Chapter 15: Small Islands

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Table of Contents

Executive Summary ... **3**
15.1 Introduction ... **5**
15.2 Points of Departure from AR5 and Recent Special Reports ... **7**
15.2.1 Points of Departure on Exposure, Vulnerability, Impacts and Risks ... *7*
15.2.2 Point of Departure on Adaptation Solutions ... *8*
15.3 Observed Impacts and Projected Risks of Climate Change ... **9**
15.3.1 Synthesis of Observed and Projected Changes in the Physical Basis ... *9*
15.3.2 Trends in Exposure and Vulnerability ... *11*
15.3.3 Observed Impacts and Projected Risks on Natural Systems ... *12*
15.3.4 Observed Impacts and Projected Risks on Human Systems ... *22*
Box 15.1: Synthesis of Key Risks in Small Islands. ... **31**
Box 15.2: Key Examples of Compound Events: Maldives Islands and Caribbean Region ... **32**
15.4 Detection and Attribution of Observed Impacts of Climate Change on Small Islands ... **34**
15.5 Assessment of Adaptation Options and Their Implementation ... **35**
15.5.1 Hard Protection ... *35*
15.5.2 Accommodation: "Staying Put" and Advance as Strategies ... *36*
15.5.3 Migration ... *37*
15.5.4 Ecosystem-based Measures ... *38*
15.5.5. Community-based Adaptation ... *42*
15.5.6 Livelihood Responses ... *42*
15.5.7 Disaster Risk Management, Early Warning Systems and Climate Services ... *43*
15.6 Enablers, Limits and Barriers to Adaptation ... **45**
15.6.1 Governance ... *45*
15.6.2 Health-Related Adaptation Strategies ... *47*
15.6.3 Adaptation Finance and Risk Transfer Mechanisms ... *47*
15.6.4 Education and Awareness-Raising ... *49*
15.6.5 Culture ... *50*
15.7 Climate Resilient Development Pathways and Future Solutions in Small Islands ... **52**
15.8 Research Gaps ... **54**
15.8.1 Island-scale Data Availability ... *54*
15.8.2 Vulnerability and Resilience ... *54*
15.8.3 Adaptation ... *55*
Frequently Asked Questions ... **57**

FAQ 15.1: How is climate change affecting nature and human life on small islands, and will further climate change result in some small islands becoming uninhabitable for humans in the near future? *57*
FAQ 15.2: How have some small-island communities already adapted to climate change? *57*
FAQ 15.3: How will climate related changes affect the contributions of agriculture and fisheries to food security in small islands? *60*
Large Tables **61**
References **71**

Executive Summary

It is not possible to provide more specific statements or quantitative information (reference periods and contrasting scenarios/temperature levels) on observed and projected impacts due to: (1) the high diversity of small islands which makes generalisation impossible; and (2) the limited available robust literature providing quantitative information for small islands.

Small islands are increasingly affected by the growing impacts of tropical cyclones, storm surges, droughts, changing precipitation patterns, sea-level rise, ocean acidification, coral bleaching, and invasive alien species, all of which are already detectable across both natural and human systems, but differ between urban and rural contexts, island types, and tropical and non-tropical islands (*high confidence*). Climate change is affecting marine and terrestrial ecosystems and ecosystem services, settlements and infrastructure, health and wellbeing, water and food security, and economies and culture, especially through compound events. Coastal cities and rural communities on small islands have been already impacted by sea-level rise, heavy precipitation events, tropical cyclones and storm surges (*very high confidence*). {15.3.3.1, 15.3.3.2, 15.3.3.3, 15.3.4.1, 15.3.4.2, 15.3.4.3, 15.3.4.4, 15.3.4.5, 15.3.4.7}

Projected climate and ocean-related changes will significantly affect marine and terrestrial ecosystems and ecosystem services, which will in turn have severe cascading impacts across both natural and human systems (*high confidence*). Changes in the wave climate superimposed on sea-level rise will significantly increase coastal flooding (*high confidence*) and coastal and reef island erosion (*limited evidence, medium agreement*). The frequency, extent, and duration of coastal flooding will significantly increase by 2050 to 2070 (*high confidence*), unless coastal and marine ecosystems are able to naturally adapt to SLR through vertical adjustment growth (*low confidence*). {15.3.3.1.1, 15.3.3.1.2, 15.3.3.1.3, 15.3.3.1.4}

Developing synergies between changing climate and human activities could lead to disproportionate changes in global terrestrial biodiversity (*medium to high confidence*). Many small islands harbour significant degrees of global terrestrial species diversity, and currently host almost half of all species presently considered to be at risk of extinction. When combined with synergies among rising sea levels, increasing intensities of extreme events, accelerating habitat destruction and degradation, and the introduction of invasive alien species, projections suggest increased extirpations (and extinctions in the case of single island endemics) even at mild warming levels (*high confidence*). {15.3.3.3}

The continued degradation and transformation of terrestrial ecosystems within small islands due to human-dominated uses amplifies the vulnerability of island inhabitants to the impacts of climate change (*high confidence*). This in turn is likely to decrease the provision of important resources (e.g., potable water) to the millions of people living on small islands across the world, resulting in impacts upon settlements and infrastructure, food and water security, health, economies, culture, and potentially migration (*high confidence*). {15.3.3.2, 15.3.3.3, 15.3.4.1, 15.3.4.2, 15.4.3, 15.3.4.4, 15.3.4.5, 15.3.4.6, 15.3.4.7}

Reef island and coastal area habitability in small islands is expected to decrease as a result of sea-level rise, changes in precipitation patterns, the changing frequency and intensity of extreme events, ocean warming, and increasing human exposure *(high confidence).* Climate and non-climate drivers of decreased habitability are context specific. In small islands increased coastal impacts (flooding, erosion and permanent inundation), changes in the frequency and/or magnitude of extreme precipitation and storm surges, and increased aridity and magnitudes of drought have been major contributors to food and water insecurities. {15.3.4.3, 15.3.4.4}

Vulnerable communities in small islands, especially those relying on coral reef environment for livelihoods, may exceed adaptation limits well before the end of this century even for a low greenhouse gas emission pathway *(high confidence).* The impacts combined with growing population, settlement and infrastructure in vulnerable low-lying and coastal areas, present serious threats to the ability of land to support human life and livelihoods (*high confidence*). Climate related migration is expected to increase, although the drivers and outcomes are highly context-specific and insufficient evidence exists to estimate numbers of climate-related migrants now and in the future (*medium evidence, high agreement*). {15.3.4.1, 15.3.4.6}

Many island communities are resilient with strong social safety nets and social capital that support responses and actions already occurring, but there is limited information on the effectiveness of the adaptation practices and the scale of needed action. This is in part due to a need for better understanding the limits to adaptation and what current resilience and successful adaptation looks like in small island contexts. Further, greater insight into which drivers weaken local and indigenous resilience, together with recognition of the socio-political context within which communities operate, and the processes by which decisions are made, can all assist in identifying opportunities at all scales to enhance climate adaptation and enable action towards climate resilient development pathways (*high agreement, medium evidence*). {15.6.1, 15.6.5, 15.7}

In small islands, several enablers can be used to improve adaptation outcomes and to build resilience while accepting that solutions are often context dependent. These enablers include better governance and legal reforms; improving justice, equity and gender considerations; building human resource capacity; increased finance and risk transfer mechanisms; education and awareness programmes; increased access to climate information; and embedding Indigenous knowledge and Local knowledge (IK & LK) as well as integrating cultural resources into decision-making (*high confidence*). {15.6.1 15.6.3, 15.6.4, 15.6.5}

Small islands however face constraints such as weak governance arrangements, limited financial resources and insufficient human resource capacity, which constrain the implementation of adaptation actions. Additionally, institutional and legal systems are ill-prepared for managing adaptation strategies such as large-scale settlement relocation and other planned and/or autonomous responses to climate risks *(high confidence)*. While adaptation strategies are already being implemented, such as ecosystem- based adaptation, such as the replanting of mangroves, restoration of coral reefs and reforestation, are being implemented on some islands, implementation faces several barriers including inadequate up-to-date and locally relevant information, limited availability of finance and technology, lack of integration of IK & LK in adaptation strategies, and institutional constraints (*high confidence*). {15.5.3, 15.5.4, 15.6.3, 15.6.4, 15.6.5}

For many small islands, actions are often incremental and do not meet the scale of extreme or compounding events. Small islands are highly dependent on international financing to face both slow and rapid onset events *(high confidence)* but face severe challenging in accessing adaptation finance. Much of the currently implemented adaptation remains small in scale (e.g., community-based adaptation projects), which do not address the needed structural and system level adaptations to address climate impacts. Even if international climate finance is increasing in magnitude, many challenges remain in accessing it across small islands. Solutions to these barriers are being explored and some small islands have started adopting enablers at both the national and local levels in responding to adaptation needs and to facilitate resiliency building. Such enablers are being integrated into National Adaptation Plans and Disaster Risk Reduction Plans (*high confidence*). {15.6.3}

15.1 Introduction

Geographically, small islands are high-risk areas because their coastal areas are large relative to land mass. Furthermore, they already face diverse climate change-related hazards, which place their resources, people and assets at serious risk (Hay et al., 2019). Even at a global warming of 1.5ºC, small islands in some regions are projected to experience high multiple interrelated climate risks including increased flooding, saltwater intrusion and damage to ecosystems, settlements and infrastructure resulting from sea level rise, tropical cyclones and distant-source swells.

