten due to processes of globalisation, colonialism and development (Campbell, 2009).
27

28 Traditional construction methods have long been identified across the Pacific as a means of adapting to tropical
29 cyclones and floods. In the Solomon Islands traditional practices include: elevating concrete floors on Ontong Java
30 to keep floors dry during heavy rainfall events; building ‘low, aerodynamic houses and sago palm leaves as roofing
31 material on Tikopia’ as preparedness for tropical cyclones; and in Bellona local perceptions are that houses
32 constructed from modern materials and practices are more easily destroyed by tropical cyclones, implying that
33 traditional construction methods are perceived to be more resilient in the face of extreme weather (Rasmussen *et al.*,
34 2009: 10). In parallel, Campbell (2009) documents the characteristics of traditional building styles (in Fiji, Samoa
35 and Tonga) where relatively steep hipped roofs, well bound connections and joints, and airtight spaces with few
36 windows or doors offer some degree of wind resistance. Traditional building measures can also reduce damages
37 associated with earthquakes – as evidenced in Haiti (Audefroy, 2011). By reducing damage caused by other stresses
38 (such as earthquakes), adaptive capacity is more likely to be maintained. The quality of home construction is critical
39 to its wind-resistance. If inadequately detailed, home construction will fail irrespective of method. While some
40 traditional measures could be challenged as potentially risky – for example using palm leaves, rather than metal
41 roofs as a preparation for tropical cyclone impacts – the documentation of traditional approaches, with an evaluation
42 of their effectiveness remains urgently needed.
43

44 Traditional systems appear less effective when multiple civilization-nature stresses are introduced. For example in
45 the island of Makira, Solomon Islands, where there have been high levels of population growth and changing social
46 objectives, these factors appear to have acted as inhibitors of adaptation (Fazey *et al.*, 2011). In Reunion and
47 Mayotte, population growth, and consequent rises in land and house prices have lead low-income families moving
48 closer to hazardous slopes that are prone to landslides and river-banks which are prone to flooding (Le Masson and
49 Kelman, 2011). Traditional belief systems can also limit adaptive capacity, for example in two Fijian villages,
50 approximately half of survey respondents identified divine will as the cause of climate change (Lata and Nunn,
51 2012). These findings reinforce earlier studies in Tuvalu (Mortreux and Barnett, 2009), and more widely across the
52 Pacific (Barnett and Campbell, 2010). The importance of taking into account local interests and traditional
53 knowledge in adaptation in small islands is emphasized by Kelman and West (2009) and McNamara and Westoby

1 (2011), yet research is also needed to identify its limits, such as in the context of rapid socio-ecological change, or
2 the impact of belief systems on adaptive capacity.

3
4 There remains limited evidence of how traditional knowledge, technologies and skills are being used to support
5 adaptation. To date research in the Pacific and Caribbean dominates small island climate change work. More
6 detailed studies on small islands in the central and western Indian Ocean, the Mediterranean and the central and
7 eastern Atlantic would improve understanding in this area.

8 9 10 29.6.2.2. Addressing Risks on Small Islands

11
12 Many of the future climate risks on small islands remain unknown due to: the lack of effective downscaling methods
13 for small islands, the lack of baseline data to ground-truth model results, and the lack of model skill in projecting the
14 climatic variables that matter to small islands, notably: tropical cyclone frequency and intensity, wind speed and
15 direction, precipitation, sea level, ocean temperature and ocean acidification (Brown *et al.*, submitted). Therefore
16 much of the research on climate risks on islands depicts either current hydro-meteorological risks and responses, or
17 risk management for hypothesised risks. In terms of present disaster risks, reflected by global disaster statistics,
18 islands rarely appear to be in the ‘worst affected’ category - this is due to their small size and population. Yet, when
19 the relative impact of current natural hazards are considered, in terms of percentage of the population exposed or in
20 terms of losses as a percentage of GDP, then islands appear to suffer disproportionately (see Table 29-4).

21
22 [INSERT TABLE 29-4 HERE

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

25
26 Much of the climate risks literature recognises the relatively severe impacts of current natural hazards on islands,
27 and identifies a range of approaches for managing this risk. Again, it is worth highlighting that most of this literature
28 considers present day risk as an analogue for future risk; yet there is little evidence of a correlation between the
29 effectiveness of current and future risk management under climate change. Given this constraint, much of the work
30 on addressing risk focuses on either risk transfer, risk spreading or risk avoidance. Risk transfer is often undertaken
31 through insurance; risk spreading through access to and use of common property resources, livelihood
32 diversification, or mutual support through networks; and risk avoidance through migration.

33
34 Risk transfer through insurance markets has limited uptake in small islands, as the markets do not function as
35 effectively as they do in larger locations, in part due to a small demand for the insurance products (Heger *et al.*,
36 2008). In the case of insurance for farmers, researchers found that a lack of demand for insurance products (in their
37 study countries: Grenada, Jamaica, Fiji and Vanuatu) meant an undersupply of customized food insurance products,
38 which in turn contributed to a lack of demand for insurance (Angelucci and Conforti, 2010). Alternatives exist such
39 as index-based schemes which provide pay outs based on the crossing of a physical threshold, e.g. when rainfall
40 drops below a certain level, rather than on drought damage sustained, (Linnerooth-Bayer and Mechler, 2009). The
41 potential for index-based insurance for climate stressors on islands is under-researched. Small island governments
42 also face expensive climate risk insurance. The Caribbean Catastrophe Risk Insurance Facility (CCRIF) pools
43 Caribbean-wide country-level risks into a central, more diversified portfolio – offering lower premiums for
44 participating national governments. CCRIF has been operating since 2007 (CCRIF, 2008). The potential for a
45 similar scheme in the Pacific is being explored (ADB, 2009, Cummins and Mahul, 2009), although there is limited
46 evidence of the long-term effectiveness of index-based or pooled-risk insurance in supporting household level
47 adaptation.

48
49 Risk spreading can take many forms from reliance on social networks and familial ties to creation of marine
50 protected areas to enhance representation of habitat types and replication of species. In Fiji, after Cyclone *Ami*
51 in 2003, households whose homes were not affected by the cyclone increased their fishing effort to support those
52 whose homes were damaged (Takasaki, 2011). In this way, risk was spread among the households, and mutual
53 support formed a central pillar for community-based adaptation. In the case of natural systems, risks can be spread
54 through the creation of marine protected areas, around key refuges that protect a diversity of habitat, that cover an

1 adequate proportion of the habitat and that protect critical areas such as nursery grounds and fish spawning
2 aggregation areas (McLeod *et al.*, 2009). In Fiji, Locally Managed Marine Areas – which involve the local
3 community in the management and protection of their local marine environment – have proven to be effective in
4 increasing biodiversity, and in reducing poverty in areas dependent on marine resources (Techera, 2008). By
5 creating a network of protected areas supported by local communities there is medium evidence that risks associated
6 with some forms of climate change can be spread and potentially reduced (Mills *et al.*, 2010).

7 8 9 29.6.2.3. Working Collectively to Address Climate Impacts on Small Islands

10
11 More attention is being focused on the relevance and application of community-based adaptation (CBA) principles
12 to island communities, to facilitate adaptation planning and implementation (Warrick, 2009; Kelman *et al.*, 2011),
13 and to tackle rural poverty in resource dependent communities (Techera, 2008). Warrick’s work in Vanuatu focuses
14 on empowerment that is ‘helping people to help themselves’, while addressing local priorities and building on local
15 knowledge and capacity. This approach to adaptation is being promoted as an appropriate strategy for small states,
16 since it is something done ‘with’ rather than ‘to’ communities (Warrick, 2009).

17
18 Nonetheless externally driven programmes to encourage community-level action have produced some evidence of
19 effective adaptation. Both Limalevu *et al.* (2010) and Dumaru (2010) describe the outcomes of externally-led pilot
20 community-based adaptation projects (addressing water security and coastal management) implemented in villages
21 across Fiji, notably: more effective management of local water resources through capacity building; enhanced
22 knowledge of climate change,-; and, the establishment of mechanisms to facilitate greater access to technical and
23 financial resources from outside the community. Limalevu *et al.* (2010) recognise that more long term monitoring
24 and evaluation of the effectiveness of community level action is needed.

25
26 There is medium evidence that collaboration between a variety of stakeholders can benefit communities through the
27 introduction of technical expertise to avoid simple mistakes that can dampen the effectiveness of adaptation actions.
28 Evidence from the Eastern Caribbean suggests that adaptations taken by individual households to reduce landslide
29 risk – building simple retaining walls – can be ineffective compared to community level responses (Anderson *et al.*,
30 2011). They argue better hillside drainage through construction of networks of drains to capture surface runoff,
31 household roof-water and grey water, with community support to construct the networks, with input from engineers
32 can significantly reduce landslide risk . Case studies from Fiji and Samoa in which multi-stakeholder and multi-
33 sector participatory approaches were used to help enhance resilience of local residents to the adverse impacts of
34 disasters and climate change (Gero *et al.*, 2011) further support this view. In the case of community based disaster
35 risk reduction (CBDRR), Pelling (2011) notes that buy-in from local and municipal governments are needed, as well
36 as strong pre-existing relationships founded on routine daily activities, to make CBDRR effective. In both the
37 Solomon Islands and the Cayman Islands there is reasonable agreement that the factors that underpin resilience to
38 hazards resonates with earlier work on successful governance of the commons, that is: community cohesion;
39 effective leadership; and, community buy-in to collective action (Schwarz *et al.*, 2011, Tompkins *et al.*, 2008).
40 Where community organisations are operating in isolation, or where there is limited coordination and collaboration
41 community vulnerability is likely to increase (Ferdinand *et al.*, 2012). Strong local networks, and trusting
42 relationships between communities and government appear to be key elements in adaptation, in terms of maintaining
43 sustainable agriculture and in disaster risk management.

44
45 All of these studies reinforce the earlier work of Barnett (2001), providing robust evidence that supporting
46 community-led approaches to disaster risk reduction and hazard management may contribute to greater community
47 engagement with anticipatory adaptation. However, it is not yet possible to identify the extent to which climate
48 resilience is a coincidental benefit of island lifestyle and cultural, or a purposeful approach, such as the community
49 benefits gained from reciprocity among kinship groups (Campbell, 2009).

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

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

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

[INSERT TABLE 29-5 HERE]

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

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

29.6.3. Barriers and Limits to Adaptation in Small Island Settings

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

1 (2008) recognise that more diversified economies have more robust responses to climate stress, yet most small
2 islands lack economies of scale in production, thus specialising in niche markets and developing monocultures (e.g.
3 sugar or bananas). Non-sovereign island states face additional exogenous barriers to adaptation. For example,
4 islands like Réunion and Mayotte experience French provision of social services, but not the French level of
5 building codes and land use planning (Le Masson and Kelman, 2011). Owing to their nature and complexity, these
6 constraints will not be easily eliminated in the short term and will require on-going attention if their impact is to be
7 minimized incrementally over time. Exogenous factors, such as the comparatively few assessments of social
8 vulnerability to climate change, adaptation potential or resilience for island communities (Barnett, 2010) limit
9 current understanding and action. In part this is due to the particularities of islands – both their heterogeneity and
10 their difference from mainland locations – as well as the limitations of climate models in delivering robust science
11 for small islands. It remains the case that thirteen years after Nurse *et al.* (2001) noted that downscaled global
12 climate models do not provide a complete or necessarily accurate picture of climate vulnerabilities on islands, there
13 is still little climate impacts research that reflects local concerns and contexts (Barnett *et al.*, 2008).

14
15 While lack of access to adequate financial, technological and human resources is often cited as the most critical
16 constraint, experience has shown that endogenous factors such as culture, ethics, knowledge and attitudes to risk are
17 important in constraining adaptation. Translating the word ‘climate’ into Marshallese implies cosmos, nature and
18 culture as well as weather and climate (Rudiak-Gould, 2012), such cultural misunderstandings can create both
19 barriers to action and novel ways of engaging with climate change. The lack of local support (due to encroachment
20 on traditional lands) for the development of new infiltration galleries to augment freshwater supply on Tarawa atoll,
21 Kiribati, highlights the importance of social acceptability (Moglia *et al.*, 2008a, 2008b). Such considerations have
22 led to the conclusion that there is still much to be learned about the drivers of past adaptation and how
23 ‘mainstreaming’ into national programs and policies, widely acclaimed to be a virtually indispensable strategy, can
24 practically be achieved (Mercer *et al.*, 2007; Adger *et al.*, 2009; Mertz *et al.*, 2009).

25
26 Notwithstanding the extensive and ever-growing body of literature on the subject, there is still a relatively low level
27 of awareness and understanding at the community level on many islands about the nature of the threat posed by
28 climate change (Nunn, 2009). Even where the threat has been identified, it is often not considered an urgent issue, or
29 a local priority, as exemplified in Malta (Akerlof *et al.*, 2010), and Funafuti, Tuvalu (Mortreux and Barnett, 2009).
30 Lack of awareness, knowledge and understanding can function as an effective barrier to the implementation and
31 ultimate success of adaptation programs. This is borne out in both Fiji and Kiribati where researchers found that
32 spiritual beliefs, traditional governance mechanisms, and a short term approach to planning were barriers to
33 community engagement and understanding of climate change (Kuruppu, 2009, Lata and Nunn, 2012). Although
34 widely acknowledged to be critical in small islands, few initiatives pay little more than perfunctory attention to the
35 importance of awareness, knowledge and understanding in climate change adaptation planning. Hence, the renewed
36 call for adaptation initiatives to include and focus directly on these elements on an ongoing basis (e.g., Crump, 2008;
37 Kelman and West, 2009; Kelman, 2010; Kuruppu and Liverman, 2011; Gero *et al.*, 2011) is timely, if these barriers
38 are to be eventually removed.

39 40 41 **29.6.4. Mainstreaming and Integrating Climate Change into Development Plans and Policies**

42
43 There is a growing body of literature that discusses the benefits and possibilities of mainstreaming or integrating
44 climate change policies in development policies. Various mechanisms through which development agencies as well
45 as donor and recipient countries can seek to capitalize on the opportunities to mainstream are beginning to emerge
46 (see for example Klein *et al.*, 2007; Mertz *et al.*, 2009). Agarwala and van Aalst (2008) provide examples from Fiji
47 and elsewhere, of where synergies (and trade-offs) can be found in integrating adaptation to climate change into
48 development cooperation activities, notably: disaster risk reduction, community-based approaches to development,
49 and building adaptive capacity. Boyd *et al.* (2009) urge for more rapid integration of adaptation into development
50 planning, to ensure that adaptation is not side-lined, or treated separately from sectoral policies. Although there are
51 synergies and benefits to be derived from the integration of climate change and development policies, care is needed
52 to avoid institutional overlaps, and differences in language and approach – which can give rise to conflict (Schipper
53 and Pelling, 2006). Overall however, there appears to be an emerging consensus around the views expressed by
54 Swart and Raes (2007) that climate change and development strategies should be considered as complementary, and

1 that some elements such as land and water management and urban planning provide important adaptation,
2 development and mitigation opportunities.
3
4

5 **29.7. Adaptation and Mitigation Interactions**

6

7 Greenhouse gas emissions from most small islands are negligible in relation to global emissions, yet small islands
8 will most probably be highly impacted by climate change (Srinivasan, 2010). Since small islands' populations are
9 not responsible for anthropogenic climate change there is little moral imperative for them to reduce greenhouse gas
10 emissions, though most have chosen to do so because of the potential co-benefits and synergies. Malta and Cyprus
11 are obliged to do so in line with EU climate and energy policies. This section considers some of the inter-linkages
12 between adaptation and mitigation on small islands and the potential synergies, conflicts, trade-offs and risks.
13 Unfortunately there is relatively little research on the emissions reduction potential of small islands, and far less on
14 the inter-linkages between climate change adaptation and emissions reduction in small islands. Therefore in this
15 section a number of assumptions are made about how and where adaptation and mitigation actions interact.
16
17

18 **29.7.1. Assumptions/Uncertainties Associated with Adaptation and Mitigation Responses**

19

20 Small islands are not homogeneous, they have diverse geo-physical characteristics and economic structures (see
21 Table 29-3, Figure 29-1). Following Nunn (2009) we assume that the combination of island geography and
22 economic types informs the extent to which adaptation and mitigation actions might interact. The geography and
23 location of islands affect their sensitivity to hydro-meteorological and related hazards such as cyclones, floods,
24 droughts, invasive alien species, vector borne disease, and landslides. On the other hand the capacity of island
25 residents to cope is often related income levels, resources endowment, technology and knowledge (see 29.6.2).
26

27 The costs of adaptation in small islands are likely to be relatively large, mostly due to the problem of overhead cost
28 indivisibilities (see 29.3.3) and also because of the potentially high climate change impacts. Bueno et al. (2008)
29 examined the potential costs to the island nations of the Caribbean if greenhouse gas emissions continue unchecked
30 and found that for just three categories—increased hurricane damages, loss of tourism revenue, and infrastructure
31 damages—the Caribbean's annual cost of inaction is projected to total \$22 billion annually by 2050 and \$46 billion
32 by 2100. These costs represent 10 per cent and 22 per cent, respectively, of the current Caribbean economy.
33

34 The potential for mitigation and emissions reductions in islands depends to a large extent on their size and stage of
35 economic development. In the small and less developed islands key 'mitigation' sectors: including energy, transport,
36 industry, built environment, agriculture, forestry, or waste management sectors are likely to be relatively small
37 (Metz *et al.*, 2007, Swart and Raes, 2007). Hence opportunities for emissions reductions are usually quite limited
38 and are mostly associated with electricity generation and utilization of vehicles. More mitigation opportunities
39 should exist in more economically advanced and larger islands that rely on forms of production that utilize fossil
40 fuels, including manufacturing, and where vehicle usage is extensive and electricity driven home appliances, such as
41 air conditioners and water heaters, are extensively used. Table 29-6 presents an indicative assessment of potential
42 areas for mitigation activity on small islands by island 'economy type'.
43

44 [INSERT TABLE 29-6 HERE

45 Table 29-6. Economic structure of small islands and areas of potential emissions reduction.]
46

47 In the absence of significant mitigation efforts at the global scale, adaptation interventions could become very costly
48 and difficult to implement, once certain thresholds of change are reached. (Nelson, 2011; Rosenzweig and Wilbanks,
49 2010, Thornton *et al.*, 2011, Birkmann, 2011). Nicholls et al. (2011) make a similar observation with respect to
50 coastal protection as a response to sea level rise. They suggest that if global mean temperatures increase by around
51 4⁰ C (which may lead to sea level rise between 0.5 m and 2 m) the likelihood of successful coastal protection in
52 some locations such as low-lying small islands, will be low. Consequently, it is argued that 'coastal abandonment'
53 would be a likely outcome in such circumstances (Nicholls *et al.*, 2011).
54

29.7.2. *Potential Synergies and Conflicts*

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

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

Renewable energy resources on small islands have only recently been considered within the context of long-term energy security (Praene *et al.*, 2012, Chen *et al.*, 2007). Stuart (2006) speculates that the lack of uptake of renewable technologies to date might be due to historical commitments to conventional fossil fuel-based infrastructure, and a lack of resources to undertake research and development of alternatives. Those islands that have introduced renewable energy technologies have often done so with support from international development agencies (Dornan, 2011). Despite this there remain significant barriers to the wider institutionalization of renewable technologies in small islands. Research in Europe and the United States has shown the mitigation and cost savings benefits of Energy Service Companies (ESCOs): companies that enter into medium-to-long term performance-based contracts with energy users, invest in energy efficiency measures in buildings and firms, and profit from the ensuing energy savings measures for the premises (see for example Steinberger *et al.*, 2009). Potential benefits exist in creating the opportunity for ESCOs to operate in small islands. Preliminary evidence from Fiji suggests that if the incentive mechanisms can be resolved, and information asymmetries between service providers and users can be aligned, ESCOs could provide an opportunity to expand renewable technologies (Dornan, 2009).

The transition towards renewable energy sources away from fossil fuel dependence has been partly driven by economic motives, notably to avoid oil price volatility and its impact. The development of hydro-power (in Fiji for example) necessitates protection and management of the water catchment zones, and thus could lead to improved management of the water resources – a critical adaptation consideration for areas expected to experience a decrease in average rainfall as a result of climate change. Whilst the cost effectiveness of renewable technologies is critical, placing it within the context of water adaptation could enhance project viability (Dornan, 2009). Cost-benefit analyses have shown that in southeast Mediterranean islands photovoltaic generation and storage systems may be more cost-effective than existing thermal power stations (Kaldellis, 2008; Kaldellis *et al.*, 2009).

Energy prices in small islands are among the highest anywhere in the world, mainly due to their dependence on imported fossil fuel, and limited ability to reap the benefits of economies of scale including bulk buying. Recent studies show that the energy sectors in small islands may be transformed into sustainable growth entities mainly through the judicious exploitation of renewable energy sources, combined with the implementation of energy efficiency measures (van Alphen *et al.*, 2008; Banuri, 2009; Mohanty, 2012; Rogers *et al.*, 2012). Realising the potential for such transformation, the countries comprising the Alliance of Small Island States (AOSIS) launched SIDS Dock, which is intended to function as a 'docking station' to connect the energy sector in SIDS with the international finance, technology and carbon markets with the objective of pooling and optimizing energy efficiency goods and services for the benefit of the group. This initiative seeks to decrease energy dependence in SIDS, while generating financial resources to support low carbon growth and adaptation interventions.

1 Many small islands rely heavily on the foreign exchange from tourism to expand and develop their economies,
2 including the costs of mitigation and adaptation. Tourism, particularly in small islands, often relies on coastal and
3 terrestrial ecosystems to provide visitor attractions and accommodation space. Much has been made of the
4 relationship between ecosystem services and tourism. In Jamaica, Thomas-Hope and Jardine-Comrie (2007) suggest
5 that sustainable tourism planning should include activities undertaken by the industry, that is tertiary treatment of
6 waste, and re-use of water, as well as composting organic material and investing in renewable energy. Gossling and
7 Schumacher (2010) and others who have examined the linkages between greenhouse gas emissions and sustainable
8 tourism argue that the tourism sector (operators and tourists) should pay to promote sustainable tourism, especially
9 where they benefit directly from environmental services sustained by these investments.

12 **29.8. Facilitating Adaptation and Avoiding Maladaptation**

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

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

30 _____ START BOX 29-1 HERE _____

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

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

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

47 _____ END BOX 29-1 HERE _____

49 Notwithstanding the observations of Barnett and O'Neill (2012), there is a concern that early foreclosure of this
50 option might well prove maladaptive, if location-specific circumstances show such action to be efficacious in the
51 longer-term. States contemplating this option may wish to consider early proactive planning, as resettlement of
52 entire communities might prove to be socially, culturally and economically disruptive (Campbell, 2010; McMichael
53 *et al.*, 2012; refer also to 29.3.3.4). The case study of the residents of Nauru who contemplated resettlement in
54 Australia after the collapse of phosphate mining (their only revenue source) in the 1950s, provides helpful insight

1 about the complex social, economic and cultural challenges associated with environmentally triggered migration
2 (Tabucanon and Opeskin, 2011). The challenge therefore is to find the middle ground between premature
3 resettlement and objective assessment of other appropriate adaptation choices.

4
5 Similarly, while insurance is being promoted as an element of the overall climate change response strategy in some
6 island regions, e.g. the Caribbean, where the Caribbean Catastrophe Risk Insurance Facility (a multi-country risk
7 pooling facility established in 2007 and owned by Caribbean governments) has been implemented, concerns have
8 also been expressed in various jurisdictions about possible linkages to maladaptation. The potential consequences
9 include the imposition of exorbitant premiums that are beyond the capacity of resource-scarce governments as the
10 perception of climate change risks increase, discriminatory coverage of sectors that may not align with local
11 priorities, and tacit encouragement for the state, individuals and the private sector to engage in behavior that is not
12 risk-averse, e.g. development in hazard-prone areas (Herweijer *et al.*, 2009; Linnerooth-Bayer *et al.*, 2009;
13 Linnerooth-Bayer *et al.*, 2011; van Nostrand and Nevius, 2011; Thomas and Leichenko, 2011). Likewise, although
14 the exploitation of renewable energy is vital to the sustainable development of small islands, more attention needs to
15 be paid to the development of energy storage technologies, if rapid transition from conventional fuels is to be
16 achieved in an efficient manner. This is especially important in the case of intermittent energy sources (e.g. solar and
17 wind), as the cost of current storage technologies can frustrate achievement of full conversion to renewables. Thus to
18 avoid the possibility of maladaptation in the sector, countries may wish to consider engaging in comprehensive
19 planning, including considerations relating to energy storage (Krajačić *et al.*, 2008; Krajačić *et al.*, 2010; Bazilian *et al.*, 2011).

20
21
22 Recent studies have demonstrated that opportunities exist in island environments for avoiding maladaptation.
23 Studies have shown for example that decisions about adaptation choices and their implementation are best facilitated
24 where there is constructive engagement with the communities at risk, in a manner that fosters transparency and trust
25 (Fazey *et al.*, 2008; Lopez Marrero, 2010; van Aalst *et al.*, 2008). Further, some analysts argue that adaptation
26 choices are often subjective in nature and suggest that participatory stakeholder involvement can yield valuable
27 information about the priorities and expectations that communities attach to the sector for which adaptation is being
28 sought. The point is underscored by Moreno and Becken (2009), whose study of the tourism sector on the
29 Mamanuca islands (Fiji) clearly demonstrates that approaches which explicitly integrate stakeholders into each step
30 of the process from vulnerability assessment right through to consideration of alternatives measures can provide a
31 sound basis for assisting destinations with the implementation of appropriate adaptation interventions. This view is
32 supported by Dulal *et al.* (2009), who argue that the most vulnerable groups in the Caribbean - the poor, elderly,
33 indigenous communities and rural children - will be at greater risk of being marginalized, if adaptation is not
34 informed by equitable and participatory frameworks.

35
36 Other studies reveal that new paradigms whose adoption can reduce the risk of maladaptation in island
37 environments, are emerging across various sectors. In the area of natural resource management, Hansen *et al.* (2010)
38 suggest that the use of protected areas for climate refugia, reduction of non-climate stressors on ecosystems,
39 adoption of adaptive management approaches combined with reduction of greenhouse gas emissions wherever
40 possible, may prove to be more effective response strategies than traditional conservation approaches. Other
41 strategic approaches, including the implementation of multi-sectoral and cross-sectoral measures, also facilitate
42 adaptation in a more equitable, integrated and sustainable manner. Similarly, 'no-regret' measures such as
43 wastewater recycling, trickle irrigation, conversion to non-fossil fuel based energy and transportation which offer
44 collateral benefits with or without the threat of climate change, and 'low-regret' strategies, which may only increase
45 existing operational costs marginally, are becoming increasingly attractive options to island governments (Gravelle
46 and Mimura, 2008; Heltberg *et al.*, 2009; Cashman *et al.*, 2010; Howard *et al.*, 2010). Together, these constitute
47 valid risk management approaches, as they are designed to assist communities in making prudent, but necessary
48 decisions, in the face of an uncertain future.

49
50 Caution is needed to ensure that donors are not driving the adaptation and mitigation agenda in small islands, as
51 there is a risk that donor-driven adaptation or mitigation will not address the salient challenges on small islands, and
52 may lead to inadequate adaptation or a waste of scarce resources (Barnett, 2010; Nunn, 2009). There is a concern
53 that donor-led initiatives may unintentionally cause enhanced vulnerability by supporting adaptation strategies that

1 are externally derived, rather than optimizing the benefits of local practices that have proven to be efficacious
2 through time (Reenberg *et al.*, 2008; Kelman and West, 2009; Campbell and Beckford, 2009).
3
4

5 **29.9. Research and Data Gaps**

6

7 Significant advances in our understanding of the actual impacts and potential effects of climate change on small
8 islands have been made since the AR4. These advances cover a range of themes including: dynamic downscaling of
9 scenarios appropriate for small islands; impacts of trans-boundary processes generated well beyond the borders of an
10 individual nation or island; barriers to adaptation in small islands and how they may be overcome; the relationships
11 between climate change adaptation and disaster risk reduction; and, the relationships between climate change
12 adaptation, maladaptation and sustainable development.
13

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

- 17 • **Lack of climate change and socio-economic scenarios and data at the required scale for small islands.**
18 For example, projected changes in climate for the Caribbean, Pacific, Indian Ocean and Mediterranean
19 islands, generally apply to the region as a whole and not to specific countries. However, most socio-
20 economic decisions are taken at smaller scales. There is need for credible simulations of future small island
21 climates and socio-economic conditions at comparable scales
- 22 • **Difficulties in detecting and attributing past impacts on small islands to climate change processes.**
23 Further investigation of the observed impacts of weather, climate and ocean events that may be related to
24 climate change is required to clarify the relative role of climate change and non-climate change drivers.
- 25 • **Uncertainty about the potential impacts of climate change.** In several small islands adaptation is being
26 progressed without adequate understanding of past or potential impacts and vulnerability. Whilst
27 assessment of future impacts is hampered because of uncertainty in climate projections at the local island
28 level, alternative scenarios could be used for vulnerability and sensitivity studies to guide adaptation
29 strategies.
- 30 • **Need for a range of climate change-related projections beyond temperature and sea-level.** Generally
31 climate-model projections of temperature and sea-level have been satisfactory, but there are strong
32 requirements for projections for other variables that are of critical importance to small islands. These
33 include rainfall and drought, wind direction and strength, tropical storms and wave climate, and recognition
34 that trans-boundary processes are also significant in a small island context.
- 35 • **Need to acknowledge the heterogeneity and complexity of small island states and territories.** Although
36 small islands have several characteristics in common, neither the variety or complexity of small islands is
37 sufficiently appreciated. Thus, transferring data and practices from a continental situation, or from one
38 small island state to another, needs to be done with care.
- 39 • **Need to develop a typology that classifies small island states into a few groupings based on their
40 social, cultural, economic, physical and ecological characteristics relevant to climate change impacts
41 and vulnerability.** This has been an elusive task to date noting the discussion on vulnerability indicators in
42 29.6.1. Notwithstanding that discussion as well as the foregoing point there is increasing evidence that such
43 a typology could be developed in stages. For example, an improved understanding of the interactions
44 between vulnerability and 'island type' could provide useful guidance for optimizing scarce adaptation
45 resources at community and local levels.
- 46 • **Within country/territory differences need to be better understood.** Many of the environmental and
47 human impacts we have reported have been attributed to the whole country, when in fact they refer only to
48 the major centre or town or region. There is need for more work on rural areas, outer islands and secondary
49 communities. Several examples of such research have been cited in this chapter. Also it should be noted that
50 some small island states are single islands and others highly fragmented multiple islands.
- 51 • **Lack of investment and attention to climate and environmental monitoring frameworks in small
52 islands.** A fundamental gap in the ability to improve empirical understanding of present and future climate
53 change impacts is the lack of climate and environmental monitoring frameworks that in turn hampers the
54 level of confidence with which adaptation responses can be designed and implemented.

- 1 • **Economic and social costs of climate change impacts and adaptation options are rarely known.** In
2 small island states and territories the costs of past weather, climate and ocean events is poorly known and
3 further research is required to identify such costs, and to determine the economic and societal costs of
4 climate change impacts and the costs of adaptation options to minimize those impacts.
- 5 • **Need to integrate adaptation to climate change and development co-operation activities.** There is some
6 evidence to indicate that longer-term climate change adaptation policies and programs in small islands are
7 compromising more immediate development objectives. Avenues need to be developed to redress this
8 situation perhaps through a combined focus on hazard risk reduction and community based approaches to
9 development and adaptation. Synergies between adaptation and development need to be explored in a small
10 island context.

11
12 The foregoing list is a sample of the gaps, needs and research agenda appropriate for small island states. If those
13 gaps are filled, needs satisfied and research achieved, we feel that the general view that small islands are highly
14 vulnerable to climate change, and, that they have low adaptive capacity, may well be challenged by some nations as
15 well as in some sectors and/or regions within small island states.

16 17 18 **Frequently Asked Questions**

19 20 ***FAQ 29.1: Are small islands experiencing the impacts of climate change?***

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

32 33 ***FAQ 29.2: Why is it difficult to detect and attribute changes on small islands to climate change?***

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

46 47 ***FAQ 29.3: Why is the cost of adaptation to climate change so high in small islands?***

48 Adaptation to climate change often involves overhead costs, such as infrastructural changes and upgrades. These
49 generally include ‘lumpy’ costs and costs that cannot be downscaled in proportion to the size of the population or
50 territory. This disadvantage, termed the ‘indivisibility’ problem, is a major socio-economic issue for many small
51 islands. It can be illustrated by way of example. A seawall, intended as a shore protection measure, 100 m
52 long, suitable for a small island, will cost much more than one-tenth of a seawall 1 km long (that is ten times as
53 much), suitable for a larger territory. This means that the cost of the seawall to the small island will be higher per m
54 than for the larger territory. This reality applies throughout much of a small island economy including the

1 indivisibility of public utilities and services. It also applies to all forms of development and redesign of the
2 infrastructure, aimed at ensuring that it is more resilient to climate change and extreme weather events. The result is
3 a relatively higher adaptation cost per capita in countries with small populations, such as small islands and
4 especially those islands that are geographically isolated, have a poor resource base and high import and transport
5 costs.