In line with Assessment Report (AR) 5, the small islands considered in this chapter are located within the tropics of the southern, northern, and western Pacific Ocean, the central and western Indian Ocean, the Caribbean Sea, the eastern Atlantic off the coast of West Africa, and in the more temperate Mediterranean Sea. Although the focus is on small islands, occasionally examples of larger islands are used. In contrast to AR5, non-sovereign states and territories are included to highlight the significant diversity of small islands in terms of island physical and biophysical characteristics, economic systems, social and cultural heterogeneity, and different political/governance systems. These differences among small islands provide important lessons to be learned for adapting to climate change as solutions are not homogeneous, but often place-specific, and will therefore vary across small island regions.
This chapter builds on the findings of the IPCC Special Report on Global Warming of 1.5°C (SR1.5); the Special Report on Climate Change and Land (SRCCL); and the Special Report on Oceans and Cryosphere (SROCC) in relation to small islands. It assesses new scientific evidence of changes in the climate system and the associated impacts on natural and human systems, and subsequent adaptation strategies. The SROCC reported that by 2050 small islands at almost all latitudes will experience extreme sea level events annually. According to the SR1.5, even if greenhouse gas emissions are reduced, increases in global temperature and extreme events are already occurring. Extreme events such as tropical cyclones (TCs), distant-source waves, droughts, El Niño/La Niña events, and marine heat waves all provide compelling evidence of the high risks facing small islands. Over the last five years, small islands have been impacted by intense TCs classified as categories 4 and 5. Evidence exists of an increasing number of rapidly intensifying storms, and research highlights such storms are affecting the Atlantic region (Bhatia et al., 2019; Knutson et al., 2019). TCs and other extreme events have caused damage to human settlements and infrastructure that resulted in a high percentage of short-term and long-term GDP loss (Eckstein, 2018, p. 223; Nalau et al., 2017) and significant damage to ecosystems.

Since AR5 more research on marine and coastal ecosystems of small islands has revealed changes arising from temperature increase and anthropogenic pressures. SR1.5, based on research by Hoegh-Guldberg et al. (2018), concludes that coral reefs are projected to decline further by 70–90% at 1.5°C (*high confidence*). New research revealed substantial declines in seagrass communities, but attribution of such declines to climatic influences remains weak (*low confidence*). Additionally, large-scale die-offs (Duke et al., 2017; Lovelock et al., 2015) including around many small islands, suggest that mangrove face increased risks from climate change.

Adaptation is expected to be challenging for small islands in the 21st century. Yet, according to the SROCC, if sufficient actions are taken in lowering greenhouse gas emissions by 2050, this will lead to a slower rate of sea-level rise which will enable opportunities for adaptation in the human and ecological systems. In small islands, adaptive capacity remains a critical issue as governance arrangements are complex and often fail to recognise the role of local governments and non-state actors, such as communities, in overcoming barriers to climate change adaptation (Kuruppu and Willie, 2015). Adaptive capacity in small islands is assessed by examining existing modalities for prioritising adaptation needs at both national and local levels and by reviewing the application of Indigenous and Local knowledge (IK & LK) in adapting to climate change risks. This chapter also reviews the role of climate services in strengthening adaptive capacity and the use of early warning systems for disaster risk reduction as these are increasingly important to small islands (Newth and Gunasekera, 2018; Vaughan and Dessai, 2014). The issue of gender is recognised as a key factor in equitable adaptation but is still largely under-researched (15.6.5).

Post AR5, the question of who pays for adaptation remains a critical question for small islands, especially SIDS. Policymakers and decision-makers in small islands have highlighted the need to leverage finance to support adaptation efforts including monitoring and evaluating the effectiveness of measures aimed at avoiding maladaptation. This chapter assesses adaptation financing barriers facing small islands and enabling approaches used to fund a range of adaptation measures. Moreover, the issue of climate justice is receiving growing attention among small islands and is reviewed (15.7).

Although a wide range of adaptation measures exist, hard coastal protection strategies continue to dominate the small islands discussion and project funding across island types (Petzold and Magnan, 2019; Weir et al., 2017; Weir and Pittock, 2017). (See Fig 15.8). However, as more recent literature post-AR5 found small islands are experimenting with other adaptation options such as accommodation, advance, migration and ecosystem-based adaptation. Recent research on climate change and adaptation in small island developing states in the Caribbean, Indian Ocean and the Pacific provides more detailed analysis (Klöck and Finch, 2019).

The main storyline of this chapter is that a growing body of scientific evidence confirms that without taking the necessary adaptation action to resolve the growing impacts of climate change risks to natural and human systems, major disruption of people's livelihoods, health, and food and water security will occur in small islands. The scientific evidence of increasing exposure, vulnerability and impacts faced by small islands calls for multi-scale action to succeed at adaptation on all fronts. This can only be achieved by pursuing the Sustainable Development Goals (SDGs) and Climate Resilient Development Pathways (CRDP) (15.7) which are mutually reinforcing. They are major priorities for small islands. However, COVID-19 has disrupted efforts aimed at achieving the SDGs and due to economic shock will involve a re-direction of investment that was targeted toward CRDP.

This chapter aims to: (i) provide a better understanding of the distribution of observed impacts and projected risks of climate change on natural and human systems, including attribution issues, across small islands regions; (ii) assess adaptation options that have been implemented in small islands to date, as well as enablers, limits and barriers to adaptation; (iii) define the enabling conditions for adaptation in small islands; (iv) examine climate resilient development pathways and future solutions; and (v) identify research gaps (See Figure 15.1).

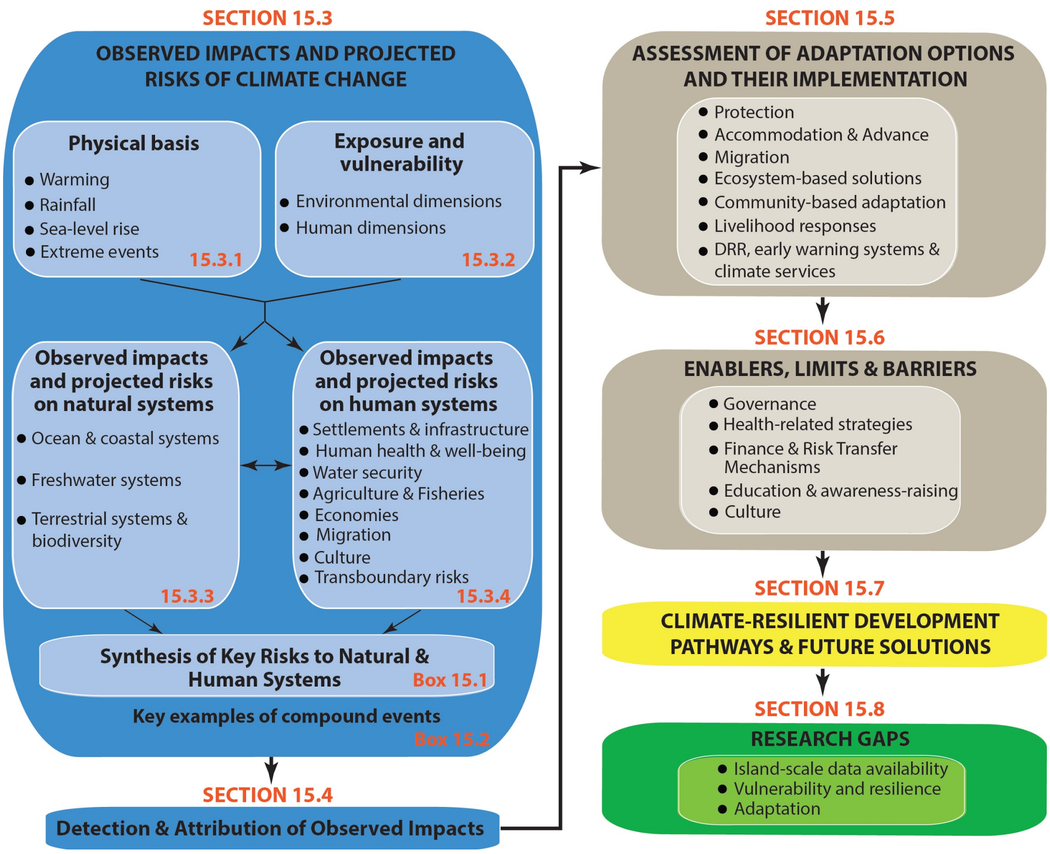

Figure 15.1: Schematic illustration of the interconnections of Chapter 15 themes, including on observed impacts and projected risks (Section 15.3) and on adaptation options and their implementation (Section 15.5).

15.2 Points of Departure from AR5 and Recent Special Reports

Since AR5, new findings in reference to small islands have emerged from scientific literature and IPCC special reports such as the Special Report on Global Warming of 1.5°C; the Special Report on Climate Change and Land (SRCCL); and the Special Report on Oceans and Cryosphere (SROCC).

15.2.1 Points of Departure on Exposure, Vulnerability, Impacts and Risks

Greater certainty and higher confidence levels on exposure, vulnerability, impacts and risks facing small islands in addition to responses, experiences and future options have been provided by more studies since AR5. A major conclusion of the SROCC (2019) is that global mean sea level (GMSL) is rising (*virtually certain*) and accelerating (*high confidence*) and the dominant cause since 1970 is anthropogenic forcing (*high confidence*). New literature found that anthropogenic drivers play a major role in shaping exposure and vulnerability to climate-related hazards in tropical small islands (Duvat et al., 2017a; Ratter et al., 2016; Weir and Pittock, 2017). The SROCC (2019) projected that in low-lying coastal areas, including those in small islands, human-induced changes could be rapid thereby altering coastlines over short time periods and outpacing the effects of SLR (*high confidence*).

Since AR5, advancements in knowledge have been made in relation to SLR projections and according to these projections, many coastal areas in lower latitudes such as small islands may expect amplification factors of 100 or larger by mid-century, regardless of the RCP scenarios (Rasmussen et al., 2018); (SROCC 4.2.3.4.1). High risk to urban atoll islands is expected before a 1 m rise in GMSL (SROCC 4.2.3.4.1). Subsequent to AR5 the future habitability of small islands is a growing concern.

Scientific evidence since AR5 has improved knowledge of coastal risks (Bindoff et al., 2019) and the respective roles of climate stressors including SLR, El Niño and La Niña, Tropical and Extra-Tropical Cyclones, droughts, marine heat waves and ocean acidification. New research revealed that such extreme events (Herring et al., 2019) provide striking illustrations of the high vulnerability of small island systems (*high confidence*) (SROCC 6.8.5, Box 4.2, Box 6.1).

Evidence exists since AR5 of several bleaching events that have severely impacted coral reefs worldwide, including those located in small islands (Perry and Morgan 2017; Hughes et al., 2018). SR1.5, based on research by Hoegh-Guldberg et al. (2018), concludes that coral reefs are projected to decline further by 70–90% at 1.5°C (*high confidence*), with even larger losses of more than 99% at 2°C (*very high confidence*). Recent modelling suggest that conditions which cause bleaching events will become more common in the future (van Hooidonk et al., 2016), placing coral reefs in small islands at greater risk, which will have repercussions for coastal and terrestrial ecosystems, coastal tourism (SROCC 4.3.3.6.2, 5.4.2.1.3), fisheries (*high confidence*) (Cinner et al., 2016; Graham et al., 2015), and other marine ecosystem-based livelihoods.

Post AR5 new studies project that ESL events that were historically rare, will become common by 2100 under all emission scenarios, leading to severe flooding if adaptation efforts are not ambitious (*high confidence*) (SROCC 4.2.3.2.1). Further, under RCP2.6 and RCP8.5 emission scenarios, many low-lying coastal areas at all latitudes, including small islands, will experience such events annually by 2050 (SROCC 4.2.3.4.1). Additionally, in AR5 compound events were not addressed but since then there is a growing body of scientific literature on these events.

New scientific literature is dominated by projection-based analyses rather than observed climate impacts upon the terrestrial biodiversity of small islands. Advancements have been made in species distribution modelling within the limited spatial scales of small islands, as have projections of SLR impacts (Bellard et al., 2014; Ferreira et al., 2019). Another key advance is an improved understanding of the synergistic relationships between climate change and direct impacts of human disturbances such as the introduction of alien invasive species (IAS), land-cover change and habitat destruction/degradation (Russell et al., 2017; S Taylor and Kumar, 2016). While new studies generally point to large population reductions and local extinctions such as 25% of endemic species within insular biodiversity hotspots being negatively impacted by the year 2100 (IPBES, 2018, Section 2.2.5.2.4), some uncertainty remains - as other studies highlight the persistence of insular species which are considered to be highly vulnerable to changing climate conditions. The latter is part of a burgeoning literature exploring the extinction-mitigation potential of highly heterogeneous landscapes within small islands and associated local climate micro-refugia (Table-Burning Embers- Climate Refugia) (Le Roux et al., 2019; Médail, 2017). Overall, small islands are amongst the regions likely to experience some of the largest increases in endemic extinctions, and hence may substantially contribute to future global biodiversity loss, as well as impaired ecosystem functioning (Fortini et al., 2015; Vogiatzakis et al., 2016; Cramer et al., 2018).

Since AR5 more scientific literature has confirmed that human systems of small islands are highly vulnerable and will be impacted by changes in the natural systems. Increasing coastal risks associated with rising sea levels, TCs, droughts, marine heat waves and ocean acidification will impact on human settlements and infrastructure, health systems, water supply, economies and livelihoods, culture and heritage (*high confidence*). Additionally, biodiversity loss and impaired ecosystem provisioning services provided by terrestrial ecosystems are likely to impact on the human settlements, infrastructure, water and food security as well as land-based tourism in small islands. Climate-related migration was not covered in AR5, however, a new body of literature is emerging in response to increased vulnerability and risks to the human system of small islands.

15.2.2 Point of Departure on Adaptation Solutions

AR5 reported limited adaptation literature for most islands, but this literature has grown significantly since then, particularly on the range of adaptation responses used (Oppenheimer et al., 2019; Robinson et al, 2019; Weir, 2020). New studies reveal that among adaptation options, hard protection continues to play a central role in response strategies for densely populated urban low elevation areas, including island cities (Mycoo and Donovan, 2017; Robinson, 2017; Oppenheimer et al., 2019; SROCC Section 4.4.2.2, Box 4.1; Petzold and Magnan, 2019). Post AR5 studies show that in small islands climate-related migration is used increasingly (Kelman, 2015a and 2018; Albert et al., 2018; Gharbaoui and Blocher, 2016; Thomas and Benjamin, 2018; Magnan et al., 2019). Further, recent research revealed that relocation is a last resort response (McNamara and Des Combes, 2015; Jamero et al., 2017; Piggott-McKellar et al., 2019) and land reclamation is used to raise land to address SLR in urban areas of some islands (Hinkel et al., 2018). Several studies confirm that the technical limits, costs, benefits, co-benefits, drawbacks, economic efficiency, barriers and governance challenges vary by island and island groups (*high confidence*) (SROCC 4.3.3.1).

Since AR5, there is an enhanced understanding of the use of ecosystem-based adaptation (EbA) in small islands although there is *medium agreement* regarding the benefits of this approach (Doswald et al., 2014; Mycoo and Donovan, 2017; Nalau et al., 2018a) and there remains *low agreement* on the cost and long-term effectiveness of EbA, especially in the context of rapid SLR (Renaud et al., 2016; Morris et al., 2018; Oppenheimer et al., 2019).

Although the treatment of IK & LK was limited in AR5, since then new knowledge has increased and strongly supports the integration of IK & LK into adaptation while emphasising the enabling role of social capital in adaptive capacity (Parsons et al., 2017; Nalau et al., 2018b; Nunn and Kumar, 2018; Abram et al., 2019; Granderson, 2017; SROCC Cross-Chapter Box 3). Additionally, knowledge of community-based adaptation (CBA) has expanded. Recent studies suggest the need to focus on enabling community capabilities for responding to climate change threats, and where necessary, complement community knowledge, skills and resources, and political influence and problem solving abilities, with external assistance and government support (Warrick et al., 2017; McNamara et al., 2020; Nunn et al., 2017; Korovulavula et al., 2019).

Since AR5 there are more studies on the importance of gender (Pearse, 2017; Pearson et al., 2019) and the role of climate services and early warning systems in small islands (Martin et al., 2015; SPREP, 2016b), although knowledge regarding the effectiveness and value of climate services for adaptation remains limited (Vaughan et al., 2018). Climate change impacts on health, water and livelihoods in small islands and the importance of disaster risk reduction have also received more research attention post-AR5.