8 References

- 10 ADB, 2009: *Natural Catastrophe Risk Insurance Mechanisms for Asia and the Pacific*. Asian Development Bank
11 (ADB), Manila, Philippines.
- 12 Adger, W.N. and K. Brown, 2009: Vulnerability and resilience to environmental change: Ecological and social
13 perspectives. *A Companion to Environmental Geography*, , 109-122.
- 14 Adger, W., N. Arnell, E. Tompkins, 2005:
15 Successful adaptation to climate change across scales. *Global Environmental Change*, **5(2)**, 77-86.
- 16 Adger, W., S. Dessai, M. Goulden, M. Hulme, I. Lorenzoni, D. Nelson, L. Naess, J. Wolf, and A. Wreford, 2009:
17 Are there social limits to adaptation to climate change? *Climatic Change*, **93(3)**, 335-354.
- 18 Afifi, T., K. Warner, and T. Rosenfeld, 2013: Environmentally induced migration, theoretical and methodological
19 research challenges. In: *The Encyclopedia of Global Human Migration*. Blackwell Publishing Ltd, .
- 20 Ainsworth, T.D., M. Fine, G. Roff, and O. Hoegh-Guldberg, 2007: Bacteria are not the primary cause of bleaching
21 in the Mediterranean coral *Oculina patagonica*. *Isme j*, **2(1)**, 67-73.
- 22 Akerlof, K., R. DeBono, P. Berry, A. Leiserowitz, C. Roser-Renouf, K. Clarke, A. Rogaeva, M.C. Nisbet, M.R.
23 Weathers, and E.W. Maibach, 2010: Public perceptions of climate change as a human health risk: surveys of the
24 United States, Canada and Malta. *International Journal of Environmental Research and Public Health*, **7(6)**,
25 2559-2606.
- 26 Albins, M.A. and M.A. Hixon, 2008: Invasive Indo-Pacific lionfish *Pterois volitans* reduce recruitment of Atlantic
27 coral-reef fishes. *Marine Ecology Progress Series*, **367**, 233-238.
- 28 Albins, M.A. and M.A. Hixon, 2011: Worst case scenario: potential long-term effects of invasive predatory lionfish
29 (*Pterois volitans*) on Atlantic and Caribbean coral-reef communities. *Environmental Biology of Fishes*, , 1-7.
- 30 Aligizaki, K. and G. Nikolaidis, 2008: Morphological identification of two tropical dinoflagellates of the genera
31 *Gambierdiscus* and *Sinophysia* in the Mediterranean Sea. *Journal of Biological Research-Thessaloniki*, **9**, 75-
32 82.
- 33 Alling, A., O. Doherty , H. Logan, L. Feldman, and P. Dustan, 2007: Catastrophic coral mortality in the remote
34 Central Pacific Ocean: Kiribati, Phoenix Islands. *Atoll Research Bulletin*, (**551**), 1-21.
- 35 Alvarez-Filip, L., N.K. Dulvy, J.A. Gill, I.M. Cote, and A.R. Watkinson, 2009: Flattening of Caribbean coral reefs:
36 region-wide declines in architectural complexity. *Proceedings of the Royal Society B-Biological Sciences*,
37 **276(1669)**, 3019-3025.
- 38 Anderson, M.G., E. Holcombe, J.R. Blake, F. Ghesquire, N. Holm-Nielsen, and T. Fisseha, 2011: Reducing
39 landslide risk in communities: Evidence from the Eastern Caribbean. *Applied Geography*, **31(2)**, 590-599.
- 40 Angelo, C.L. and C.C. Daehler, 2012: Upward expansion of fire-adapted grasses along a warming tropical elevation
41 gradient. *Ecography*, , no-no.
- 42 Angelucci, F. and P. Conforti, 2010: Risk management and finance along value chains of Small Island Developing
43 States. Evidence from the Caribbean and the Pacific. *Food Policy*, **35(6)**, 565-575.
- 44 Anthoff, D., R. Nicholls, and R. Tol, 2010: The economic impact of substantial sea-level rise. *Mitigation and
45 Adaptation Strategies for Global Change*, **15(4)**, 321-335.
- 46 Audefroy, J.F., 2011: Haiti: post-earthquake lessons learned from traditional construction. *Environment and
47 Urbanization*, **23(2)**, 447-462.
- 48 Australian Bureau of Meteorology and CSIRO, 2011: Climate Change in the Pacific: Scientific Assessment and
49 New Research. Volume 1: Regional Overview. , 1-257.
- 50 Australian Bureau of Meteorology and CSIRO, 2011: Climate Change in the Pacific: Scientific Assessment and
51 New Research. Volume 2: Country Reports Overview. , 1-273.
- 52 Baider, C. and F.B.V. Florens, 2011: Control of invasive alien weeds averts imminent plant extinction. *Biological
53 Invasions*, **13(12)**, 2641-2646.

- 1 Baines, G., P. Beveridge, and J. Maragos, 1974: Storms and island building at Funafuti Atoll, Ellice Islands. In:
2 *Proceedings of the Second International Symposium on Coral Reefs*. Proceedings of Proceedings of the Second
3 International Symposium on Coral Reefs. pp. 485-496.
- 4 Baker, J.L., 2012: *Climate Change, Disaster Risk, and the Urban Poor: Cities Building Resilience for a Changing*
5 *World*. World Bank Publications, .
- 6 Ballu , V., M.-. Bouin, P. Simeoni, W.C. Crawford, S. Calmant, J.-. Bore, T. Kanas, and B. Pelletier, 2011:
7 Comparing the role of absolute sea-level rise and vertical tectonic motions in coastal flooding, Torres Islands
8 (Vanuatu). *Proceedings of the National Academy of Sciences.*, .
- 9 Banuri, T., 2009: Climate change and sustainable development. *Natural Resources Forum*, **33(4)**, 257-258.
- 10 Barnett, J., 2001: Adapting to climate change in Pacific Island Countries: The problem of uncertainty. *World*
11 *Development*, **29(6)**, 977-993.
- 12 Barnett, J., S. Lambert, and I. Fry, 2008: The hazards of indicators: insights from the environmental vulnerability
13 index. *Annals of the Association of American Geographers*, **98(1)**, 102-119.
- 14 Barnett, J. and J. Campbell, 2010: *Climate Change and Small Islands States: Power, Knowledge and the South*
15 *Pacific*. Earthscan, London and Washington D.C., pp. 218.
- 16 Barnett, J. and S.J. O'Neill, 2012: Islands, resettlement and adaptation. *Nature Climate Change*, **2**, 8-10.
- 17 Barnett, J. and N. Chamberlain, 2010: Migration as Climate Change Adaptation: Implications for the Pacific. In:
18 *Climate Change and Migration, South Pacific Perspectives*. [BURSON, B. (ed.)]. Institute of Policy Studies,
19 Victoria University of Wellington, Wellington, New Zealand, pp. 51-60.
- 20 Barnett, J. and M. Webber, 2010: Accommodating migration to promote adaptation to climate change. *World Bank*
21 *Policy Research Working Paper no 5270*, .
- 22 Barnett, J., 2008: The effect of aid on capacity to adapt to climate change: insights from Niue. *Political Science*,
23 **60(1)**, 31-45.
- 24 Barnett, J., 2010: Climate change science and policy, as if people mattered. In: *Climate change, ethics and human*
25 *security*. [O'Brien, K., S. Clair, A. Lera, and B. Kristoffersen(eds.)]. Cambridge University Press, pp. 47-62.
- 26 Bazilian, M., H. Rogner, M. Howells, S. Hermann, D. Arent, D. Gielen, P. Steduto, A. Mueller, P. Komor, R.S.J.
27 Tol, and K.K. Yumkella, 2011: Considering the energy, water and food nexus: Towards an integrated modelling
28 approach. *Energy Policy*, **39(12)**, 7896-7906.
- 29 Becker, M., B. Meyssignac, C. Letetrel, W. Llovel, A. Cazenave, and T. Delcroix , 2012: Sea level variations at
30 tropical Pacific islands since 1950. *Global and Planetary Change*, **80-81**, 85-98.
- 31 Bedford, R. and C. Bedford, 2010: International Migration and Climate Change: A Post-Copenhagen Perspective on
32 Options for Kiribati and Tuvalu. *Climate Change and Migration: South Pacific Perspectives*, .
- 33 Béguin, A., S. Hales, J. Rocklöv, C. Åström, V.R. Louis, and R. Sauerborn, 2011: The opposing effects of climate
34 change and socio-economic development on the global distribution of malaria. *Global Environmental Change*,
35 **21(4)**, 1209-1214.
- 36 Bell, J.D., C. Reid, M.J. Batty, P. Lehodey, L. Rodwell, A.J. Hobday, J.E. Johnson, and A. Demmke, 2013: Effects
37 of climate change on oceanic fisheries in the tropical Pacific: implications for economic development and food
38 security. *Climatic Change*, , 1-14.
- 39 Bell, J.D., J.E. Johnson, and A.J. Hobday (eds.), 2011: *Vulnerability of tropical Pacific fisheries and aquaculture to*
40 *climate change*. Secretariat of the Pacific Community, Noumea, New Caledonia, pp. 925.
- 41 Benning, T.L., D. LaPointe, C.T. Atkinson, and P.M. Vitousek, 2002: Interactions of climate change with biological
42 invasions and land use in the Hawaiian Islands: Modeling the fate of endemic birds using a geographic
43 information system. *Proceedings of the National Academy of Sciences*, **99**, 14246-14249.
- 44 Berringer, A.C., 2012: Climate Change and Emigration: Comparing “Sinking Islands” and Jamaica. *Naturally*
45 *Immigrants*, , 106.
- 46 Biermann, F. and I. Boas, 2008: Protecting climate refugees: the case for a global protocol. *Environment: Science*
47 *and Policy for Sustainable Development*, **50(6)**, 8-17.
- 48 Biermann, F. and I. Boas, 2010: Preparing for a warmer world: Towards a global governance system to protect
49 climate refugees. *Global Environmental Politics*, **10(1)**, 60-88.
- 50 Bijlsma, L., C.N. Ehler, R.J.T. Klein, S.M. Kulshrestha, R.F. McLean, N. Mimura, R.J. Nicholls, L.A. Nurse, H.
51 Perez Nieto, E.Z. Stakhiv, R.K. Turner, and R.A. Warrick, 1996: Coastal zones and small islands. In: *Climate*
52 *Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific - Technical Analyses*.
53 *Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate*

- 1 *Change*. [Watson, R.T., M.C. Zinyowera, and R.H. Moss(eds.)]. Cambridge University Press, Cambridge, UK
2 and New York, USA, pp. 289-324.
- 3 Birkmann, J., 2011: First-and second-order adaptation to natural hazards and extreme events in the context of
4 climate change. *Natural Hazards*, **58(2)**, 811-840.
- 5 Bishop, M.L., 2012: The political economy of small states: enduring vulnerability? *Review of International Political*
6 *Economy*, **19(5)**, 942-960.
- 7 Blackburn, T.M., P. Cassey, R.P. Duncan, K.L. Evans, and K.J. Gaston, 2004: Avian extinction and mammalian
8 introductions on oceanic islands. *Science*, **305**, 1955-1958.
- 9 Bokhorst, S., A. Huiskes, P. Convey, and R. Aerts, 2007: The effect of environmental change on vascular plant and
10 cryptogam communities from the Falkland Islands and the Maritime Antarctic. *BMC Ecology*, **7(1)**, 15.
- 11 Bokhorst, S., A. Huiskes, P. Convey, P.M. van Bodegom, and R. Aerts, 2008: Climate change effects on soil
12 arthropod communities from the Falkland Islands and the Maritime Antarctic. *Soil Biology and Biochemistry*,
13 **40(7)**, 1547-1556.
- 14 Boyd, E., N. Grist, S. Juhola, and V. Nelson, 2009: Exploring development futures in a changing climate: Frontiers
15 for development policy and practice. *Development Policy Review*, **27(6)**, 659-674.
- 16 Brandt, M.E. and J.W. McManus, 2009: Disease incidence is related to bleaching extent in reef-building corals.
17 *Ecology*, **90(10)**, 2859-2867.
- 18 Bridges, K.W. and W.C. McClatchey, 2009: Living on the margin: Ethnoecological insights from Marshall Islanders
19 at Rongelap atoll. *Global Environmental Change*, **19(2)**, 140-146.
- 20 Briguglio, L., G. Cordina, N. Farrugia, and S. Vella, 2009: Economic vulnerability and resilience: Concepts and
21 measurements. *Oxford Development Studies*, **37(3)**, 229-247.
- 22 Brooks, N., W.N. Adger, and P.M. Kelly, 2005: The determinants of vulnerability and adaptive capacity at the
23 national level and the implications for adaptation. *Global Environmental Change Part A*, **15(2)**, 151-163.
- 24 Brown, J.N., J.R. Brown, C. Langlais, R. Colman, J. Risbey, B.F. Murphy, A. Moise, A.S. Gupta, I. Smith, and L.
25 Wilson, submitted: *Exploring qualitative regional climate projections: a case study for Nauru* .
- 26 Bueno, R., C. Herzfeld, E. Stanton, and F. Ackerman, 2008: *The Caribbean and Climate Change: The Costs of*
27 *Inaction*. Stockholm Environment Institute and US Center of Global Development and Environment Institute,
28 Tufts University, pp. 37.
- 29 Bush, D.M., W.J. Neal, and C.W. Jackson, 2009: Summary of Puerto Rico's vulnerability to coastal hazards: Risk,
30 mitigation, and management with examples. *Geological Society of America Special Papers*, **460**, 149-165.
- 31 Byravan, S. and S.C. Rajan, 2006: Providing new homes for climate change exiles. *Climate Policy*, **6(2)**, 247-252.
- 32 Cambers, G., 2009: Caribbean beach changes and climate change adaptation. *Aquatic Ecosystem Health and*
33 *Management*, **12(2)**, 168-176.
- 34 Campbell, D. and C. Beckford, 2009: Negotiating Uncertainty: Jamaican Small Farmers' Adaptation and Coping
35 Strategies, Before and After Hurricanes—A Case Study of Hurricane Dean. *Sustainability*, **1(4)**, 1366-1387.
- 36 Campbell, J.D., M.A. Taylor, T.S. Stephenson, R.A. Watson, and F.S. Whyte, 2011: Future climate of the Caribbean
37 from a regional climate model. *International Journal of Climatology*, **31(12)**, 1866-1878.
- 38 Campbell, J., 2009: Islandness: Vulnerability and resilience in Oceania. *Shima: The International Journal of*
39 *Research into Island Cultures*, **3**, 85-97.
- 40 Campbell, J., 2010: Climate Change and Population Movement in Pacific Island Countries. *Climate Change and*
41 *Migration*, , 29.
- 42 Campbell, J.R., M. Goldsmith, and K. Koshy, 2007: *Community relocation as an option for adaptation to the effects*
43 *of climate change and climate variability in Pacific Island countries (PICs)*. Asia-Pacific Network for Global
44 Change Research, .
- 45 Campbell, S.J., L.J. McKenzie, and S.P. Kerville, 2006: Photosynthetic responses of seven tropical seagrasses to
46 elevated seawater temperature. *Journal of Experimental Marine Biology and Ecology*, **330(2)**, 455-468.
- 47 Cantin, N.E., A.N. Cohen, K.B. Karnauskas, A.N. Tarrant, and D.C. McCorkle, 2010: Ocean Warming slows coral
48 growth in the Central Red Sea. *Science*, **329(5989)**, 322-325.
- 49 Cardona, O.D., 2007: *Indicators of disaster risk and risk management*. Inter-American Development Bank,
50 Washington D.C.
- 51 Carilli, J.E., R.D. Norris, B. Black, S.M. Walsh, and M. McField, 2010: Century-scale records of coral growth rates
52 indicate that local stressors reduce coral thermal tolerance threshold. *Global Change Biology*, **16(4)**, 1247-1257.
- 53 Carpenter, R.C. and P.J. Edmunds, 2006: Local and regional scale recovery of *Diadema* promotes recruitment of
54 scleractinian corals. *Ecology Letters*, **9(3)**, 268-277.

- 1 Cashman, A., L. Nurse, and J. Charlery, 2010: Climate change in the Caribbean: The water management
2 implications. *Journal of Environment and Development*, **19(1)**, 42-67.
- 3 Caujape-Castells, J., A. Tye, D.J. Crawford, A. Santos-Guerra, A. Sakai, K. Beaver, W. Lobin, F. Vincent Florens,
4 M. Moura, and R. Jardim, 2010: Conservation of oceanic island floras: present and future global challenges.
5 *Perspectives in Plant Ecology, Evolution and Systematics*, **12(2)**, 107-129.
- 6 Cazenave, A. and W. Llovel, 2010: Contemporary Sea Level Rise. *Annual Review of Marine Science*, **2**, 145-173.
- 7 Cazenave, A. and F. Remy, 2011: Sea level and climate: measurements and causes of changes. *Wiley*
8 *Interdisciplinary Reviews: Climate Change*, **2(5)**, 647-662.
- 9 CCRIF, 2008: *The Caribbean Catastrophe Risk Insurance Facility Annual Report 2007-2008*.
- 10 Cervino, J.M., F.L. Thompson, B. Gomez-Gil, E.A. Lorence, T.J. Goreau, R.L. Hayes, K.B. Winiarski-Cervino,
11 G.W. Smith, K. Huguen, and E. Bartels, 2008: The *Vibrio* core group induces yellow band disease in Caribbean
12 and Indo-Pacific reef-building corals. *Journal of Applied Microbiology*, **105(5)**, 1658-1671.
- 13 Chadee, D., B. Shivnauth, S. Rawlins, and A. Chen, 2007: Climate, mosquito indices and the epidemiology of
14 dengue fever in Trinidad (2002–2004). *Annals of Tropical Medicine and Parasitology*, **101(1)**, 69-77.
- 15 Chadee, D.D., 2009: Dengue cases and *Aedes aegypti* indices in Trinidad, West Indies. *Acta Tropica*, **112(2)**, 174-
16 180.
- 17 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,
18 and M.B. Murphy, 2011: Spatial distribution of ciguateric fish in the Republic of Kiribati. *Chemosphere*, **84(1)**,
19 117-123.
- 20 Charlery, J. and L. Nurse, 2010: Areal downscaling of global climate models: An approach that avoids data
21 remodelling. *Climate Research*, **43(3)**, 2412-249.
- 22 Chaves, L.F. and J.M. Koenraadt, 2010: Climate change and highland malaria: Fresh air in a hot debate
23 . *The Quarterly Review of Biology*, **85(1)**, 27-55.
- 24 Chen, F., N. Duic, L.M. Alves, and M.G. Carvalho, 2007: Renewislands—Renewable energy solutions for islands.
25 *Renewable and Sustainable Energy Reviews*, **8(11)**, 1888-1902.
- 26 Chen, I., H.J. Shiu, S. Benedick, J.D. Holloway, V.K. Chey, H.S. Barlow, J.K. Hill, and C.D. Thomas, 2009:
27 Elevation increases in moth assemblages over 42 years on a tropical mountain. *Proceedings of the National*
28 *Academy of Sciences*, **106(5)**, 1479.
- 29 Christenhusz, M.J.M. and T.K. Toivonen, 2008: Giants invading the tropics: the oriental vessel fern, *Angiopteris*
30 *evecta* (Marattiaceae). *Biological Invasions*, **10(8)**, 1215-1228.
- 31 Church, J.A. and N.J. White, 2011: Sea-Level Rise from the Late 19th to the Early 21st Century. *Surveys in*
32 *Geophysics*, **32(4-5)**, 585-602.
- 33 Cinner, J.E., T.R. McClanahan, N.A.J. Graham, T.M. Daw, J. Maina, S.M. Stead, A. Wamukota, K. Brown, and Ö.
34 Bodin, 2012: Vulnerability of coastal communities to key impacts of climate change on coral reef fisheries.
35 *Global Environmental Change*, **22(1)**, 12-20.
- 36 Cochard, R., S.L. Ranamukhaarachchi, G.P. Shivakoti, O.V. Shipin, P.J. Edwards, and K.T. Seeland, 2008: The
37 2004 tsunami in Aceh and Southern Thailand: A review on coastal ecosystems, wave hazards and vulnerability.
38 *Perspectives in Plant Ecology Evolution and Systematics*, **10(1)**, 3-40.
- 39 Connell, J. and J.P. Lea, 2002: *Urbanisation in the Island Pacific: Towards Sustainable Development*. Routledge,
40 London, .
- 41 Cournil, C. and F. Gemenne, 2010: Les populations insulaires face aux changements climatique: des migrations a
42 anticiper. *Vertigo*, **10(3)**.
- 43 Coutinho, R., J. Pacheco, N. Wallenstein, A. Pimentel, R. Marques, and R. Silva, 2009: Integrating Geological
44 Knowledge in Planning Methods for Small Islands Coastal Plans. *Journal of Coastal Research*, , 1199-1203.
- 45 Croquer, A. and E. Weil, 2009: Changes in Caribbean coral disease prevalence after the 2005 bleaching event.
46 *Diseases of Aquatic Organisms*, **87(1-2)**, 33-43.
- 47 Croquer, A. and E. Weil, 2009: Spatial variability in distribution and prevalence of Caribbean scleractinian coral and
48 octocoral diseases. II. Genera-level analysis. *Diseases of Aquatic Organisms*, **83(3)**, 209-222.
- 49 Crump, J., 2008: Snow, sand, ice and sun: Climate change and equity in the Arctic and small island developing
50 states. *Sustainable Development Law and Policy*, **8(3)**, 8-13.
- 51 Cruz, M., R. Aguiar, A. Correia, T. Tavares, J. Pereira, and F. Santos, 2009: Impacts of climate change on the
52 terrestrial ecosystems of Madeira. *International Journal of Design and Nature and Ecodynamics*, **4(4)**, 413-422.
- 53 Cummins, J.D. and O. Mahul, 2009: *Catastrophe risk financing in developing countries: Principles for Public*
54 *Intervention*. World Bank Publications, Washington D.C., .

- 1 Daly, M., N. Poutasi, F. Nelson, and J. Kohlhase, 2010: Reducing the climate vulnerability of coastal communities
2 in Samoa. *Journal of International Development*, **22(2)**, 265-281.
- 3 Danovaro, R., S.F. Umani, and A. Pusceddu, 2009: Climate Change and the potential spreading of marine mucilage
4 and microbial pathogens in the Mediterranean Sea. *Plos One*, **4(9)**, e7006.
- 5 Dawson, J.L. and S.G. Smithers, 2010: Shoreline and beach volume change between 1967 and 2007 at Raine Island,
6 Great Barrier Reef, Australia. *Global and Planetary Change*, **72(3)**, 141-154.
- 7 de Haas, H., 2011: Mediterranean migration futures: Patterns, drivers and scenarios. *Global Environmental Change*,
8 **21, Supplement 1**, S59-S69.
- 9 De'ath, G., J.M. Lough, and K.C. Fabricius, 2009: Declining coral calcification on the Great Barrier Reef. *Science*,
10 **323(5910)**, 116-119.
- 11 Dema, B., 2012: Sea Level Rise and the Freely Associated States: Addressing Environmental Migration Under the
12 Compacts of Free Association. *Columbia Journal of Environmental Law*, **37**, 177-204.
- 13 Department of Meteorology (Maldives), 2007: *The Unusually Strong Tidal Waves Hit Maldives, 15-18 May.*, pp. 12.
- 14 Didham, R.K., J.M. Tylianakis, M.A. Hutchison, R.M. Ewers, and N.J. Gemmill, 2005: Are invasive species the
15 drivers of ecological change? *Trends in Ecology & Evolution*, **20(9)**, 470-474.
- 16 Donelson, J.M., P.L. Munday, M.I. McCormick, N.W. Pankhurst, and P.M. Pankhurst, 2010: Effects of elevated
17 water temperature and food availability on the reproductive performance of a coral reef fish. *Marine Ecology*
18 *Progress Series*, **401**, 233-243.
- 19 Donn, W.L. and W.T. McGuinness, 1959: Barbados storm swell. *Journal of Geophysical Research*, **64(12)**, 2341-
20 2349.
- 21 Donner, S.D., 2009: Coping with commitment: Projected thermal stress on coral reefs under different Future
22 scenarios. *Plos One*, **4(6)**, e5712.
- 23 Donner, S.D., T. Kirata, and C. Vieux, 2010: Recovery from the 2004 coral bleaching event in the Gilbert Islands,
24 Kiribati. *Atoll Research Bulletin.*, **(587)**, 1-25.
- 25 Dornan, M., 2009: Methods for assessing the contribution of renewable technologies to energy security: the
26 electricity sector of Fiji. *Pacific Economic Bulletin*, **24(3)**, 71-91.
- 27 Dornan, M., 2011: Solar-based rural electrification policy design: The Renewable Energy Service Company
28 (RESCO) model in Fiji. *Renewable Energy*, **36(2)**, 797-803.
- 29 Dulal, H.B., K.U. Shah, and N. Ahmad, 2009: Social Equity Considerations in the Implementation of Caribbean
30 Climate Change Adaptation Policies. *Sustainability*, **1(3)**, 363-383.
- 31 Dumaru, P., 2010: Community-based adaptation: enhancing community adaptive capacity in Druadrua Island, Fiji.
32 *Wiley Interdisciplinary Reviews Climate Change*, **1(5)**, 751-763.
- 33 Dunne, R.P., S.M. Barbosa, and P.L. Woodworth, 2012: Contemporary sea level in the Chagos Archipelago, central
34 Indian Ocean. *Global and Planetary Change*, **82-83(0)**, 25-37.
- 35 Dupon, J., 1987: Les atolls et le risque cyclonique. *Cah.Sci.Hum*, **23(5-4)**, 567-599.
- 36 Eakin, C.M., J.M. Lough, and S.F. Heron, 2009: Climate variability and change: Monitoring data and evidence for
37 increased coral bleaching stress. *Ecological Studies*, **205**, 41-67.
- 38 Ellison, J.C., 1993: Mangrove Retreat with Rising Sea-Level, Bermuda. *Estuarine, Coastal and Shelf Science*, **37(1)**,
39 75-87.
- 40 Ellison, J.C., 2009: Wetlands of the Pacific Island region. *Wetlands Ecology and Management*, **17(3)**, 169-206.
- 41 Emmanuel, K. and B. Spence, 2009: Climate change implications for water resource management in Caribbean
42 tourism. *Worldwide Hospitality and Tourism Themes*, **1(3)**, 252-268.
- 43 Englund, R.A., 2008: Invasive species threats to native aquatic insect biodiversity and conservation measures in
44 Hawai'i and French Polynesia. *Journal of Insect Conservation*, **12(3-4)**, 415-428.
- 45 Etienne, S., 2012: Marine inundation hazards in French Polynesia: geomorphic impacts of Tropical Cyclone Oli in
46 February 2010. *Geological Society, London, Special Publications*, **361(1)**, 21-39.
- 47 Etienne, S. and J.P. Terry, 2012: Coral boulders, gravel tongues and sand sheets: Features of coastal accretion and
48 sediment nourishment by Cyclone Tomas (March 2010) on Taveuni Island, Fiji. *Geomorphology*, **175-176(0)**,
49 54-65.
- 50 Farbotko, C. and H. Lazrus, 2012: The first climate refugees? Contesting global narratives of climate change in
51 Tuvalu. *Global Environmental Change*, **22(2)**, 382-390.
- 52 Fazey, I., N. Pettorelli, J. Kenter, D. Wagatora, and D. Schuett, 2011: Maladaptive trajectories of change in Makira,
53 Solomon Islands. *Global Environmental Change*, **21(4)**, 1275-1289.

- 1 Feagin, R.A., N. Mukherjee, K. Shanker, A.H. Baird, J. Cinner, A.M. Kerr, N. Koedam, A. Sridhar, R. Arthur, L.P.
2 Jayatissa, D. Lo Seen, M. Menon, S. Rodriguez, M. Shamsuddoha, and F. Dahdouh-Guebas, 2010: Shelter from
3 the storm? Use and misuse of coastal vegetation bioshields for managing natural disasters. *Conservation*
4 *Letters*, **3(1)**, 1-11.
- 5 Ferdinand, I., G. O'Brien, P. O'Keefe, and J. Jayawickrama, 2012: The double bind of poverty and community
6 disaster risk reduction: A case study from the Caribbean. *International Journal of Disaster Risk Reduction*, **2(0)**,
7 84-94.
- 8 Figueroa, J., 2008: The need to strengthen malaria control in the Caribbean in the era of HIV/AIDS. *West Indian*
9 *Medical Journal*, **57(5)**, 425-426.
- 10 Fish, M.R., I.M. Cote, J.A. Horrocks, B. Mulligan, A.R. Watkinson, and A.P. Jones, 2008: Construction setback
11 regulations and sea-level rise: Mitigating sea turtle nesting beach loss. *Ocean & Coastal Management*, **51(4)**,
12 330-341.
- 13 Fletcher, C.H., C. Bochicchio, C. Conger, M. Engels, F. Feirstein, N. Frazer, C. Glenn, R.W. Grigg, E.E. Grossman,
14 and J.N. Harvey, 2008: Geology of Hawaii reefs. In: *Coral Reefs of the USA* [Riegl, B. and R.E. Dodge(eds.)].
15 Springer, pp. 435-487.
- 16 Ford, M., 2012: Shoreline Changes on an Urban Atoll in the Central Pacific Ocean: Majuro Atoll, Marshall Islands.
17 *Journal of Coastal Research*, **28(1)**, 11-22.
- 18 Fox, J.C., C.K. Yosi, P. Nimiago, F. Oavika, J.N. Pokana, K. Lavong, and R.J. Keenan, 2010: Assessment of above
19 ground carbon in primary and selectively harvested tropical forest in Papua New Guinea. *Biotropica*, **42(4)**,
20 410-419.
- 21 Freed, L.A., R.L. Cann, M.L. Goff, W.A. Kuntz, and G.R. Bodner, 2005: Increase in avian malaria at upper
22 elevations in Hawaii. *The Condor*, **107**, 753-764.
- 23 Gaigher, R., M. Samways, J. Henwood, and K. Jolliffe, 2011: Impact of a mutualism between an invasive ant and
24 honeydew-producing insects on a functionally important tree on a tropical island. *Biological Invasions*, **13(8)**,
25 1717-1721.
- 26 Gamble, D.W., D. Campbell, T.L. Allen, D. Barker, S. Curtis, D. McGregor, and J. Popke, 2010: Climate change,
27 drought, and Jamaican agriculture: Local knowledge and the climate record. *Annals of the Association of*
28 *American Geographers*, **100(4)**, 880-893.
- 29 Gemenne, F., 2011: Climate-induced population displacements in a 4° C world. *Philosophical Transactions of the*
30 *Royal Society A: Mathematical, Physical and Engineering Sciences*, **369(1934)**, 182-195.
- 31 Gero, A., K. Méheux, and D. Dominey-Howes, 2011: Integrating community based disaster risk reduction and
32 climate change adaptation: examples from the Pacific. *Natural Hazards and Earth System Sciences*, **11(1)**, 101-
33 113.
- 34 Gillespie, T.W., J. Chu, and S. Pau, 2008: Non-native plant invasion of the Hawaiian Islands. *Geography Compass*,
35 **2(5)**, 1241-1265.
- 36 Gilman, E.L., J. Ellison, N.C. Duke, and C. Field, 2008: Threats to mangroves from climate change and adaptation
37 options: A review. *Aquatic Botany*, **89(2)**, 237-250.
- 38 Goodman, J., J. Maschinski, P. Hughes, J. McAuliffe, J. Roncal, D. Powell, and L.O. Sternberg, 2012: Differential
39 response to soil salinity in endangered key tree cactus: Implications for survival in a changing climate. *Plos*
40 *One*, **7(3)**, e32528.
- 41 Gordon-Clark, M., 2012: Paradise lost? Pacific island archives threatened by climate change. *Archival Science*,
42 **12(1)**, 51-67.
- 43 Gossling, S. and K.P. Schumacher, 2010: Implementing carbon neutral destination policies: issues from the
44 Seychelles. *Journal of Sustainable Tourism*, **18(3)**, 377-391.
- 45 Gössling, S., M. Bredberg, A. Randow, E. Sandström, and P. Svensson, 2006: Tourist perceptions of climate
46 change: A study of international tourists in Zanzibar. *Current Issues in Tourism*, **9(4)**, 419-435.
- 47 Gravelle, G. and N. Mimura, 2008: Vulnerability assessment of sea-level rise in Viti Levu, Fiji Islands.
48 *Sustainability Science*, **3(2)**, 171-180.
- 49 Greaver, T.L. and L.S.L. Sternberg, 2010: Decreased precipitation exacerbates the effects of sea level on coastal
50 dune ecosystems in open ocean islands. *Global Change Biology*, **16(6)**, 1860-1869.
- 51 Green, S.J., J.L. Akins, and I.M. Côté, 2011: Foraging behaviour and prey consumption in the Indo-Pacific lionfish
52 on Bahamian coral reefs. *Marine Ecology Progress Series*, **433**, 159-167.
- 53 Green, S.J., J.L. Akins, A. Maljković, and I.M. Côté, 2012: Invasive lionfish drive Atlantic coral reef fish declines.
54 *PLoS One*, **7(3)**, e32596.

- 1 Griffin, D.W., 2007: Atmospheric movement of microorganisms in clouds of desert dust and implications for human
2 health. *Clinical Microbiology Reviews*, **20(3)**, 459-477.
- 3 Gritti, E., B. Smith, and M. Sykes, 2006: Vulnerability of Mediterranean Basin ecosystems to climate change and
4 invasion by exotic plant species. *Journal of Biogeography*, **33(1)**, 145-157.
- 5 Guillaumont, P., 2010: Assessing the economic vulnerability of small island developing states and the least
6 developed countries. *The Journal of Development Studies*, **46(5)**, 828-854.
- 7 Gulev, S.K. and V. Grigorieva, 2006: Variability of the winter wind waves and swell in the North Atlantic and
8 North Pacific as revealed by the voluntary observing ship data. *Journal of Climate*, **19(21)**, 5667-5685.
- 9 Haigh, I.D., M. Eliot, and C. Pattiaratchi, 2011: Global influences of the 18.61 year nodal cycle and 8.85 year cycle
10 of lunar perigee on high tidal levels. *Journal of Geophysical Research*, **116(C6)**, C06025.
- 11 Hansen, L., J. Hoffman, C. Drews, and E. Mielbrecht, 2010: Designing climate-smart conservation: Guidance and
12 case Studies. *Conservation Biology*, **24(1)**, 63-69.
- 13 Harangozo, S.A., 1992: Flooding in the Maldives and its implications for the global sea level rise debate. In: *Sea
14 Level Changes: Determination and Effects*. [Woodworth, P.L., D.T. Pugh, J.G. DeRonde, R.G. Warrick, and J.
15 Hannah(eds.)]. International Union of Geodesy and Geophysics and the American Geophysical Union, pp. 95-
16 99.
- 17 Hardman, E.R., N.S. Stampfli, L. Hunt, S. Perrine, A. Perry, and J.S.J. Raffin, 2007: The impacts of coral bleaching
18 in Rodrigues, Western Indian Ocean. *Atoll Research Bulletin*, **(555)**, 10.
- 19 Harmsen, E.W., N.L. Miller, N.J. Schlegel, and J.E. Gonzalez, 2009: Seasonal climate change impacts on
20 evapotranspiration, precipitation deficit and crop yield in Puerto Rico. *Agricultural Water Management*, **96**,
21 1085-1095.
- 22 Harris, A., G. Manahira, A. Sheppard, and Gough, C., Sheppard, C, 2010: Demise of Madagascar's once great
23 barrier reef: changes in coral reef conditions over 40 years. *Atoll Research Bulletin*, **(574)**, 1-16.
- 24 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. Elyazar,
25 and S. Brooker, 2009: A world malaria map: Plasmodium falciparum endemicity in 2007. *PLoS Medicine*, **6(3)**,
26 e1000048.
- 27 Heger, M., A. Julca, and O. Paddison, 2008: Analysing the impact of natural hazards in small economies: The
28 Caribbean case. UNU-WIDER research paper, No. 2008/25.
- 29 Herrmann-Storck, C., D. Postic, I. Lamaury, and J.M. Perez, 2008: Changes in epidemiology of leptospirosis in
30 2003-2004, a two El nino Southern Oscillation period, Guadeloupe archipelago, French West Indies.
31 *Epidemiology and Infection*, **136(10)**, 1407-1415.
- 32 Herweijer, C., N. Ranger, and R.E.T. Ward, 2009: Adaptation to climate change: threats and opportunities for the
33 insurance industry. *The Geneva Papers on Risk and Insurance-Issues and Practice*, **34(3)**, 360-380.
- 34 Hoegh-Guldberg, O., P.J. Mumby, A.J. Hooten, R.S. Steneck, P. Greenfield, E. Gomez, C.D. Harvell, P.F.H. Sale,
35 A. Dubi, and M.E. Hatziolos, 2007: Coral reefs under rapid climate change and ocean acidification. *Science*,
36 **318(5857)**, 1737-1742.
- 37 Hoeke, R.K., K.L. McInnes, J. Kruger, R. McNaught, J. Hunter, and S. Smithers, submitted: Supplemental Material
38 for: Widespread inundation of Pacific islands by distant-source wind-waves. *Global Environmental Change*, .
- 39 Howard, G., K. Charles, K. Pond, A. Brookshaw, R. Hossain, and J. Bartram, 2010: Securing 2020 vision for 2030:
40 climate change and ensuring resilience in water and sanitation services. *Journal of Water and Climate Change*,
41 **1(1)**, 2-16.
- 42 Hughes, T.P., A.H. Baird, D.R. Bellwood, M. Card, S.R. Connolly, C. Folke, R. Grosberg, O. Hoegh-Guldberg, J.
43 Jackson, J. Kleypas, J.M. Lough, P. Marshall, M. Nyström, S.R. S. R. Palumbi, J.M. J. M. Pandolfi, B. Rosen,
44 and J. Roughgarden, 2003: Climate change, human impacts, and the resilience of coral reefs. *Science*,
45 **301(5635)**, 929-933.
- 46 Idjadi, J.A., R.N. Haring, and W.F. Precht, 2010: Recovery of the sea urchin *Diadema antillarum* promotes
47 scleractinian coral growth and survivorship on shallow Jamaican reefs. *Marine Ecology-Progress Series*, **403**,
48 91-100.
- 49 Jarvis, R., 2010: Sinking nations and climate change adaptation strategies. *Seattle Journal of Social Justice*, **9(1)**,
50 447-486.
- 51 Joe, S.M. and C.C. Daehler, 2008: Invasive slugs as under-appreciated obstacles to rare plant restoration: evidence
52 from the Hawaiian Islands. *Biological Invasions*, **10(2)**, 245-255.
- 53 Jones, G.P., M.I. McCormick, M. Srinivasan, and J.V. Eagle, 2004: Coral decline threatens fish biodiversity in
54 marine reserves. *Proceedings of the National Academy of Sciences*, **101(21)**, 8251-8253.