Adaptation limits have been studied more since AR5 and both the SR1.5 and the SROCC reinforced that vulnerable human communities, especially those in coral reef environments such as tropical small islands, may exceed adaptation limits well before the end of this century and even in a low greenhouse gas emission pathway (*high confidence*). Technical limits to hard protection are expected to be reached under high emission scenarios (RCP8.5) beyond 2100 (*high confidence*) and biophysical limits to ecosystem-based adaptation (EbA) may arise during the 21st century, but economic and social barriers arise well before the end of the century (*medium confidence*).

Evaluation of the efficacy of adaptation measures used in small islands is receiving more research attention since AR5. New research suggests that for all adaptation responses, evaluation of short-term success is essential, especially in terms of project appropriateness, inclusiveness and community engagement in design, implementation and monitoring and evaluation, but also issues of long-term sustainability of effective community-driven interventions (Nalau et al., 2018a; McNamara et al., 2020). Knowledge also has improved considerably on adaptation financing for small islands (Robinson and Dornan, 2017) and risk transfer mechanisms such as insurance (Lashley and Warner, 2013; Baarsch and Kelman, 2016; Handmer and Nalau, 2019; Sainsbury et al., 2018).

15.3 Observed Impacts and Projected Risks of Climate Change

Compared to larger landmasses, many climate change driven impacts and risks are amplified for small islands. This is due largely to their boundedness (surrounded by ocean), their comparatively small land areas, and often their remoteness from more populated parts of the world, which restricts the global connectivity of islands and makes global adaptation strategies both more costly and more challenging to implement (Nunn and Kumar, 2018). This is true on all types of islands (Figure 15.2).

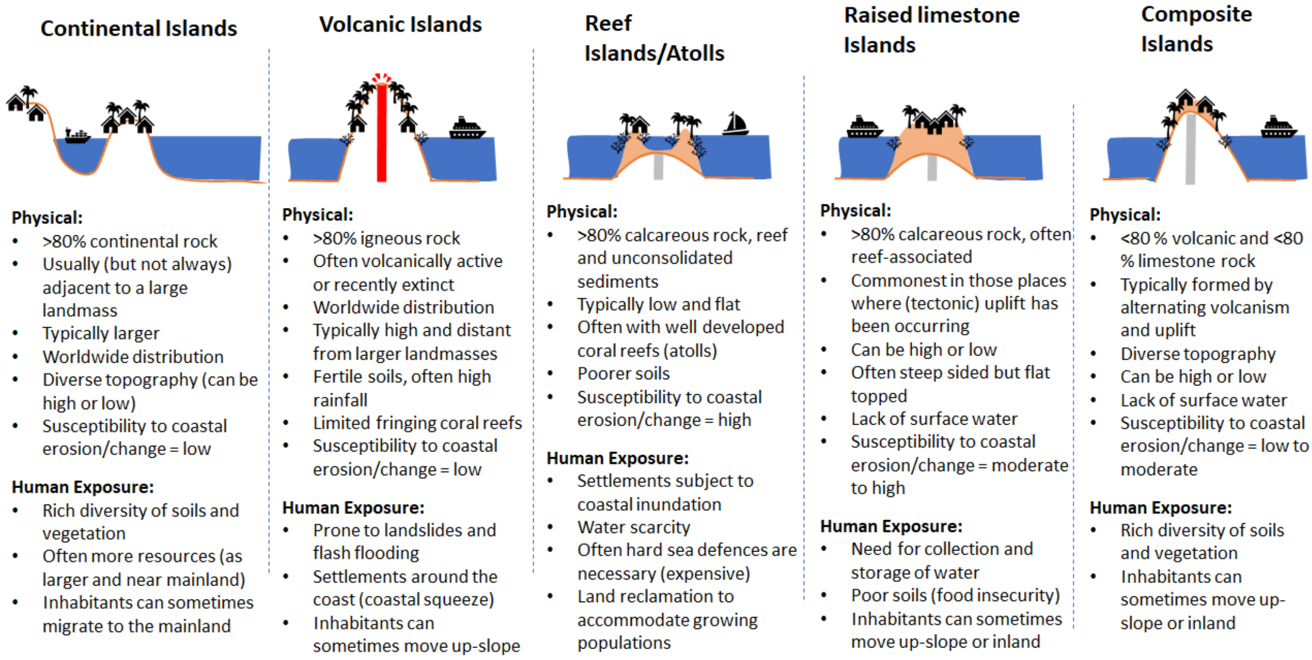

Figure 15.2: Classification of small island types - showing island characteristics, elements of human exposure and examples of adaptation options (based on Nunn et al. 2016; Kumar et al., 2018). [PLACEHOLDER FOR THE FINAL DRAFT: aesthetics will continue to be improved]

15.3.1 Synthesis of Observed and Projected Changes in the Physical Basis

There is increased evidence of warming in the small islands, particularly in the latter half of the 20th century (*high confidence*). A warming trend of 0.14°C decade^{-1} in the Western Pacific over the 1951 to 2015 period, and up to 0.28°C decade^{-1} in daily minimum temperatures in the Caribbean region over the 1961 to 2010 period are observed, as well as higher warming at the upper end of the temperature extremes (McGree et al., 2019; Stephenson et al., 2014). estimated the annual mean surface air temperature trend in the Mediterranean region over the 1960–2005 period to be 0.19–0.25 °C per decade and the Mediterranean Sea summer surface temperature has increased 1.15°C during the last three decades (Mariotti et al. 2015; Marba et. al, 2015). In the regions where inter-annual and decadal variabilities such as the El Niño-Southern Oscillation, North Atlantic Oscillation, Pacific Decadal Variability, Atlantic Multidecadal Variability are dominant, observation records indicate no significant long-term trends in rainfall (Jones et al., 2016; McGree et al., 2014, McGree et al., 2019). In the Mediterranean, annual mean precipitation trend has been estimated to be decreasing for the last century (Ducrocq et.al, 2016). Increasing trends in drought have been noted in many small islands (Herrera and Ault, 2017) although in the western Pacific these trends are generally not significant (McGree et al., 2016, McGree et al., 2019). For the period 1989–2009, increases in TC trends are seen in the North Atlantic and decreases in the Western North Pacific while modest trends in the South Pacific and the South Indian basins (both upwards). Trends have not been significant in the Eastern North Pacific and the North Indian basin due to insufficient data (Walsh et al., 2016). Tauvale and Tsuboki (2019) also show increasing TC activities in the Southwest Pacific over the past 48 TC seasons, from 1969–1970 to 2016–2017. There are marked regional variations in the rates of SLR (Esteban et al., 2019; Merrifield and Maltrud, 2011; Palanisamy et al., 2012). Over the past decades, Relative (that is, felt by people living at the coast) Sea-level Rise (RSLR) rates were greater than the rates of the GMSL rise (1.6–1.8 mm/year-1 over the 20th century; Church et al., 2013) in some small island regions, including the Lesser Antilles (3–5 mm/year-1 between 1993 and 2014 vs. 2.5-3 mm/year-1 in the Greater Antilles), the Western Tropical Pacific (~4-5 mm/year-1 since 1960 and 5–11 mm/year-1 since 1993) and some Indian Ocean sub-regions (e.g., ~4 mm/year–1 in Mauritius and ~6 mm/year-1 in Rodrigues) (Becker et al., 2019). Various factors, including interannual and decadal sea level variations associated with low frequency modulation of ENSO and the Pacific Decadal Oscillation (PDO) and vertical land motion contribute to both relative sea-level variations and related uncertainties. For example, in the Southwest and Central Pacific, where the dominant trend is a moderate subsidence (–1.1 mm/year-1), vertical land motion rates vary from an uplift of 1.6±0.3 mm/year–1 in the Federated States of Micronesia and in Tonga (where climate-induced RSLR is therefore partly offset by vertical uplift) to a subsidence of –5.4 ±0.3 mm/year-1 in Vanuatu and in Papua New Guinea (where subsidence is a greater contributor to RSLR than global climate change) (Ballu et al., 2019). As a result of the unequal contribution of vertical land motion to RSLR, small island sub-regions are unequally exposed to SLR and have more or less predictable SLR trends: predictability is much lower in tectonically active (e.g., Samoa, Tonga, Vanuatu, the Solomon Islands) compared to less active (e.g., French Polynesia, Tuvalu, Kiribati, Marshall Islands, Nauru) settings. Increased distant-source swell height from extra-tropical cyclones (ETCs) also contributes to extreme sea levels (ESLs) (Mentaschi et al., 2017; Vitousek et al., 2017). Together, these stressors increase ESLs and their impacts, including coastal erosion and marine flooding (See table 15.2).