- 1 Jones, P., 2005: Managing Urban development in the Pacific. *Australian Planner*, **42(1)**, 39-46.
- 2 Jury, M.R. and A. Winter, 2010: Warming of an elevated layer over the Caribbean. *Climatic Change*, **99**, 247-259.
- 3 Kaldellis, J.K., 2008: Integrated electrification solution for autonomous electrical networks on the basis of RES and
4 energy storage configurations. *Energy Conversion and Management*, **49(12)**, 3708-3720.
- 5 Kaldellis, J.K., D. Zafirakis, E.L. Kaldelli, and K. Kavadias, 2009: Cost benefit analysis of a photovoltaic-energy
6 storage electrification solution for remote islands. *Renewable Energy*, **34(5)**, 1299-1311.
- 7 Keener, V., J.J. Marra, M.L. Finucane, D. Spooner, and M.H. Smith, 2012: *Climate Change and Pacific Islands:
8 Indicators and Impacts: Report for the 2012 Pacific Islands Regional Climate Assessment*. Island Press,
9 Washington, DC, .
- 10 Kelman, I. and J. West, 2009: Climate change and small island developing states: A critical review. *Ecological and
11 Environmental Anthropology*, **5(1)**, 1-16.
- 12 Kelman, I., J. Lewis, J.C. Gaillard, and J. Mercer, 2011: Participatory action research for dealing with disasters on
13 islands. *Island Studies Journal*, **6(1)**, 59-86.
- 14 Kelman, I., 2010: Introduction to climate, disasters and international development. *Journal of International
15 Development*, **22(2)**, 208-217.
- 16 Kench, P.S. and R.W. Brander, 2006: Response of reef island shorelines to seasonal climate conditions: South
17 Maalhosmadulu atoll, Maldives. *Journal of Geophysical Research*, **111(F01001)**.
- 18 Kench, P.S., S.G. Smithers, R.F. McLean, and S.L. Nichol, 2009: Holocene reef growth in the Maldives: Evidence
19 of a mid-Holocene sea-level highstand in the central Indian Ocean. *Geology*, **37(5)**, 455-458.
- 20 Kingsford, R., J. Watson, C. Lundquist, O. Venter, L. Hughes, E. Johnston, J. Atherton, M. Gawel, D. Keith, B.
21 Mackey, C. Morley, H.B. Possingham, B. Raynor, H.F. Recher, and K.A. Wilson, 2009: Major conservation
22 policy issues for biodiversity in Oceania. *Conservation Biology*, **23(4)**, 834-840.
- 23 Klein, R., S. Ericksen, L. Ness, A. Hammill, T. Tanner, C. Robledo, and K. O'Brien, 2007: Portfolio screening to
24 support the mainstreaming of adaptation to climate change into development assistance. *Climatic Change*,
25 **84(1)**, 23-44.
- 26 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
27 epidemic in Singapore: epidemiology, prevention and control. *Annals Academy of Medicine Singapore*, **37(7)**,
28 538.
- 29 Kolmannskog, V. and L. Trebbi, 2010; 2010: Climate change, natural disasters and displacement: a multi-track
30 approach to filling the protection gaps *International Review of the Red Cross*, **92(879)**, 713-730.
- 31 Komar, P.D. and J.C. Allan, 2008: Increasing hurricane-generated wave heights along the US East coast and their
32 climate controls. *Journal of Coastal Research*, , 479-488.
- 33 Krajačić, G., R. Martins, A. Busuttil, N. Duić, and M. da Graça Carvalho, 2008: Hydrogen as an energy vector in the
34 islands' energy supply. *International Journal of Hydrogen Energy*, **33(4)**, 1091-1103.
- 35 Krajačić, G., N. Duić, B. Vad Mathiesen, and M.D.G. Carvalho, 2010: Smart energy storages for integration of
36 renewables in 100% independent energy systems. *Chemical Engineering Transactions*, **21**, 391-396.
- 37 Krauss, K.W., J.A. Allen, and D.R. Cahoon, 2003: Differential rates of vertical accretion and elevation change
38 among aerial root types in Micronesian mangrove forests. *Estuarine, Coastal and Shelf Science*, **56**, 251-259.
- 39 Krauss, K.W., D.R. Cahoon, J.A. Allen, K.C. Ewel, J.C. Lynch, and N. Cormier, 2010: Surface elevation change
40 and susceptibility of different mangrove zones to sea-level rise on Pacific high islands of Micronesia.
41 *Ecosystems*, **13(1)**, 129-143.
- 42 Kravchenko, S., 2008: Right to Carbon or Right to Life: Human Rights Approaches to Climate Change. *Available at
43 SSRN 1304844*, .
- 44 Krishnamurthy, P.K., 2012: Disaster-induced migration: Assessing the impact of extreme weather events on
45 livelihoods. *Environmental Hazards*, **11(2)**, 96-111.
- 46 Kueffer, C., C.C. Daehler, C.W. Torres-Santana, C. Lavergne, J.Y. Meyer, R. Otto, and L. Silva, 2010: A global
47 comparison of plant invasions on oceanic islands. *Perspectives in Plant Ecology Evolution and Systematics*,
48 **12(2)**, 145-161.
- 49 Kuruppu, N., 2009: Adapting water resources to climate change in Kiribati: the importance of cultural values and
50 meanings. *Environmental Science & Policy*, **12(7)**, 799-809.
- 51 Kuruppu, N. and D. Liverman, 2011: Mental preparation for climate adaptation: The role of cognition and culture in
52 enhancing adaptive capacity of water management in Kiribati. *Global Environmental Change*, **21(2)**, 657-669.
- 53 Laczko, F. and C. Aghazarm, 2009: *Migration, environment and climate change: assessing the evidence*.
54 International Organization for Migration, Geneva, Switzerland, .

- 1 Lata, S. and P. Nunn, 2012: Misperceptions of climate-change risk as barriers to climate-change adaptation: a case
2 study from the Rewa Delta, Fiji. *Climatic Change*, **110**, 169-186.
- 3 Lauer, M. and S. Aswani, 2010: Indigenous knowledge and long-term ecological change: detection, interpretation,
4 and responses to changing ecological conditions in Pacific Island Communities. *Environmental Management*,
5 **45(5)**, 985-997.
- 6 Lazrus, H., 2012: Sea Change: Island Communities and Climate Change*. *Annual Review of Anthropology*, **41(1)**,
7 285-301.
- 8 Le Masson, V. and I. Kelman, 2011: Disaster risk reduction on non-sovereign islands: La Réunion and Mayotte,
9 France. *Natural Hazards*, **56(1)**, 251-273.
- 10 Le Roux, P.C., M.A. McGeoch, M.J. Nyakatia, and S.L. Chown, 2005: Effects of a short-term climate change
11 experiment on a sub-Antarctic keystone plant species. *Global Change Biology*, **11(10)**, 1628-1639.
- 12 Le Roux, J.J., A.M. Wiczorek, and J.Y. Meyer, 2008: Genetic diversity and structure of the invasive tree *Miconia*
13 *calvescens* in Pacific islands. *Diversity and Distributions*, **14(6)**, 935-948.
- 14 Lefale, P., 2010: *Ua afa le Aso* stormy weather today: traditional ecological knowledge of weather and climate. The
15 Samoa experience. *Climatic Change*, **100(2)**, 317-335.
- 16 Lesser, M.P. and M. Slattery, 2011: Phase shift to algal dominated communities at mesophotic depths associated
17 with lionfish (*Pterois volitans*) invasion on a Bahamian coral reef. *Biological Invasions*, **13(8)**, 1855-1868.
- 18 Lessios, H.A., 1988: Mass mortality of *Diadema Antillarum* in the Caribbean: What have we learned? *Annual*
19 *Review of Ecology and Systematics*, **19(1)**, 371-393.
- 20 Lessios, H.A., 1995: *Diadema antillarum* 10 years after mass mortality: Still rare, despite help from a competitor.
21 *Proceedings of the Royal Society of London. Series B: Biological Sciences*, **259(1356)**, 331-337.
- 22 Limalevu, L., B. Aalsbersberg, P. Dumar, and T. Weir, 2010: Adaptation on a small island. *Tiempo*, **77**, 16.
- 23 Linnerooth-Bayer, J., K. Warner, C. Bals, P. Höpfe, I. Burton, T. Loster, and A. Haas, 2009: Insurance, developing
24 countries and climate change. *The Geneva Papers on Risk and Insurance-Issues and Practice*, **34(3)**, 381-400.
- 25 Linnerooth-Bayer, J., R. Mechler, and S. Hochrainer, 2011: Insurance against Losses from Natural Disasters in
26 Developing Countries. Evidence, gaps and the way forward. *Journal of Integrated Disaster Risk Management*,
27 **1(1)**, 1-23.
- 28 Linnerooth-Bayer, J. and R. Mechler, 2009: *Insurance against Losses from Natural Disasters in De-veloping*
29 *Countries*. In: DESA Working Paper No. 85. UN/DESA Working Papers, New York, USA, pp. 1-35.
- 30 Llewellyn, L.E., 2010: Revisiting the association between sea surface temperature and the epidemiology of fish
31 poisoning in the South Pacific: Reassessing the link between ciguatera and climate change. *Toxicon*, **56(5)**, 691-
32 697.
- 33 Locke, J.T., 2009: Climate change-induced migration in the Pacific Region: sudden crisis and long-term
34 developments. *The Geographical Journal*, **175(3)**, 171-180.
- 35 Lopez-Marrero, T., 2010: An integrative approach to study and promote natural hazards adaptive capacity: a case
36 study of two flood-prone communities in Puerto Rico. *Geographical Journal*, **176**, 150-163.
- 37 López-Marrero, T. and B. Yarnal, 2010: Putting adaptive capacity into the context of people's lives: a case study of
38 two flood-prone communities in Puerto Rico. *Natural Hazards*, **52(2)**, 277-297.
- 39 Loughry, M. and J. McAdam, 2008: Kiribati—relocation and adaptation. *Forced Migration Review*, **31**, 51-52.
- 40 Lovell, S., 2011: *Health governance and the impact of climate change on Pacific small island developing states*. In:
41 IHDP Update (Human Health and Global Environmental Change). International Human Dimensions Program,
42 pp. 50-55.
- 43 Lo-Yat, A., S.D. Simpson, M. Meekan, D. Lecchini, E. Martinez, and R. Galzin, 2011: Extreme climatic events
44 reduce ocean productivity and larval supply in a tropical reef ecosystem. *Global Change Biology*, **17(4)**, 1695-
45 1702.
- 46 Maina, J., T.R. McClanahan, V. Venus, M. Ateweberhan, and J. Madin, 2011: Global gradients of coral exposure to
47 environmental stresses and implications for local management. *PLoS One*, **6(8)**, e23064.
- 48 Marba, N. and C.M. Duarte, 2010: Mediterranean warming triggers seagrass (*Posidonia oceanica*) shoot mortality.
49 *Global Change Biology*, **16(8)**, 2366-2375.
- 50 Martens, P., R.S. Kovats, S. Nijof, P. deVries, M.T.J. Livermore, D.J. Bradley, and et al., Global environmental
51 Change: Climate change and future populations at risk of malaria. *1999*, **9(Suppl 1)**, S89-S107.
- 52 Martins, P., J. Rosado-Pinto, M. Do Céu Teixeira, N. Neuparth, O. Silva, H. Tavares, J.L. Spencer, D. Mascarenhas,
53 A.L. Papoila, N. Khaltaev, and I. Annesi-Maesano, 2009: Under-report and underdiagnosis of chronic
54 respiratory diseases in an African country. *Allergy*, **64(7)**, 1061-1067.

- 1 Maunsell Australia Pty Ltd., 2009: *Climate Change Risk Assessment for the Australian Indian Ocean Territories*.
2 Commonwealth Attorney General's Department, Canberra, Australia, pp. 1-93.
- 3 McClanahan, T.R., E. Weil, and J. Maina, 2009: Strong relationship between coral bleaching and growth anomalies
4 in massive Porites. *Global Change Biology*, **15(7)**, 1804-1816.
- 5 McGranahan, G., D. Balk, and B. Anderson, 2007: The rising tide: assessing the risks of climate change and human
6 settlements in low elevation coastal zones. *Environment and Urbanization*, **19(1)**, 17-37.
- 7 McKee, K.L., D.R. Cahoon, and I.C. Feller, 2007: Caribbean mangroves adjust to rising sea level through biotic
8 controls on change in soil elevation. *Global Ecology and Biogeography*, **16(5)**, 556.
- 9 McLeman, R.A. and L.M. Hunter, 2010: Migration in the context of vulnerability and adaptation to climate change:
10 Insights from analogues. *Wiley Interdisciplinary Reviews Climate Change*, **1(3)**, 450-461.
- 11 McLeman, R.A., 2011: Settlement abandonment in the context of global environmental change. *Global
12 Environmental Change*, **21, Supplement 1(0)**, S108-S120.
- 13 McLeod, E., R. Salm, A. Green, and J. Almany, 2009: Designing marine protected area networks to address the
14 impacts of climate change. *Frontiers in Ecology and the Environment*, **7(7)**, 362-370.
- 15 McMichael, C., J. Barnett, and A.J. McMichael, 2012: An Ill Wind? Climate Change, Migration, and Health.
16 *Environmental Health Perspectives*, **120(5)**, 646-654.
- 17 McMichael, A.J. and E. Lindgren, 2011: Climate change: present and future risks to health, and necessary responses.
18 *Journal of Internal Medicine*, **270(5)**, 401-413.
- 19 McNamara, D. and B. Werner, 2008: Coupled barrier island–resort model: 1. Emergent instabilities induced by
20 strong human-landscape interactions. *Journal of Geophysical Research*, **113(F1)**, F01016.
- 21 McNamara, K.E. and C. Gibson, 2009: ‘We do not want to leave our land’: Pacific ambassadors at the United
22 Nations resist the category of ‘climate refugees’. *Geoforum*, **40(3)**, 475-483.
- 23 McNamara, K.E. and R. Westoby, 2011: Local knowledge and climate change adaptation on Erub Island, Torres
24 Strait. *Local Environment*, , 887-901.
- 25 Mercer, J., D. Dominey-Howes, I. Kelman, and K. Lloyd, 2007: The potential for combining indigenous and
26 western knowledge in reducing vulnerability to environmental hazards in small island developing states.
27 *Environmental Hazards*, **7(4)**, 245-256.
- 28 Merrifield, M., S. Merrifield, and G. Mitchum, 2009: An anomalous recent acceleration of global sea level rise.
29 *Journal of Climate*, **22**, 5772-5781.
- 30 Mertz, O., T.B. Bruun, B. Fog, K. Rasmussen, and J. Agergaard, 2010: Sustainable land use in Tikopia: Food
31 production and consumption in an isolated agricultural system. *Singapore Journal of Tropical Geography*,
32 **31(1)**, 10-26.
- 33 Mertz, O., K. Halsnæs, J. Olesen, and K. Rasmussen, 2009: Adaptation to climate change in developing countries.
34 *Environmental Management*, **43(5)**, 743-752.
- 35 Metz, B., O.R. Davidson, P.R. Bosch, R. Dave, and L.A. Meyers (eds.), 2007: *Mitigation. Contribution of Working
36 Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge
37 University Press, Cambridge, UK; New York, NY, USA, .
- 38 Meyer, W.M., K.A. Hayes, and A.L. Meyer, 2008: Giant African snail, *Achatina fulica*, as a snail predator.
39 *American Malacological Bulletin*, **24(1-2)**, 117-119.
- 40 Meyssignac, B., M. Becker, W. Llovel, and A. Cazenave, 2012: An assessment of two-dimensional past sea level
41 reconstructions over 1950-2009 based on tide-gauge data and different input sea level grids. *Surveys in
42 Geophysics.*, **33(945)**, 972.
- 43 Michon, P., J.L. Cole-Tobian, E. Dabod, S. Schoepflin, J. Igu, M. Susapu, N. Tarongka, P.A. Zimmerman, J.C.
44 Reeder, and J.G. Beeson, 2007: The risk of malarial infections and disease in Papua New Guinean children. *The
45 American Journal of Tropical Medicine and Hygiene*, **76(6)**, 997-1008.
- 46 Middleton, N., P. Yiallourous, S. Kleanthous, O. Kolokotroni, J. Schwartz, D.W. Dockery, P. Demokritou, and P.
47 Koutrakis, 2008: A 10-year time-series analysis of respiratory and cardiovascular morbidity in Nicosia, Cyprus:
48 The effect of short-term changes in air pollution and dust storms. *Environmental Health*, **7(39)**.
- 49 Miller, J., E. Muller, C. Rogers, R. Waara, A. Atkinson, K.R.T. Whelan, M. Patterson, and B. Witcher, 2009: Coral
50 disease following massive bleaching in 2005 causes 60% decline in coral cover on reefs in the US Virgin
51 Islands. *Coral Reefs*, **28(4)**, 925-937.
- 52 Mills, M., R.L. Pressey, R. Weeks, S. Foale, and N.C. Ban, 2010: A mismatch of scales: challenges in planning for
53 implementation of marine protected areas in the Coral Triangle. *Conservation Letters*, **3(5)**, 291-303.