There is *high confidence* that warming over small islands will *very likely* continue over the 21st century with increasing trends in the heat index (Angeles-Malaspina et al., 2018; Newth and Gunasekera, 2018). Projected increases in temperature can reach 2.8°C (RCP 8.5) by 2081–2100 relative to 1986–2005 (*very likely*) where equatorial regions will be relatively warmer (Harter et al., 2015). Projections indicate a small median increase of 2–3% in precipitation during the period 2081–2100 for RCP 2.6 to RCP 8.5 relative to 1986–2005 for many small islands due to spatial variability (Cantet et al., 2014; Timm et al., 2015). For example, drier conditions are projected in the Caribbean, Eastern South Pacific Ocean, Northern and Southern Atlantic Ocean, and Southern Indian Ocean, while wetter conditions over parts of the equatorial and Western Pacific, and Southern Ocean. In the Mediterranean, intense warming is almost certain and drying is *very likely* at the end of the 21st century. However, actual values and spatial distribution of precipitation changes remain uncertain as they are strongly model dependent (Paeth et al. 2017). Projections indicate that both extreme El Niño and extreme La Niña events could be twice as frequent, wherein most extreme La Niña events occur in the year following an extreme El Niño event, which will have impacts on extreme weather globally (Cai et al., 2014; Cai et al., 2015b). The trend in ENSO SST amplitude is also increasing before 2040, which becomes decreasing afterwards (Kim et al., 2014). By the late 21st century, tropical cyclones (TCs) are projected to be less frequent in the Western North Pacific, Eastern North Pacific, Bay of Bengal, Caribbean Sea and in the Southern Hemisphere, but more frequent in the subtropical Central Pacific and the Arabian Sea (Murakami et al., 2014; Bell et al., 2019). Furthermore, TCs in the Western North Pacific are projected to continue moving poleward (Kossin et al., 2016). Projections also indicate a decrease in the frequency of TCs during El Niño (La Niña) events in the Pacific at the end of the 21st century (Chand et al., 2017). However, the current capabilities of climate models, such as adequately representing variability in climate drivers including ENSO, and the topography of small islands, limit confidence in these future changes (Cai et al., 2015a; Harter et al., 2015; Guilyardi et al., 2016).

15.3.2 Trends in Exposure and Vulnerability

Most of the research that has been conducted on exposure and vulnerability from climate change demonstrate that many factors including those that are geopolitical and political, environmental, socio-economic and cultural, contribute to the increase in exposure and vulnerability of small islands (Barclay et al., 2019; Betzold, 2015; Borner et al., 2020; Douglass and Cooper, 2020; Hay et al., 2019; McCubbin et al., 2015; Duvat et al., 2017a; Otto et al., 2017; Salmon et al., 2019; Box 15.2). Furthermore, these factors exacerbate climate change induced problems such as marine flooding, storm surges, and coastal erosion faced by small islands. These problems continue to worsen, which put small islands at increasingly higher exposure and vulnerability to the impacts of climate change (see Box 15.2). There are multiple stressors that affect the vulnerability of small islands to climate change.

The problems of increasing exposure and vulnerability is most clearly seen in atoll islands. For example, in Tuvalu, economic stressors, food related stressors, and overcrowding make the islands much more vulnerable to climate impacts including changing precipitation patterns, ESLs, intense strong winds, warming SST and ocean acidification (McCubbin et al., 2015). Culturally, the people of Tuvalu are obligated to support extended family members, which is one of the main reasons for overcrowding and large households. However, the high number of people living in these households makes them more vulnerable to drought and because they generate a high demand for water, short-term water saving measures are insufficient. In addition, because of poverty, people do not have the resources to build more tanks to increase their capacity to store water (McCubbin et al., 2015).
In Majuro, Marshall Islands (Ford, 2012), Tarawa, Kiribati (Biribo and Woodroffe, 2013; Duvat, 2013), and the Maldives Islands (Kench, 2012; Naylor, 2015; Duvat and Magnan, 2019), population growth has led to land reclamation and the building of coastal protection structures, such as seawalls. Land reclamation and coastal protection structures negatively impact coastal and marine ecosystems, including reefs and mangroves, which compromise the protection services that they deliver to island communities through wave energy attenuation and sediment supply (Duvat et al., 2019). In addition, these construction activities disrupt natural coastal processes, thereby causing coastal erosion, which in turn increases the risk of flooding (Yamano et al., 2007; Duvat et al., 2017a). This becomes a cycle, with more land reclamation necessary to accommodate growing populations. Land reclamation requires stabilisation by protection structures, which then contributes to environmental degradation that increases the exposure and vulnerability of the communities living in these atolls (Duvat et al., 2017a).

The increasing exposure and vulnerability are not limited to highly populated atolls or capitals (see figure 15.3) (Kulp et.al, 2019). For example, even the sparsely populated atolls of the Marshall Islands, which are more rural in nature, have experienced an increase in exposure to coastal flooding (Owen et al., 2016). But not all atoll islands have similar levels of exposure; the lowest islands are the most flood-prone and will be the first to experience permanent inundation, while the higher islands will likely experience flooding overwash toward the middle of the 21st century (Owen et al. 2016).

Exposure to coastal risks is also high in mountainous islands because of settlement patterns; most infrastructure and settlements are concentrated in low-lying coastal areas (Box 15.2). For example, in Reunion Island, France, population growth led to more buildings, coastal roads and coastal protection structures being built near the shoreline, which in turn increased population exposure and vulnerability to coastal erosion and marine flooding (Magnan and Duvat, 2018). The clearing of the natural vegetation by residents, which reduced the natural buffer zone, increased population, buildings and infrastructure exposure. In the most populous islands of Rangiroa and Tikehau atolls, French Polynesia, the number of buildings located in flood-prone areas was multiplied by 2.1 to 4.6 between 1981 and 2013–14, as a result of rapid urbanisation (Magnan et al., 2018).

This also applies to terrestrial systems. In Kahua, Solomon Islands, population growth and desire for monetary prosperity are the underlying drivers of change to the community. The increase in population leads to an increase in the demand for food and building material, which in turn causes increased pressure on natural resources, which in the end undermines the ability of ecological systems to keep providing provisional and protection ecosystem services, thereby increasing community vulnerability (Fazey et al., 2011).

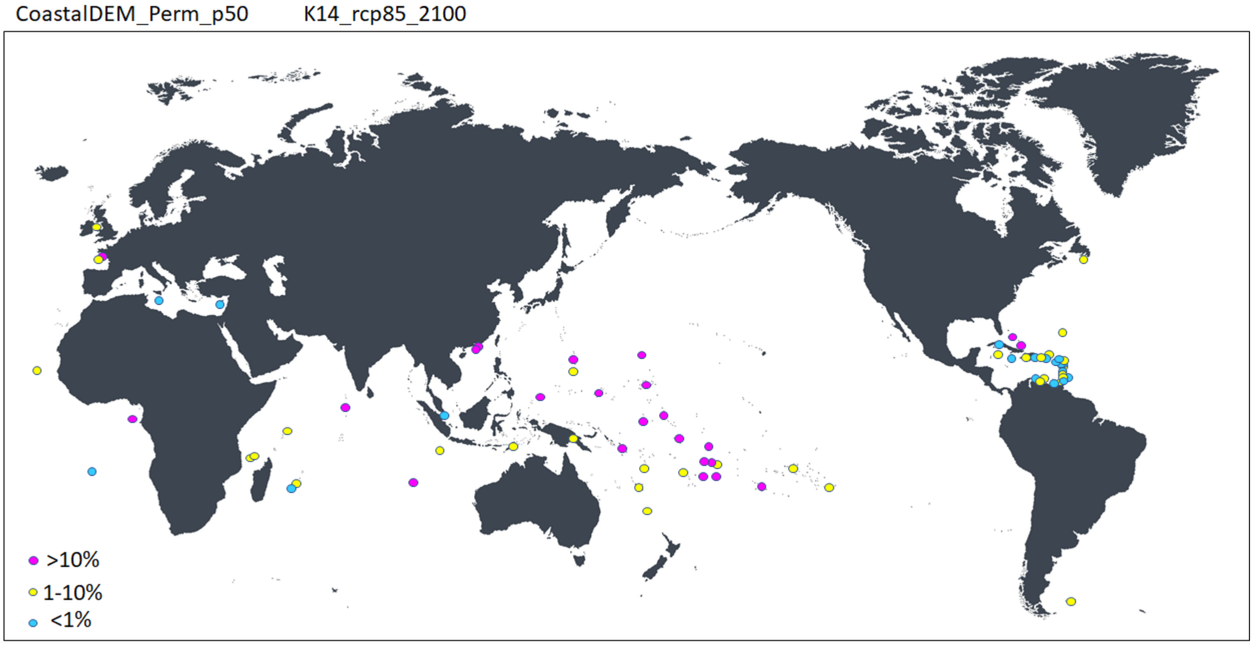

Figure 15.3: Percentage of current population in selected small islands occupying vulnerable land (the number of people on land that may be exposed to coastal inundation—either by permanently falling below MHHW, or temporarily falling below the local annual flood height) in 2100 under an RCP8.5 scenario (adapted from Kulp et al. 2019). [PLACEHOLDER FOR FINAL DRAFT: aesthetics will continue to be improved]

15.3.3 Observed Impacts and Projected Risks on Natural Systems

15.3.3.1 Impacts on Marine and Coastal Systems

15.3.3.1.1 Submergence and flooding of islands and coastal areas

Recent studies confirmed that observed ESL events causing extensive flooding generally resulted from compound effects, i.e. the combination of SLR (see Chapter 3, Section 3.2.2.2. and Cross-Chapter Box SLR in Chapter 3) with ETCs, TCs and tropical depressions (see WGI AR6 Sections 11.7.1 and 11.7.2), ENSO-related high-water levels associated with high or spring tide and/or local human disturbances amplifying impacts (*high confidence*). For example, the major flood events that occurred in 1987 and 2007 in the Maldives involved the combination of distant-source swells and high spring tides and the existing settlement patterns of reclaimed low-lying areas (Wadey et al., 2017) (Box 15.2). In the north-western Tuamotu atolls, French Polynesia, the 1996 and 2011 flood events were due to the combination of distant-source swells causing lagoon filling and the obstruction of inter-islet channels by construction activity by the population (Canavesio, 2019). In 2011, the flooding of the lagoon-facing coast of Majuro Atoll, Marshall Islands, resulted from the combination of high sea levels occurring during La Niña conditions and seasonally high tides (Ford et al., 2018). On high tropical islands, major floods often occurred during TC events, due to the cumulative effects of storm surge and river flooding, the impacts of which were exacerbated by human-induced changes to natural processes in urban areas. This occurred in 2014 (TC Bejisa) on the coral coast of Reunion Island, France, in a harbour area favourable to water accumulation (Duvat et al., 2016), and in 2015 (TC Pam) in Port Vila, Vanuatu, where urbanisation and human-induced changes to the river occurred (Rey et al., 2017). Likewise, urbanisation and river channelling exacerbated TC Irma-induced flooding in Saint-Martin, Caribbean region, in 2017 (Rey et al., 2019). Successive tropical depressions generating heavy rains also caused extensive flooding in Fiji in 2012 (Kuleshov et al., 2014) and flash flood in Solomon Islands in 2014 (Ha'apio et. al, 2019).

Reconstructions of past storm surges and modelling studies assessing storm surge risk similarly highlighted high variations of risk along island coasts, due to variations in exposure, topography and bathymetry (*high confidence*). For example, the storm surge caused by TC Oli (2010) on the mountainous island of Tubuai, French Polynesia, ranged from a few centimetres on the sheltered coast to 2.5 m on the exposed coast (Barriot et al., 2016). Investigating the contribution of reef characteristics to variations in wave-driven flooding on Roi-Namur Island, Kwajalein Atoll, Marshall Islands, Quataert et al. (2015) found that the coasts fronted by narrow reefs with steep fore reef slopes and smoother reef flats are the most flood-prone. Modelling studies assessing storm surge risk in Fiji (McInnes et al., 2014) and Samoa (McInnes et al., 2016) confirmed the influence of coast exposure and water depth on risk distribution. In Apia, Samoa, Hoeke et al. (2015, p. 1117) found "differences in extreme sea levels in the order of 1 m at spatial scales of less than 1 km." and estimated (p. 1131) that a "1 m SLR relative to constant topography increases wave energy reaching the shore by up to 200% during storm surges." These studies reaffirmed the main control exerted by SLR on ESL events and associated storm surges compared to ENSO (*high confidence*). A study simulating how SLR will affect flooding on Fatato Island, Funafuti Atoll, Tuvalu, under the annual storm and swell conditions qualified the conclusions of previous studies, demonstrating that a "keep-up" reef (realistic under RCP4.5) would dissipate 72% of wave energy and thereby stressed the importance of including "natural reef morphology feedbacks" in simulations (Beetham et al., 2017, p.1009) (See Figure 15.4).

Larger-scale studies confirmed that projected changes in the wave climate superimposed on SLR will rapidly increase flooding in small islands, despite highly contrasting exposure profiles between ocean sub-regions (*high confidence*) (Shope et al., 2016; Mentaschi et al., 2017; Shope et al., 2017; Vitousek et al., 2017). In particular, Vitousek et al. (2017) showed that even a 5-10 cm additional SLR (expected for ~2030–2050) will double flooding frequency in much of the Indian Ocean and Tropical Pacific and consequently challenge the habitability of atoll islands and coastal areas, while TCs will remain the main driver of (rarer) flooding in the Caribbean Sea and Southern Tropical Pacific. Mentaschi et al. (2017) projected a decrease in wave energy and related flood risk in the Caribbean region and Tropical Pacific north to ~5°S, a slight increase in the Pacific south to~5°S, and no significant change in the Indian Ocean. They also found a marked increase in wave energy in the southern temperate zone and north-eastern Pacific that will increase ETC-induced flooding in Pacific and Indian Ocean islands. Some Pacific atoll islands, which already experience major floods, will likely undergo annual wave-driven flooding over their entire surface from the 2060s–2070s (Storlazzi et al., 2018) to 2090s (Beetham et al., 2017) under RCP8.5, although future reef growth may delay the onset of flooding (*limited evidence, low agreement*) (Beetham et al., 2017).

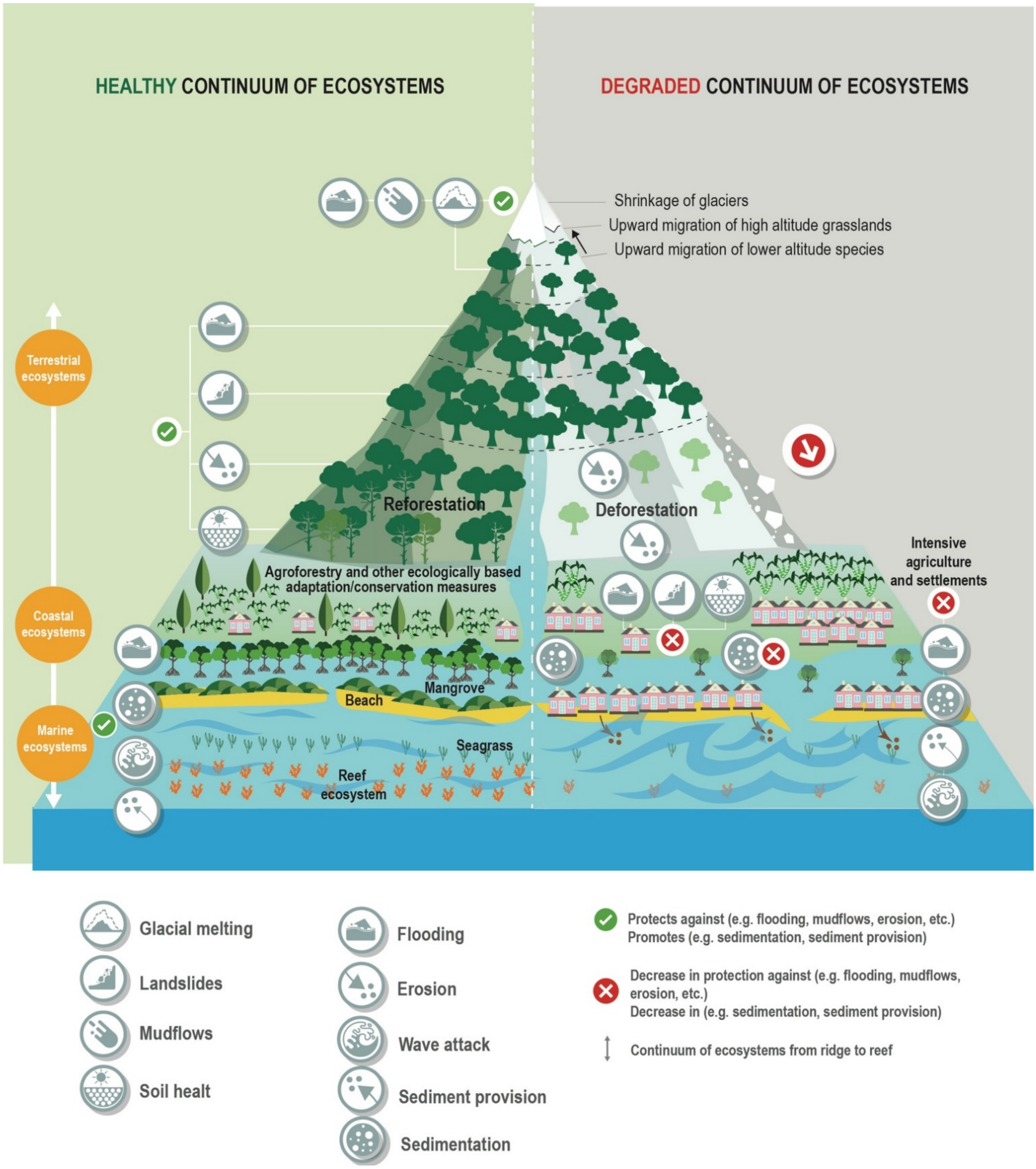

Figure 15.4: Ridge-to-reef interrelated protection services delivered by ecosystems on small islands. On small islands, terrestrial, coastal and marine ecosystems are interconnected and interdependent, with each ecosystem contributing towards maintaining the health of the others. Together, these ecosystems provide protection services against natural hazards (including flooding, erosion, landslides, mudflows, glacial melting and sedimentation) to human populations living on islands. As a consequence, the degradation of one or more of these ecosystems significantly reduces the protection services provided by this continuum of ecosystems. Conversely, the protection or restoration of one or more of these ecosystems also provides benefits to the other ecosystems and enhances the protection services provided to island inhabitants. See Box CCP1.1 in Cross-Chapter Paper 1 for more details