- 1 Mimura, N., L.A. Nurse, R.F. McLean, J. Agard, P. Brigguglio, R. Lefale, R. Payet, and G. Sem, 2007: Small
2 islands. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability Contribution of Working Group II in*
3 *the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. [Parry, M., O.F. Canziani,
4 J.P. Palutikof, P.J. van der Linden, and C.E. Hanson(eds.)]. Cambridge University Press, Cambridge, U.K., pp.
5 687-716.
- 6 Moglia, M., P. Perez, and S. Burn, 2008a: Urbanization and water development in the Pacific Islands. *Development*,
7 **51**, 49-55.
- 8 Moglia, M., P. Perez, and S. Burn, 2008b: Water troubles in a Pacific atoll town. *Water Policy*, **10(6)**, 613-637.
- 9 Mohan, A., A. Cumberpatch, A. Adesiyun, and D.D. Chadee, 2009: Epidemiology of human leptospirosis in
10 Trinidad and Tobago, 1996-200: A retrospective study. *Acta Tropica*, **112(3)**, 260-265.
- 11 Mohanty, M., 2012: New renewable energy sources, green energy development and climate change: Implications to
12 Pacific Island countries. *Management of Environmental Quality: An International Journal*, **23(3)**, 264-274.
- 13 Monteil, M., 2008: Saharan dust clouds and human health in the English-speaking Caribbean: what we know and
14 don't know. *Environmental Geochemistry and Health*, **30(4)**, 339-343.
- 15 Monteil, M. and R. Antoine, 2009: African dust and asthma in the Caribbean: medical and statistical perspectives.
16 *International Journal of Biometeorology*, **53(5)**, 379-381.
- 17 Moore, W.R., 2010: The impact of climate change on Caribbean tourism demand. *Current Issues in Tourism*, **13(5)**,
18 495-505.
- 19 Moreno, A. and Becken, S., 2009: A climate change vulnerability assessment methodology for coastal tourism.
20 *Journal of Sustainable Tourism*, **17(4)**, 473-488.
- 21 Moreno, A., 2010: Mediterranean tourism and climate (change): A survey-based study. *Tourism and Hospitality*
22 *Planning & Development*, **7(3)**, 253-265.
- 23 Morrison, K., P. Prieto, A. Dominguez, D. Waltner-Toews, and J. FitzGibbon, 2008: Ciguatera Fish Poisoning in La
24 Habana, Cuba: A Study of Local Social-Ecological Resilience. *Ecohealth*, **5(3)**, 346-359.
- 25 Mortreux, C. and J. Barnett, 2009: Climate change, migration and adaptation in Funafuti, Tuvalu. *Global*
26 *Environmental Change*, **19(1)**, 105-112.
- 27 Moss, R.H., J.A. Edmonds, K.A.M. Hibbard M.R., S.K. Rose, D.P. van Vuuren, T.R. Carter, S. Emori, M. Kainuma,
28 T. Kram, G.A. Meehl, J.F.B. Mitchell, N. Nakicenovic, K. Riahi, S.J. Smith, R.J. Stouffer, A.M. Thomson, J.P.
29 Weyant, and T.J. Wilbanks, 2010: The next generation of scenarios for climate change research and assessment.
30 *Nature*, **463**, 747-756.
- 31 Munday, P.L., J.M. Leis, J.M. Lough, C.B. Paris, M.J. Kingsford, M.L. Berumen, and J. Lambrechts, 2009: Climate
32 change and coral reef connectivity. *Coral Reefs*, **28**, 379-395.
- 33 Mycoo, M., 2011: Natural hazard risk reduction: Making St. Lucia safe in an era of increased hurricanes and
34 associated events. *Natural Hazards Review*, **12**, 37-45.
- 35 Myers, N., 2002: Environmental refugees: a growing phenomenon of the 21st century. *Philosophical Transactions*
36 *of the Royal Society of London. Series B: Biological Sciences*, **357(1420)**, 609-613.
- 37 Myhre, S. and A. Acevedo-Gutierrez, 2007: Recovery of sea urchin *Diadema antillarum* populations is correlated to
38 increased coral and reduced macroalgal cover. *Marine Ecology-Progress Series*, **329**, 205-210.
- 39 Nicholls, R.J. and A. Cazenave, 2010: Sea-level rise and its impact on coastal zones. *Science*, **328(5985)**, 1517-
40 1520.
- 41 Nicholls, R.J. and R.S. Tol, 2006: Impacts and responses to sea-level rise: a global analysis of the SRES scenarios
42 over the twenty-first century. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and*
43 *Engineering Sciences*, **364(1841)**, 1073-1095.
- 44 Nicholls, R.J., N. Marinova, J.A. Lowe, S. Brown, P. Vellinga, D. De Gusmao, J. Hinkel, and R.S.J. Tol, 2011: Sea-
45 level rise and its possible impacts given a 'beyond 4 degrees C world' in the twenty-first century. *Philosophical*
46 *Transactions of the Royal Society A Mathematical Physical and Engineering Sciences*, **369(1934)**, 161-181.
- 47 Nicoll, K.A., R.G. Harrison, and Z. Ulanowski, 2011: Observation of Saharan dust electrification. *Environmental*
48 *Research Letters*, **6**.
- 49 Novelo-Casanova, D.A. and Suarez G., 2010: Natural and man-made hazards in the Cayman Islands. *Natural*
50 *Hazards*, **55(2)**, 441-466.
- 51 Nunn, P.D., 2009: Responding to the challenges of climate change in the Pacific Islands: management and
52 technological imperatives. *Climate Research*, **40(2-3)**, 211-231.
- 53 Nurse, L.A., G. Sem, J.E. Hay, A.G. Suarez, P.P. Wong, S. Brigguglio, and S. Ragoonaden, 2001: Small island states.
54 In: *Climate Change 2001: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the*

- 1 *Third Assessment of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge,
2 UK, pp. 843-912.
- 3 Ogston, A.S. and M.E. Field, 2010: Predictions of turbidity due to enhanced sediment resuspension resulting from
4 sea-level rise on a fringing coral reef: Evidence from Molokai, Hawaii. *Journal of Coastal Research*, **26(6)**,
5 1027-1037.
- 6 Otero, P., S. Perez, A. Alfonso, C. Vale, P. Rodriguez, N.N. Gouveia, N. Gouveia, J. Delgado, P. Vale, M. Hirama,
7 Y. Ishihara, J. Molgo, and L.M. Botana, 2010: First toxin profile of Ciguateric fish in Madeira Arquipelago
8 (Europe). *Analytical Chemistry*, **82(14)**, 6032-6039.
- 9 Oxenford, H.A., R. Roach, A. Brathwaite, L. Nurse, R. Goodridge, F. Hinds, K. Baldwin, and C. Finney, 2008:
10 Quantitative observations of a major coral bleaching event in Barbados, Southeastern Caribbean. *Climatic*
11 *Change*, **87(3-4)**, 435-449.
- 12 Palanisamy, H., M. Becker, B. Meyssignac, O. Henry, and A. Cazenave, 2012: Regional sea level change and
13 variability in the Caribbean sea since 1950. *Journal of Geodetic Science*, **2(2)**, 125-133.
- 14 Pappas, G., P. Papadimitriou, V. Siozopoulou, L. Christou, and N. Akritidis, 2008: The globalization of
15 leptospirosis: worldwide incidence trends. *International Journal of Infectious Diseases*, **12(4)**, 351-357.
- 16 Parham, P.E. and E. Michael, 2010: Modelling the effects of weather and climate change on malaria transmission.
17 *Environmental Health Perspectives*, **118(5)**, 620-626.
- 18 Park, S., N. Marshall, E. Jakku, A. Dowd, S. Howden, E. Mendham, and A. Fleming, 2012: Informing adaptation
19 responses to climate change through theories of transformation. *Global Environmental Change*, **22(1)**, 115-126.
- 20 Parks, B.C. and J.T. Roberts, 2006: Globalization, vulnerability to climate change, and perceived injustice. *Society*
21 *and Natural Resources*, **19(4)**, 337-355.
- 22 Parolo, G. and G. Rossi, 2008: Upward migration of vascular plants following a climate warming trend in the Alps.
23 *Basic and Applied Ecology*, **9(2)**, 100-107.
- 24 Pascual, M., J.A. Ahumada, L.F. Chaves, X. Rodo, and M. Bouma, 2006: Malaria resurgence in the East African
25 highlands: temperature trends revisited. *Proceedings of the National Academy of Sciences*, **103(15)**, 5829-5834.
- 26 Pauli, H., M. Gottfried, K. Reiter, C. Klettner, and G. Grabherr, 2007: Signals of range expansions and contractions
27 of vascular plants in the high Alps: observations (1994–2004) at the GLORIA* master site Schrankogel, Tyrol,
28 Austria. *Global Change Biology*, **13(1)**, 147-156.
- 29 Payet, R. and W. Agricole, 2006: Climate change in the Seychelles: Implications for water and coral reefs. *Ambio*,
30 **35(4)**, 182-189.
- 31 Peduzzi, P., H. Dao, C. Herold, and F. Mouton, 2009: Assessing global exposure and vulnerability towards natural
32 hazards: the Disaster Risk Index. *Natural Hazards and Earth System Sciences*, **9(4)**, 1149-1159.
- 33 Pelling, M., 2011: Urban governance and disaster risk reduction in the Caribbean: the experiences of Oxfam GB.
34 *Environment and Urbanization*, **23(2)**, 383-400.
- 35 Perch-Nielsen, S.L., 2010: The vulnerability of beach tourism to climate change – an index approach. *Climatic*
36 *Change*, **100(3-4)**, 579-606.
- 37 Piskorska, M., G. Smith, and E. Weil, 2007: Bacteria associated with the coral *Echinopora lamellosa* (Esper 1795)
38 in the Indian Ocean - Zanzibar Region. *African Journal of Environmental Science and Technology*, **1(5)**, 93-98.
- 39 Polidoro, B.A., K.E. Carpenter, L. Collins, N.C. Duke, A.M. Ellison, J.C. Ellison, E.J. Farnsworth, E.S. Fernando,
40 K. Kathiresan, N.E. Koedam, S.R. Livingstone, T. Miyagi, G.E. Moore, V.N. Nam, J.E. Ong, J.H. Primavera,
41 S.G. Salmo, J.C. Sanciangco, S. Sukardjo, Y. Wang, and J.W.H. Yong, 2010: The Loss of Species: Mangrove
42 Extinction Risk and Geographic Areas of Global Concern. *PLoS One*, **5(4)**, e10095.
- 43 Praene, J.P., M. David, F. Sinama, D. Morau, and O. Marc, 2012: Renewable energy: Progressing towards a net zero
44 energy island, the case of Reunion Island. *Renewable and Sustainable Energy Reviews*, **16(1)**, 426-442.
- 45 Pratchett, M.S., S.K. Wilson, A.J. Graham, P.L. Munday, G.P. Jones, and N.V.C. Polunin, 2009: Coral bleaching
46 and consequences for motile reef organisms: past, present and uncertain future effects. *Ecological Studies*, **205**,
47 139-158.
- 48 Prospero, J.M., 2006: Case study: Saharan dust impacts and climate change. *Oceanography*, **19(2)**, 59-61.
- 49 Prospero, J., E. Blades, R. Naidu, G. Mathison, H. Thani, and M. Lavoie, 2008: Relationship between African dust
50 carried in the Atlantic trade winds and surges in pediatric asthma attendances in the Caribbean. *International*
51 *Journal of Biometeorology*, **52(8)**, 823-832.
- 52 Prospero, J.M. and P.J. Lamb, 2003: African droughts and dust transport to the Caribbean: Climate change
53 implications. *Science*, **302(5647)**, 1024-1027.

- 1 Prospero, J.M., E. Blades, G. Mathison, and R. Naidu, 2005: Interhemispheric transport of viable fungi and bacteria
2 from Africa to the Caribbean with soil dust. *Aerobiologia*, **21(1)**, 1-19.
- 3 Pulwarty, R.S., L.A. Nurse, and U.O. Trotz, 2010: Caribbean Islands in a changing climate. *Environment: Science
4 and Policy for Sustainable Development*, **52(6)**, 16-27.
- 5 Ralph, P.J., M.J. Durako, S. Enriquez, C.J. Collier, and M.A. Doblin, 2007: Impact of light limitation on seagrasses.
6 *Journal of Experimental Marine Biology and Ecology*, **350(1-2)**, 176-193.
- 7 Ranger, N., K. Gohar, J.A. Lowe, S.C.B. Raper, A. Bowen, and R.E. Ward, 2012: Is it possible to limit global
8 warming to no more than 1.5°C? *Climatic Change*, **111**, 973-981.
- 9 Rankey, E.C., 2011: Nature and stability of atoll island shorelines: Gilbert Island chain, Kiribati, equatorial Pacific.
10 *Sedimentology*, **58(7)**, 1831-1859.
- 11 Rasmussen, K., W. May, T. Birk, M. Mataki, and O. Mertz, 2011: Prospects for climate change on three Polynesian
12 outliers in Solomon Islands: Exposure, sensitivity and adaptive capacity. *Geografisk Tidsskrift-Danish Journal
13 of Geography*, **111(1)**, 43-57.
- 14 Rasmussen, K., W. May, T. Birk, M. Mataki, O. Mertz, and D. Yee, 2009: Climate change on three Polynesian
15 outliers in the Solomon Islands: Impacts, vulnerability and adaptation. *Geografisk Tidsskrift – Danish Journal
16 of Geography*, **109(1)**, 1-13.
- 17 Rawlins, S.C., A. Hinds, and J.M. Rawlins, 2008: Malaria and its vectors in the Caribbean: The continuing
18 challenge of the disease forty-five years after eradication from the islands. *West Indian Medical Journal*, **57(5)**,
19 462-469.
- 20 Reaser, J.K., L.A. Meyerson, Q. Cronk, M. De Poorter, L.G. Eldrege, E. Green, M. Kairo, P. Latasi, R.N. Mack, J.
21 Mauremootoo, D. O'Dowd, W. Orapa, S. Sastroutomo, A. Saunders, C. Shine, S. Thrainsson, and L. Vaiutu,
22 2007: Ecological and socioeconomic impacts of invasive alien species in island ecosystems. *Environmental
23 Conservation*, **34(02)**, 98-111.
- 24 Reenberg, A., T. Birch-Thomsen, O. Mertz, B. Fog, and S. Christiansen, 2008: Adaptation of human coping
25 strategies in a small island society in the SW Pacific-50 Years of change in the coupled human-environment
26 system on Bellona, Solomon Islands. *Human Ecology*, **36(6)**, 807-819.
- 27 Restrepo, C.J., L.Otero, A.C. Casa, A.Henao and J.Gutierrez, 2012: Shoreline changes between 1954 and 2007 in
28 the marine protected areas of the Rosario Island Archipelago (Caribbean of Colombia). *Ocean and Coastal
29 Management*, **69**, 133-142.
- 30 Richmond, N. and B.K. Sovacool, 2012: Bolstering resilience in the coconut kingdom: Improving adaptive capacity
31 to climate change in Vanuatu. *Energy Policy*, **50**, 843-848.
- 32 Rocha, S., I. Ineich, and J. Harris, 2009: Cryptic variation and recent bipolar range expansion within the Stumped-
33 Toed Gecko *Gehyra mutilata* across Indian and Pacific Ocean islands. *Contributions to Zoology*, **78(1)**, 1-8.
- 34 Rogers, T., K. Chmutina, and L.L. Moseley, 2012: The potential of PV installations in SIDS—an example in the
35 island of Barbados. *Management of Environmental Quality: An International Journal*, **23(3)**, 284-290.
- 36 Rongo, T. and R. van Woesik, 2011: Ciguatera poisoning in Rarotonga, southern Cook Islands. *Harmful Algae*,
37 **10(4)**, 345-355. A. Henao and J. Guitierrez, 2012: Shoreline changes between 1954 and 2007between
- 38 Rosenberg, E., A. Kushmaro, E. Kramarsky-Winter, E. Banin, and L. Yossi, 2009: The role of microorganisms in
39 coral bleaching. *The ISME Journal*, **3(2)**, 139-146.
- 40 Rosenzweig, C. and T.J. Wilbanks, 2010: The state of climate change vulnerability, impacts, and adaptation
41 research: strengthening knowledge base and community. *Climatic Change*, **100(1)**, 103-106.
- 42 Ross, M.S., J.J. O'Brien, R.G. Ford, K. Zhang, and A. Morkill, 2009: Disturbance and the rising tide: the challenge
43 of biodiversity management on low-island ecosystems. *Frontiers in Ecology and the Environment*, **7(9)**, 471-
44 478.
- 45 Rotjan, R. and S. Lewis, 2008: Impact of coral predators on tropical reefs. *Marine Ecology Progress Series*, **367**, 73-
46 91.
- 47 Rozell, D.J. and Wong T.F., 2010: Effects of climate change on groundwater resources at Shelter Island, New York
48 State, USA. *Hydrogeology Journal*, **18**, 1657-1665.
- 49 Rudiak-Gould, P., 2012: Promiscuous corroboration and climate change translation: A case study from the Marshall
50 Islands. *Global Environmental Change*, **22(1)**, 46-54.
- 51 Russell, L., 2009: *Poverty, Climate Change and Health in Pacific Island Countries*. Menzies Centre for Health
52 Policy, Sydney and Canberra, pp. 55.
- 53 Sanò, M., M. Marchand, and R. Medina, 2010: Coastal setbacks for the Mediterranean: a challenge for ICZM.
54 *Journal of Coastal Conservation*, **14(4)**, 295-301.