15.3.3.1.2 Reef island destabilisation and coastal erosion

Over the past three to five decades, and even in regions where the rate of SLR was higher than the global mean, atoll islands had the capacity to maintain their land area by adjusting vertically to sea level (*robust* *evidence, high agreement).* A literature review including 709 Indian and Pacific Oceans islands showed that 73.1% of these islands were stable in area, while respectively 15.5% and 11.4% increased and decreased in area over this period (Duvat, 2019). The rates of change correlated with island size, but not with SLR rates, suggesting that the impact of SLR on island land area is obscured by other climate drivers and human disturbances on some islands (*high confidence*) (Kench et al., 2015; McLean and Kench, 2015; Duvat, 2019). Despite important gaps in knowledge on coastal erosion in high tropical islands, recent studies confirmed increasing shoreline retreat and beach loss over the past decades, mainly due to TC and ETC waves and human disturbances (*high confidence*), e.g., in the Caribbean region (Anguilla, Saint-Kitts, Nevis, Montserrat, Dominica and Grenada; Cambers, 2009), and Pacific (Hawaii (Romine and Fletcher, 2013); Tubuai, French Polynesia (Salmon et al., 2019) and Indian Oceans (Anjouan, Comoros (Ratter et al., 2016).

Despite storm-induced erosion prevailing on some islands, recent studies reaffirmed the contribution of TC and ETC waves to coastal area vertical building through massive reef-to-island sediment transfer *(high confidence*) (Figure 15.4). For example, TC Ophelia (1958) and Category 5 TC Fantala (2016), which respectively eroded the islands of Jaluit Atoll, Marshall Islands (Ford and Kench, 2016), and Farquhar Atoll, Seychelles (Duvat et al., 2017c), also contributed to island and beach expansion across various timescales. Likewise, tropical depressions can have constructional effects through reef-to-island sediment transfer associated with sediment accumulation in coastal and inland areas, as reported on Fakarava Atoll, French Polynesia, in 2017 (Duvat et al., 2020). On Saint-Martin/Sint Maarten and Saint-Barthélemy, the 2017 hurricanes, which caused marked shoreline retreat at most beach sites, also allowed beach formation and beach ridge development along some natural coasts (Pillet et al., 2019; Duvat et al., 2019). Similarly, El Niño and La Niña were involved in rapid and highly contrasting shoreline changes (*high confidence*), including reef island accretion in the Ryukyu Islands, Japan (Kayanne et al., 2016), beach shifts on Maiana and Aranuka Atolls, Kiribati (Rankey, 2011), and beach erosion on Hawaii, USA (Barnard et al., 2015). These contrasting shoreline responses were respectively due to coral reef degradation from past bleaching events providing material to islands, wave directional shifts, and increased wave energy. The role of bleaching events in increasing short-term sediment generation in atoll contexts was confirmed by a study conducted on Gaafu Dhaalu Atoll, Maldives, which reported an increase of sediment production from ~0.5 kg CaCO3 m–2 yr-1 to ~3.7 kg CaCO3 m-2 yr-1 between 2016 (pre-bleaching) and 2019 (bleaching + 3 years) as a result of an increase in parrotfish biomass and Halimeda spp. abundance (Perry et al., 2020).

There is *high confidence* that SLR and increased wave height will affect the geomorphology of reef islands (Baldock et al., 2015; Costa et al., 2019; Tuck et al., 2019) and coastal systems on high islands (Grady et al., 2013; Barnard et al., 2015; Bindoff et al., 2019), and that the responses of these systems will highly depend on changes in boundary conditions (wave regime and direction, exposure to extreme events, impacts of ocean warming and acidification on supporting ecosystems, bathymetry and reef flat roughness) and the degree of disturbance of their natural dynamics by human activities (Smithers and Hoeke, 2014; Baldock et al., 2015; McLean and Kench, 2015; Bheeroo et al., 2016; Ratter et al., 2016; Shope et al., 2016; Duvat et al., 2017b; Kench and Mann, 2017; Kench et al., 2018; Oppenheimer et al., 2019; Duvat et al., 2019). Reef islands and beach and beach-dune systems that are not disturbed by human activities are expected to migrate lagoon-ward (Webb and Kench, 2010; Albert et al., 2016; Beetham et al., 2017; Costa et al., 2019; Tuck et al., 2019) and landward (Bindoff et al., 2019), respectively, and to also experience changes in configuration, volume and elevation (Kench and Mann, 2017; Tuck et al., 2019). In contrast, small reef islands and narrow coastal systems affected by human disturbances will increasingly be at risk of disappearance due to SLR (Albert et al., 2016; Garcin et al., 2016; KR7 in Box 15.1), enhanced sediment loss occurring either during extreme events (Duvat et al., 2019) or as a result of human-induced gradual beach degradation (*high confidence*), as reported in Hawaii (Romine and Fletcher, 2013), Puerto Rico (Jackson et al., 2012), Sicily (Anfuso et al., 2012), and Takuu, Papua New Guinea (Mann and Westphal, 2014). Coastal erosion is also projected to increase with SLR in the Mediterranean Sea, e.g., in the Aegean Archipelago, Greece (Monioudi et al., 2017), and Mallorca, Spain (Enríquez et al., 2017).
The maintenance of atoll islands' habitability over the 21st century is controversial (Cross-Chapter Box DEEP in Chapter 17). While some studies supported that these islands will retain habitable land as a result of vertical island adjustment to SLR through sediment reworking (McLean and Kench, 2015; Beetham et al., 2017; Kench et al., 2018; Le Cozannet et al., 2018; Tuck et al., 2019; Masselink et al., 2020), other studies assuming rapid reef ecosystem degradation (Hughes et al., 2017a; Perry and Morgan, 2017; Perry et al., 2018) projected a loss of habitability due to increased flooding (Giardino et al., 2018; Storlazzi et al., 2018)

and an intensification of pre-existing erosional and accretional patterns (Shope et al., 2017; Shope and Storlazzi, 2019).

15.3.3.1.3 Impacts on Marine and Coastal Ecosystems

Loss of marine and coastal biodiversity and ecosystem services is a Key Risk in small islands (see KR2 in Box 15.1). Coral bleaching is the most visible and widespread manifestation of a climate change impact on coastal ecosystems in most small islands but is far from being the only one (Spalding and Brown, 2015; Hoegh-Guldberg et al., 2017; IPCC, 2018; Bindoff et al., 2019, Section 5.3.4). Severe coral bleaching, together with declines in coral abundance have been documented in many small islands, especially those in the Pacific and Indian Oceans, e.g., Guam, Vanuatu, Fiji, Chagos, Comoros, Mauritius, Seychelles, and the Maldives (Perry and Morgan, 2017; Hughes et al., 2018) (Box 15.2). During severe bleaching events, not only do reefs lose a significant amount of live coral cover, but they also experience a decrease in growth potential, so reef erosion surpasses reef accretion (Perry and Morgan, 2017). Median return time between pairs of severe bleaching events has diminished steadily since 1980 and is now only 6 years (e.g., Hughes et al., 2017b; Hughes et al., 2018) and is often associated with ENSO events (*high confidence*). Modelling of both bleaching and ocean acidification effects under future climate scenarios suggested that some Pacific small islands (e.g., Nauru, Guam, Northern Marianas Islands) will experience conditions that cause severe bleaching on an annual basis before 2040 and that 90% of the world reefs are projected to experience conditions that result in severe bleaching annually by 2055 (van Hooidonk et al., 2016) (*medium confidence*).