- 1 Santese, M., M.R. Perrone, A.S. Zakey, F. De Tomasi, and F. Giorgi, 2010: Modeling of Saharan dust outbreaks
2 over the Mediterranean by RegCM3: Case studies. *Atmospheric Chemistry and Physics Discussions*, **10(1)**, 133-
3 156.
- 4 Sax, D.F. and S.D. Gaines, 2008: Species invasions and extinction: the future of native biodiversity on islands.
5 *Proceedings of the National Academy of Sciences*, **105**, 11490-11497.
- 6 Scheffers, A. and S. Scheffers, 2006: Documentation of the impact of Hurricane Ivan on the coastline of Bonaire
7 (Netherlands Antilles). *Journal of Coastal Research*, **22**, 1437-1450.
- 8 Schipper, L. and M. Pelling, 2006: Disaster risk, climate change and international development: scope for, and
9 challenges to, integration. *Disasters (Special Issue on Climate Change and Disasters)*, **30(1)**, 19-38.
- 10 Schlepupner, C., 2008: Evaluation of coastal squeeze and its consequences for the Caribbean island Martinique.
11 *Ocean & Coastal Management*, **51(5)**, 383-390.
- 12 Schofield, P.J., 2010: Update on geographic spread of invasive lionfishes (*Pterois volitans* [Linnaeus, 1758] and *P.*
13 *miles* [Bennett, 1828]) in the Western North Atlantic Ocean, Caribbean Sea and Gulf of Mexico.
14 *Aquat. Invasions*, **5(1)**, S117-S122.
- 15 Schwarz, A., C. Béné, G. Bennett, D. Boso, Z. Hilly, C. Paul, R. Posala, S. Sibiti, and N. Andrew, 2011:
16 Vulnerability and resilience of remote rural communities to shocks and global changes: Empirical analysis from
17 Solomon Islands. *Global Environmental Change*, **21(3)**, 1128-1140.
- 18 Scott, D., M.C. Simpson, and R. Sim, 2012: The vulnerability of Caribbean coastal tourism to scenarios of climate
19 change related sea level rise. *Journal of Sustainable Tourism*, **20(6)**, 883-898.
- 20 Sekercioglu, C.H., S.H. Schneider, J.P. Fay, and S.R. Loarie, 2008: Climate change, elevational range shifts, and
21 bird extinctions. *Conservation Biology*, **22(1)**, 140-150.
- 22 Senapathi, D., M.A.C. Nicoll, C. Teplitsky, C.G. Jones, and K. Norris, 2011: Climate change and the risks
23 associated with delayed breeding in a tropical wild bird population. *Proceedings of the Royal Society B:*
24 *Biological Sciences*, **278(1722)**, 3184-3190.
- 25 Shen, S. and F. Gemenne, 2011: Contrasted Views on Environmental Change and Migration: the Case of Tuvaluan
26 Migration to New Zealand. *International Migration*, **49**, e224-e242.
- 27 Sheppard, C., D.J. Dixon, M. Gourlay, A. Sheppard, and R. Payet, 2005: Coral mortality increases wave energy
28 reaching shores protected by reef flats: examples from the Seychelles. *Estuarine, Coastal and Shelf Science*,
29 **64(2-3)**, 223-234.
- 30 Sinane, K., G. David, G. Pennober, and R. Troadec, 2010: Fragilisation et modification des formations littorales
31 meubles sur l'île d'Anjouan (Comores): Quand l'érosion d'origine anthropique se conjugue au changement
32 climatique. [VertigO] *La Revue Électronique En Sciences De l'environnement*, **10(3)**.
- 33 Smit, B., I. Burton, R.J.T. Klein, and J. Wandel, 2000: An anatomy of adaptation to climate change and variability.
34 *Climatic Change*, **45(1)**, 223-251.
- 35 Sovacool, B.K., 2012: Expert views of climate change adaptation in the Maldives. *Climatic Change*, **114(2)**, 295-
36 300.
- 37 Spennemann, D.H.R., 1996: Nontraditional settlement patterns and typhoon hazard on contemporary Majuro Atoll,
38 Republic of Marshall Islands. *Environmental Management*, **20(3)**, 337-348.
- 39 Srinivasan, U.T., 2010: Economics of climate change: risk and responsibility by world region. *Climate Policy*,
40 **10(3)**, 298-316.
- 41 Steinberger, J.K., J. van Niel, and D. Bourg, 2009: Profiting from negawatts: Reducing absolute consumption and
42 emissions through a performance-based energy economy. *Energy Policy*, **37(1)**, 361-370.
- 43 Stephenson, T.S., A.A. Chen, and M.A. Taylor, 2008: Toward the development of prediction models for the primary
44 Caribbean dry season. *Theoretical and Applied Climatology*, **92**, 87-101.
- 45 Storey, D. and S. Hunter, 2010: Kiribati: an environmental 'perfect storm'. *Australian Geographer*, **41(2)**, 167-181.
- 46 Stuart, E.K., 2006: Energizing the island community: a review of policy standpoints for energy in small island states
47 and territories. *Sustainable Development*, **14(2)**, 139-147.
- 48 Swart, R. and F. Raes, 2007: Making integration of adaptation and mitigation work: mainstreaming into sustainable
49 development policies. *Climate Policy*, **7(4)**, 288-303.
- 50 Tabucanon, G.M. and B. Opeskin, 2011: The Resettlement of Nauruans in Australia: An early case of failed
51 environmental migration. *The Journal of Pacific History*, **46(3)**, 337-356.
- 52 Takasaki, Y., 2011: Do the commons help augment mutual insurance among the poor? *World Development*, **39(3)**,
53 429-438.

- 1 Tanzil, J.T.I., B.E. Brown, and A.W. Tudhope, 2009: Decline in skeletal growth of the coral *Porites lutea* from the
2 Andaman Sea, South Thailand between 1984 and 2005. *Coral Reefs*, **28(2)**, 519-528.
- 3 Taylor, M.A., A. Centella, J. Charlery, I. Borrajero, A. Benzanilla, J. Campbell, R. Rivero, T.S. Stephenson, F.
4 Whyte, and R. Watson, 2007:
5 *Glimpses of the Future: A briefing from the PRECIS Caribbean Climate Change Project*. . Caribbean
6 Community Climate Change Centre, Belmopan, Belize, pp. 1-24.
- 7 Taylor, M.A., F.S. Whyte, T.S. Stephenson, and J.D. Campbell, 2013: Why dry? Investigating the future evolution
8 of the Caribbean low level Jet to explain projected Caribbean drying *International Journal of Climatology*,
9 **33(3)**, 784-792.
- 10 Techera, E., 2008: Customary law and community based conservation of marine areas in Fiji. In: *Beyond the Global*
11 *Village. Environmental Challenges inspiring Global Citizenship*. [Hillerbrand, R. and R. Karlsson(eds.)].
12 Interdisciplinary Press, Oxford, UK, pp. 107.
- 13 Tegart, W.J.M., G.W. Sheldon, and D.C. Griffiths, 1990: Executive summary. In: *Climate Change: The IPCC*
14 *Impacts Assessment. Contribution of Working Group II to the First Assessment Report of the Intergovernmental*
15 *Panel on Climate Change*. [Tegart, W.J.M., G.W. Sheldon, and D.C. Griffiths(eds.)]. Australian Government
16 Publishing Service, Canberra, Australia, pp. 1-5.
- 17 Teles, F.R., 2011: Update on dengue in Africa. *Dengue Bulletin*, **Dec; 35**, 35-51.
- 18 Terry, J.P. and A.C. Falkland, 2010: Responses of atoll freshwater lenses to storm-surge overwash in the Northern
19 Cook Islands. *Hydrogeology Journal*, **18(3)**, 749-759.
- 20 Terry, J.P., S. Garimella, and R.A. Kostaschuk, 2002: Rates of floodplain accretion in a tropical island river system
21 impacted by cyclones and large floods. *Geomorphology*, **42(3-4)**, 171-182.
- 22 Tester, P.A., R.L. Feldman, A.W. Nau, S.R. Kibler, and R. Wayne Litaker, 2010: Ciguatera fish poisoning and sea
23 surface temperatures in the Caribbean Sea and the West Indies. *Toxicon*, **56(5)**, 698-710.
- 24 Thiengo, S.C., A. Maldonado, E.M. Mota, E.J.L. Torres, R. Caldeira, O.S. Carvalho, A.P.M. Oliveira, R.O. Simoes,
25 M.A. Fernandez, and R.M. Lanfredi, 2010: The giant African snail *Achatina fulica* as natural intermediate host
26 of *Angiostrongylus cantonensis* in Pernambuco, northeast Brazil. *Acta Tropica*, **115(3)**, 194-199.
- 27 Thomas, A. and R. Leichenko, 2011: Adaptation through insurance: lessons from the NFIP. *International Journal of*
28 *Climate Change Strategies and Management*, **3(3)**, 250-263.
- 29 Thomas-Hope, E. and A. Jardine-Comrie, 2007: Valuation of environmental resources for tourism in small island
30 developing states: Implications for planning in Jamaica. *International Development Planning Review*, **29(1)**, 93-
31 112.
- 32 Thornton, P.K., P.G. Jones, P.J. Ericksen, and A.J. Challinor, 2011: Agriculture and food systems in sub-Saharan
33 Africa in a 4 C world. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and*
34 *Engineering Sciences*, **369(1934)**, 117-136.
- 35 Tkachenko, K.S., 2012: The northernmost coral frontier of the Maldives: The coral reefs of Ihavandippolu Atoll
36 under long-term environmental change. *Marine Environmental Research*, **82(0)**, 40-48.
- 37 Tompkins, E.L., M.C. Lemos, and E. Boyd, 2008: A less disastrous disaster: Managing response to climate-driven
38 hazards in the Cayman Islands and NE Brazil. *Global Environmental Change-Human and Policy Dimensions*,
39 **18(4)**, 736-745.
- 40 Tompkins, E.L., L. Hurlston, and W. Poortinga, 2009: Foreignness as a constraint on learning: the impact of
41 migrants on disaster resilience in small islands. *Environmental Hazards*, **8**, 263-277.
- 42 Tompkins, E.L., W.N. Adger, E. Boyd, S. Nicholson-Cole, K. Weatherhead, and N. Arnell, 2010: Observed
43 adaptation to climate change: UK evidence of transition to a well-adapting society. *Global Environmental*
44 *Change*, **20(4)**, 627-635.
- 45 Tsyban, A., J.T. Everett, and J. Titus, 1990: World oceans and coastal zones. In: *Climate Change: The IPCC*
46 *Impacts Assessment*. [McG. Tegart, W.J., G.W. Sheldon, and D.C. Griffiths(eds.)]. Australian Government
47 Publishing Service, Canberra, pp. 6.1-6.28.
- 48 Turvey, R., 2007: Vulnerability Assessment of Developing Countries: The Case of Small-island Developing States.
49 *Development Policy Review*, **25(2)**, 243-264.
- 50 Uno, I., K. Eguchi, K. Yumimoto, T. Takemura, A. Shimizu, M. Uematsu, Z. Liu, Z. Wang, Y. Hara, and N.
51 Sugimoto, 2009: Asian dust transported one full circuit around the globe. *Nature Geoscience*, **2**, 557-560.
- 52 Uyarra, M.C., I.M. Cote, J.A. Gill, R.R.T. Tinch, D. Viner, and A.R. Watkinson, 2005: Island-specific preferences
53 of tourists for environmental features: implications of climate change for tourism-dependent states.
54 *Environmental Conservation*, **32(1)**, 11-19.

- 1 Van Aalst, M.K., T. Cannon, and I. Burton, 2008: Community level adaptation to climate change: the potential role
2 of participatory community risk assessment. *Global Environmental Change*, **18(1)**, 165-179.
- 3 van Alphen, K., H.S. Kunz, and M.P. Hekkert, 2008: Policy measures to promote the widespread utilization of
4 renewable energy technologies for electricity generation in the Maldives. *Renewable and Sustainable Energy*
5 *Reviews*, **12(7)**, 1959-1973.
- 6 van der Werf, G.R., D.C. Morton, R.S. DeFries, J.G. Olivier, P.S. Kasibhatla, R.B. Jackson, G.J. Collatz, and J.T.
7 Randrsn, 2009: CO₂ emissions from forest loss. *Nature Geoscience*, **2**, 737-738.
- 8 Van Kleef, E., H. Bambrick, and S. Hales, 2010: The geographic distribution of dengue fever and the potential
9 influence of global climate change. *TropIKA.Net*, , 0-0.
- 10 van Ledden, M., G. Vaughn, J. Lansen, F. Wiersma, and M. Amsterdam, 2009: Extreme wave event along the
11 Guyana coastline in October 2005. *Continental Shelf Research*, **29(1)**, 352-361.
- 12 Van Nostrand, J.M. and J.G. Nevius, 2011: Parametric Insurance: Using Objective Measures to Address the Impacts
13 of Natural Disasters and Climate Change. *Environmental Claims Journal*, **23(3-4)**, 227-237.
- 14 van Vuuren D.P., J. Edmonds, M. Kainuma, K. Riahi, A. Thomson, K. Hibbard, G.C. Hurtt, T. Kram, V. Krey, J.
15 Lamarque, T.M. Masui, M. Meinshausen, N. Nakicenovic, S.J. Smith, and S.K. Rose, 2010:
16 The representative concentration pathways: an overview. *Climatic Change*, **109**, 5-31.
- 17 Vassie, J.M., P.L. Woodworth, and M.W. Holt, 2004: An example of North Atlantic deep-ocean swell impacting
18 ascension and St. Helena Islands in the Central South Atlantic. *Journal of Atmospheric and Oceanic*
19 *Technology*, **21(7)**, 1095-1103.
- 20 Voccia, A., 2012: Climate change: what future for small, vulnerable states? *International Journal of Sustainable*
21 *Development & World Ecology*, **19(2)**, 101-115.
- 22 Walsh, K.J.E., K.L. McInnes, J.L. McBride, 2012: Climate change impacts on tropical cyclones and extreme sea
23 levels in the South Pacific – A regional assessment, *Global and Planetary Change*, **80-81**, 140-164.
- 24 Warrick, O., 2009: Ethics and methods in research for community-based adaptation: Reflections from rural Vanuatu.
25 *Participatory Learning and Action*, **60**, 76-87.
- 26 Waycott, M., L.J. McKenzie, J.E. Mellors, J.C. Ellison, M.T. Sheaves, C. Collier, A.M. Schwarz, A. Webb, J.E.
27 Johnson, and C.E. Payri, 2011: Vulnerability of mangroves, seagrasses and intertidal flats in the tropical Pacific
28 to climate change. In: *Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change*. [Bell, D.,
29 J.E. Johnson, and J.A. Hobday(eds.)]. Secretariat of the Pacific Community, Noumea, New Caledonia., .
- 30 Waycott, M., C.M. Duarte, T.J.B. Carruthers, R.J. Orth, W.C. Dennison, S. Olyarnik, A. Calladine, J.W.
31 Fourqurean, K.L. Heck, A.R. Hughes, G.A. Kendrick, W.J. Kenworthy, F.T. Short, and S.L. Williams, 2009:
32 Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National*
33 *Academy of Sciences*, **106(30)**, 12377-12381.
- 34 Webb, N., S. Coulson, I. Hodkinson, W. Block, J. BalE, and A. Strathdee, 1998: The effects of experimental
35 temperature elevation on populations of cryptostigmatic mites in high Arctic soils *Pedobiologia*, **42**, 298-308.
- 36 Webb, A.P., and P.S. Kench, 2010: The dynamic response of reef islands to sea-level rise: Evidence from multi-
37 decadal analysis of island change in the central Pacific. *Global and Planetary Change*, **72(3)**, 234-246.
- 38 Weil, E. and A. Cróquer, 2009: Spatial variability in distribution and prevalence of Caribbean scleractinian coral and
39 octocoral diseases. I. Community-level analysis. *Diseases of Aquatic Organisms*, **83(3)**, 195-208.
- 40 Weil, E. and C.S. Rogers, 2011: Coral reef diseases in the Atlantic-Caribbean. In: *Coral Reefs: An Ecosystem in*
41 *Transition*. [Dubinsky, Z. and N. Stambler(eds.)]. Springer Netherlands, Dordrecht; Heidelberg; London; New
42 York, pp. 465-491-491.
- 43 Weir, T. and Z. Virani, 2011: Three linked risks for development in the Pacific Islands: Climate change, disasters
44 and conflict. *Climate and Development*, **3(3)**, 193-208.
- 45 Westphal, M., M. Browne, K. MacKinnon, and I. Noble, 2008: The link between international trade and the global
46 distribution of invasive alien species. *Biological Invasions*, **10(4)**, 391-398.
- 47 Wheeler, D., 2011: Quantifying vulnerability to climate change: implications for adaptation assistance. *Center for*
48 *Global Development Working Paper*, **(240)**.
- 49 White, I., T. Falkland, P. Perez, A. Dray, T. Metutera, E. Metai, and M. Overmars, 2007: Challenges in freshwater
50 management in low coral atolls. *Journal of Cleaner Production*, **15**, 1522-1528.
- 51 White, I. and T. Falkland, 2010: Management of freshwater lenses in small Pacific islands. *Hydrogeology Journal*,
52 **18(1)**, 227-246.
- 53 Whyte, F.S., M.A. Taylor, T.S. Stephenson, and J.D. Campbell, 2008: Features of the Caribbean low level jet.
54 *International Journal of Climatology*, **28**, 119-128.

- 1 Williams, G.J., I.S. Knapp, J.E. Maragos, and S.K. Davy, 2010: Modelling patterns of coral bleaching at a remote
2 Pacific atoll. *Marine Pollution Bulletin*, **60**, 1467-1476.
- 3 Willis, J.K. and J.A. Church, 2012: Regional sea-level projection. *Science*, **336(6081)**, 550-551.
- 4 Winters, L.A. and P.M. Martins, 2004: When comparative advantage is not enough: business costs in small remote
5 economies. *World Trade Review*, **3(3)**, 347-383.
- 6 Woodroffe, C.D., 2008: Reef-island topography and the vulnerability of atolls to sea-level rise. *Global and*
7 *Planetary Change*, **62**, 77-96.
- 8 Yamamoto, L. and M. Esteban, 2010: Vanishing Island States and sovereignty. *Ocean & Coastal Management*,
9 **53(1)**, 1-9.
- 10 Yamano, H., H. Kayanne, T. Yamaguchi, Y. Kuwhara, H. Yokoki, H. Shimazaki, and M. Chicamori, 2007: Atoll
11 island vulnerability to flooding and inundation revealed by historical reconstruction: Fongafale Island, Funafuti
12 Atoll, Tuvalu. *Global and Planetary Change*, **57(3-4)**, 407-416.
- 13 Zahibo, N., E. Pelinovsky, T. Talipova, A. Rabinovich, A. Kurkin, and I. Nikolkina, 2007: Statistical analysis of
14 cyclone hazard for Guadeloupe, Lesser Antilles. *Atmospheric Research*, **84(1)**, 13-29.
- 15

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

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

Table 29-2: Preliminary projected percentage changes in tuna catches relative to the 20 year average (1980-2000) and estimated percentage change to government revenue resulting from projected changes in the catch of skipjack tuna in 2035 and 2100 (Bell et al., 2011).

SRES Scenario		2035		2100	
		B1/A2		B1	A2
Skipjack tuna	Western fishery	+ 11%		-0.2%	-21%
	Eastern fishery	+37%		+43%	+27%
Bigeye tuna	Western fishery	-2%		-12%	-24%
	Eastern fishery	+3%		-4%	-18%
Skipjack tuna	Total	+19%		+12%	-7%
Bigeye tuna	Total	+0.3%		-9%	-27%
Change to Government Revenue (Percent)	FSM	0.8 to 1.7%		-0.9 to -1.9%	
	Solomon Is	0.01 to 0.16%		-0.03 to 0.77%	
	Kiribati	+11 to 18.4%		+7.2 to 12.0%	
	Tuvalu	+3.7 to 9.2%		+2.5 to 6.2%	

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

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

Source: Campbell (2009:89)

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

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

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

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

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

Source: Campbell (2010: 34).

Table 29-6: Economic structure of small islands and areas of potential emissions reduction.

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

Notes:

X = low potential for emissions reduction due to excessive cost or limited effectiveness

? = possible area for emissions reduction, although may depend on capacities within the islands

√ = rich area for exploring emissions reduction

Island Typology

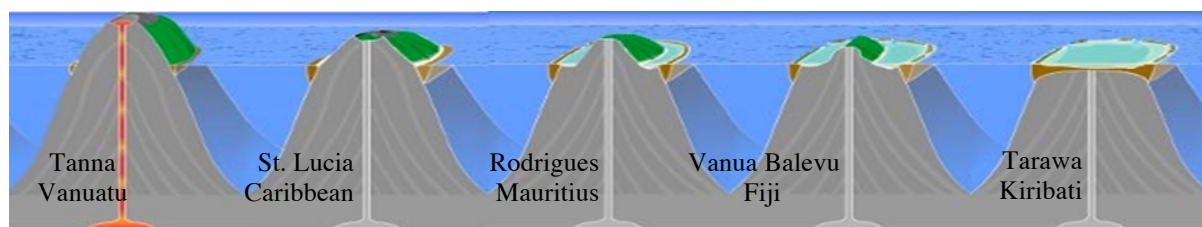


Figure 29-1: This schematic describes common tropical island typology from young high volcanic islands (left) through to atolls (submerged volcanics) on the far right. This simple overview highlights important components such as elevation and differing land and marine resources as well as the presence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

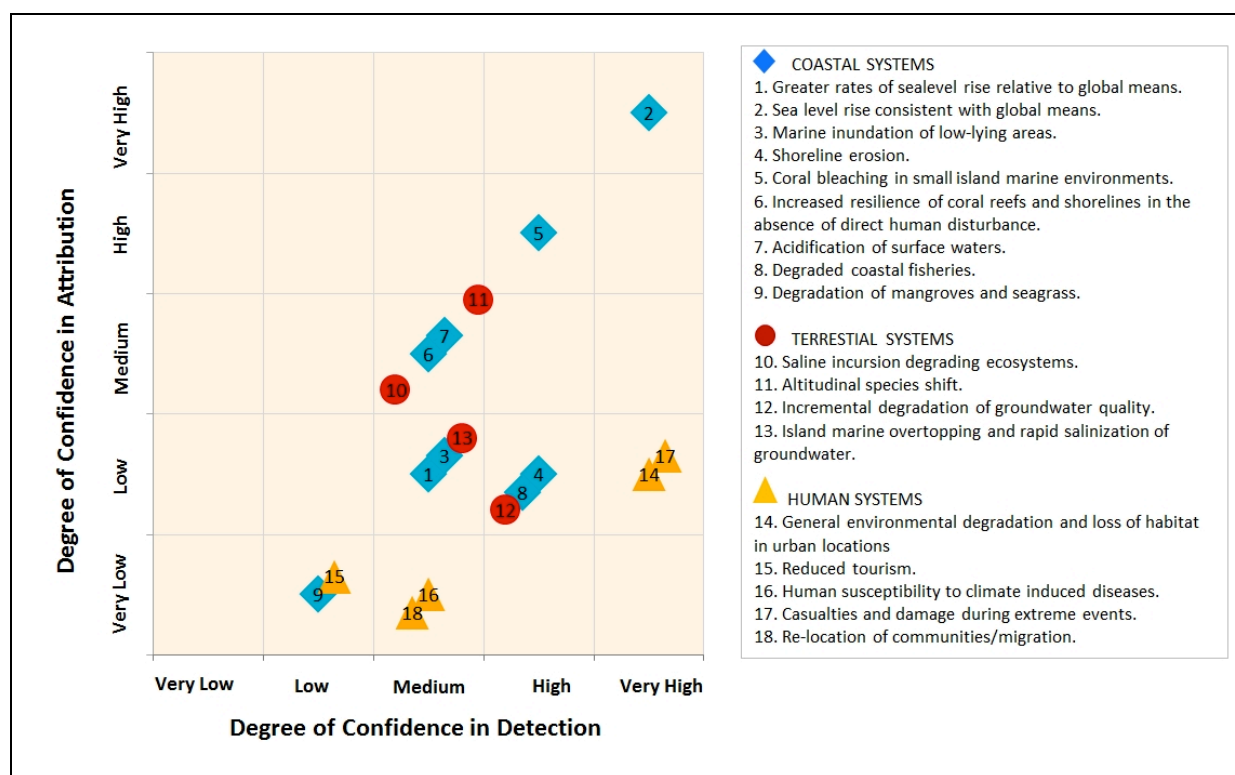


Figure 29-2: Based on available literature discussed in this chapter, the diagram shows a comparison of the degree of confidence in the detection of tropical small island impacts (horizontal axis) with the degree of confidence in attribution to climate change drivers (vertical axis). For example; the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

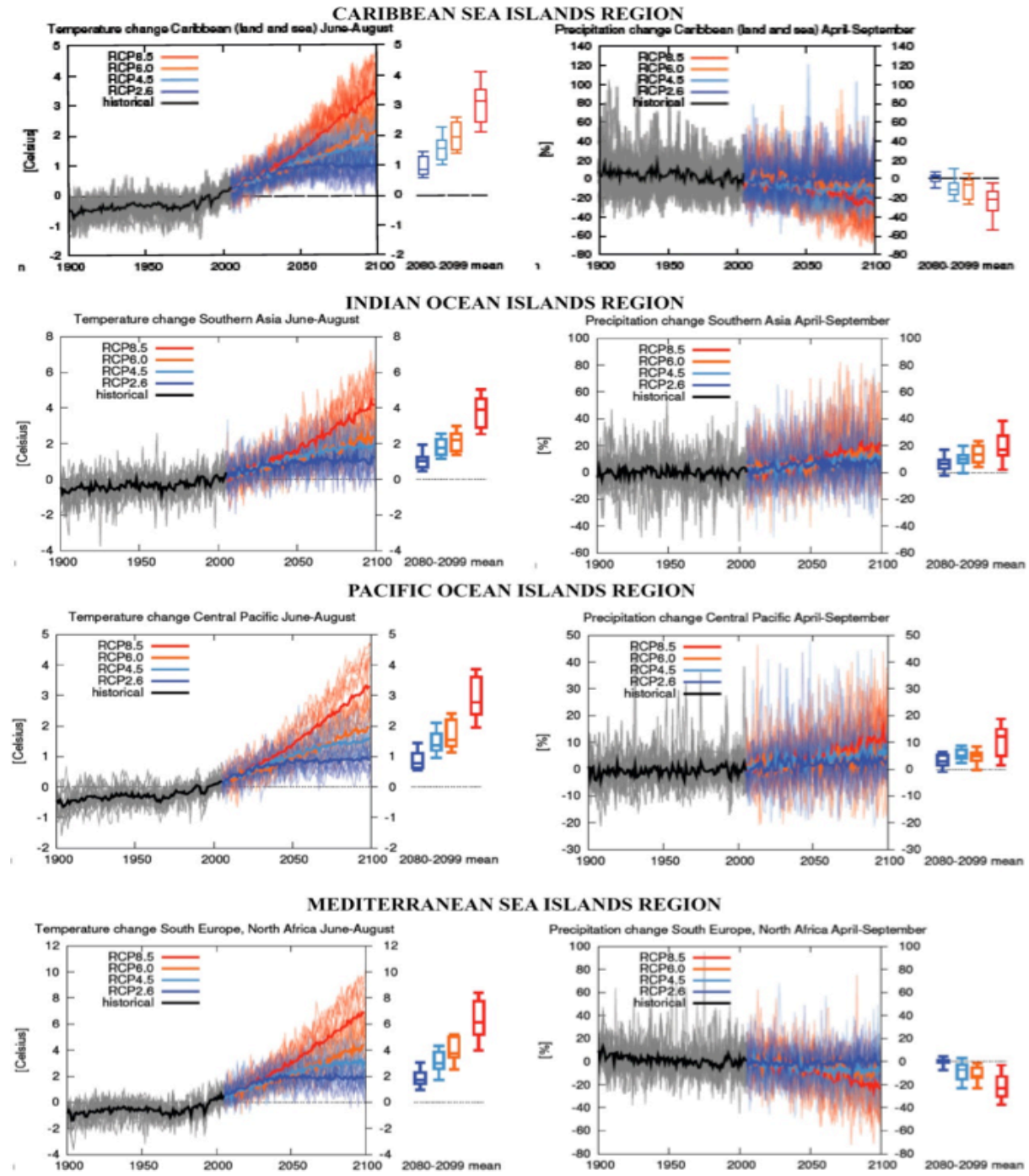


Figure 29-3: RCP Scenario projections to the year 2100 for the four main small island regions (adapted from AR5 WG1, Annex 1).

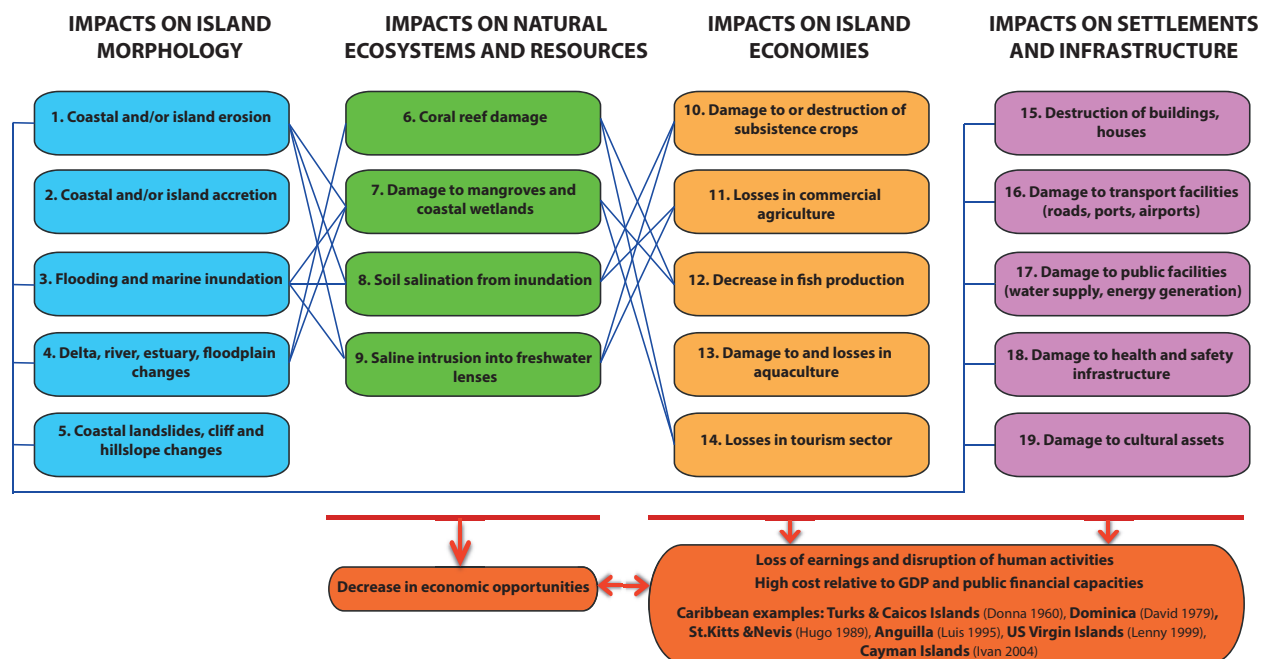
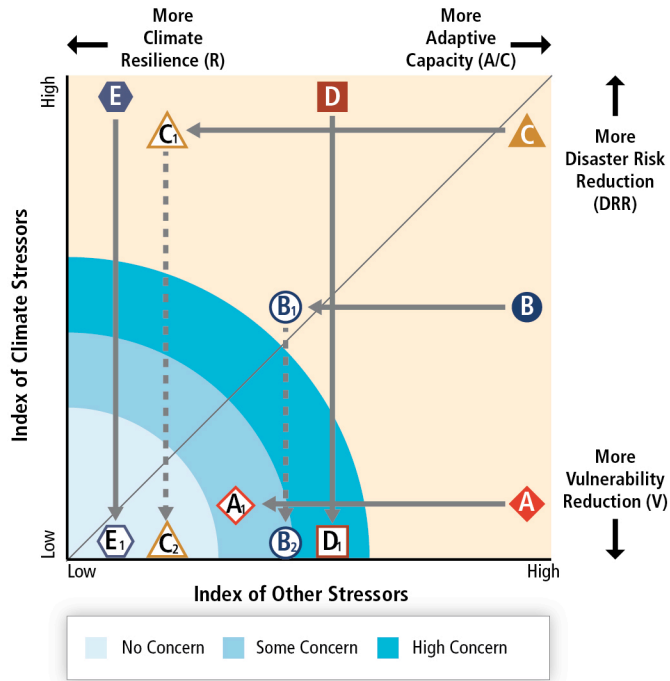


Figure 29-4: Tropical and extra-tropical cyclone impacts on the coasts of small islands: a. Example of tropical cyclone impacts on small island coasts with reference; b. Example of extra-tropical cyclone (mid-high-latitude lows) impacts on small island coasts with reference.

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



	Policy Focus		Additional Policy Objective	
A	Reducing vulnerability to non-climate stressors	A ₁		
B	Reducing vulnerability to non-climate stressors AND disaster risk reduction	B ₁	Creating climate resilience	B ₂
C	Reducing vulnerability to non-climate stressors AND disaster risk reduction	C ₁	Climate resilience	C ₂
D	Disaster risk reduction AND climate resilience	D ₁		
E	Climate resilience	E ₁		

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