Satellite data and local field studies at 3351 sites in 81 countries including small islands show that not all coral reefs are equally exposed to severe temperature stress events, and even comparable coral reefs show local and regional variation and species-specific responses (Sully et al., 2019). There is great variability in terms of sensitivity of corals to climate change, as also demonstrated in the Comoros Archipelago (Cowburn et al., 2018) and globally (Sully et al., 2019). It has been hypothesised that low-latitude tropical reefs bleached less because: (i) of the geographical differences in species composition, (ii) of the higher genotypic diversity at low latitudes, and (iii) some corals were pre-adapted to thermal stress because of consistently warmer temperatures at low latitude prior to thermal stress events (Sully et al., 2019). However, latitudinal variation was not reported in other global surveys of coral bleaching occurrence (Hughes et al. 2017a, b, Donner et al. 2017, McClanahan et al. 2019). Ainsworth et al. (2016) and Ateweberhan et al. (2013) showed that coral bleaching can be mitigated by pre-exposure to elevated temperatures. Regionally, recovery is also highly variable. While some reefs in the Seychelles and Maldives were shown to recover to pre-disturbance levels after previous bleaching events (Pisapia et al., 2017) (Box 15.2), other reefs underwent seemingly permanent regime shifts toward domination by fleshy macro algae (Graham et al., 2015), or collapse of carbonate budgets, and thus the capacity of reefs to sustain vertical growth under rising sea levels (Perry and Morgan, 2017).

Despite their vital social and ecological value, substantial declines in seagrass communities have been documented in many small islands, including Fiji (Joseph et al., 2019), Reunion Island (Cuvillier et al., 2017), Bermuda, Cayman Islands, US Virgin Islands (Waycott et al., 2009), Federated States of Micronesia, and Palau (Short et al. 2014), but attribution of such declines to climatic influences remains weak (*low confidence*). Seagrasses face a multitude of threats including physical abrasion and direct damage caused by rapidly growing human populations, declines in water quality, and coastal erosion (Short et al., 2016). Experimental studies have shown increased mortality, leaf necrosis, and respiration when seagrasses are exposed to higher than normal temperatures (Hernan et al., 2017). As such, seagrass meadows growing near the edge of their thermal tolerance are at risk from rising temperatures (Pedersen et al., 2016). In the Mediterranean, seagrass meadows are already showing signs of regression, which may have been aggravated by climate change (*high confidence*). Chefaoui et al. (2018) attempted to forecast the distribution of two seagrasses in the future, including around the islands of Cyprus, Malta, Sicily and the Balearic Islands. Under the worst-case scenario, *Posidonia oceanica* was projected to lose 75% of suitable habitat by 2050. Conversely, it has been suggested that seagrasses could actually benefit from an increase in anthropogenic carbon dioxide because of increased growth and photosynthesis (Waycott et al., 2011; Repolho et al., 2017). However, Collier et al. (2017) argued that when faced with increased heat waves, thermal stress will rarely be offset by the benefit of elevated CO2 and therefore that the widespread belief that seagrasses will be a 'winner' under future climate change conditions seems unlikely *(low confidence*).

Since 2011, the Caribbean region has been experiencing unprecedented influxes of the pelagic seaweed Sargassum. These extraordinary sargassum 'blooms' have resulted in mass strandings throughout the Lesser Antilles, with significant damage to coastal habitats, mortality of seagrass beds and associated corals (van Tussenbroek et al., 2017), as well as consequences for fisheries and tourism. Whether or not such events are related to long-term climate change remains unclear, however it has been suggested that the influx may be related to strong Amazon discharge, enhanced West African upwelling, together with rising seawater temperatures in the Atlantic (Wang et al., 2019; Oviatt et al., 2019) (*low confidence*). Since 2011, the Pacific atoll nation of Tuvalu has also been affected by algal blooms, the most recent being a large growth of *Sargassum* on the main atoll of Funafuti, this phenomenon has been related to anthropogenic eutrophication and high seawater temperatures (De Ramon N'Yeurt and Iese, 2015).

Mangroves face serious risks from deforestation and unsustainable coastal development (Gattuso et al., 2015). Large-scale die-offs (Lovelock et al., 2015; Duke et al., 2017) including around many small islands, suggest that mangrove face increased risks from climate change. Mangrove seaward edge retreat has been demonstrated in American Samoa and Tikina Wai, Fiji, and this has been attributed to long-term SLR or tectonic subsidence (Gilman et al., 2007; Ellison and Strickland, 2015). Inundation-related mortality of mangroves could, in theory, be mitigated if mangrove substrates can "keep up" with rising sea level by accretion. However, at the majority of mangrove locations studied worldwide, the current rate of SLR has been shown to exceed the soil surface elevation gain, including in Pacific islands (Lovelock et al., 2015). Mangroves with low tidal range and low sediment supply could be submerged as early as 2070, in northern Papua New Guinea and the Solomon Islands (Krauss et al., 2014; Lovelock et al., 2015) (*medium confidence*). TCs can cause extensive damage to mangroves (Short et al., 2016). While immediate physical damage is often considerable, trees can sometimes recover by re-foliating, re-sprouting or regenerating (Kauffman and Cole, 2010). Examples of substantive mangrove recovery include the regrowth of trees in the Bay Islands of Honduras following Hurricane Mitch (October 1998) (Fickert, 2018) and in the Nicobar Islands, India, following the December 2004 Indian Ocean Tsunami (Nehru and Balasubramanian, 2018).

Sandy beaches are an important ecosystem in small islands, with high socio-economic as well as ecosystem services values (Barbier et al. 2011). These ecosystems are impacted by climate change, with the biggest impact from sea level rise and increase in temperature (*high confidence*) (Butt et al., 2016; Ranasinghe, 2016; Scapini et al., 2019; Varela et al., 2018; Vousdoukas et al., 2020). Nesting turtles (Butt et al., 2016; Varela et al., 2018) and other macrofauna will be affected by climate change, leading to local extirpations for some while others will have to survive in new niches but there is limit to how macrofauna can respond to climate change (Scapini et al., 2019). Sea level rise is driving coastal recession, which would lead to disappearance of about half of sandy beaches worldwide by the end of this century (Vousdoukas et al., 2020).

Turtles and many seabirds nest just above the high-water mark on sandy beaches or among sand dunes, but TCs, rising seas, storm surges and heavy rainfall as well as inappropriate coastal development can erode beaches resulting in damage to nests and eggs (Fuentes et al., 2010). Beach-nesting turtle populations are projected to become threatened in many small islands, e.g., Bonaire - Netherlands Antilles, Bioko Island - Equatorial Guinea, northern Cyprus, Raine Island - Australia (Fish, 2005; Veelenturf et al., 2020; Varela et al., 2018; Pike et al., 2015), whereas other populations such as in the Cape Verde Islands are anticipated to remain remarkably resilient (Perez et al., 2016).

15.3.3.1.4 Ecosystem Services

Intact coral reefs (Woodhead et al., 2019), seagrass meadows (Hejnowicz et al., 2015), and mangroves (UNEP, 2014b; Friess, 2016) provide a variety of ecosystem services that are key to island communities, including provisioning (e.g., timber, fisheries, aquaculture), regulating (e.g., coastal protection, carbon storage, filtering of pollutants), cultural and supporting community resilience (Förster et al., 2019). If coastal ecosystems are degraded and lost, then the benefits they provide are also lost (Oleson et al., 2018; Förster et al., 2019; Brodie et al., 2020). In small islands where the risk of loss to ecosystem services is high (Cross-Chapter Box DEEP in Chapter 17), many of these ecosystem services cannot be easily replaced (*medium confidence*). The beneficial role that coral reefs play in coastal protection through wave attenuation, and therefore enhancing climate resilience in small islands, has been extensively studied (e.g., Elliff and Silva, 2017; Harris et al., 2018; Reguero et al., 2018). Based on 69 case studies worldwide, Narayan et al. (2016) estimated that coral reefs, mangroves, and seagrass reduced wave height by 70%, 31% and 36%, respectively

(Figure 15.4) and thus offer an essential role in protecting human lives and livelihoods (*high confidence*). Similarly, Ferrario et al. (2014) conducted a global meta-analysis (including many small islands such as Mayotte, Hawaii, Guam, the Maldives, the US Virgin Islands) and found that coral reefs reduce wave energy by 97% and that reef crests alone dissipated most of this energy (86%). Post-TC studies have provided further evidence for the protection services offered by coastal ecosystems. On some Caribbean islands (e.g., Saint-Martin/Sint Maarten, Saint-Barthélemy) where the dense indigenous vegetation belt was preserved, the vegetative structure buffered the waves of TCs Irma and José (2017), reducing the extent of marine inundation and shoreline retreat to a 30 m-wide coastal strip against values >160 m in deforested areas (Duvat et al., 2019; Pillet et al., 2019). By contrast, the destruction of mangrove ecosystems can accelerate coastal erosion, as exemplified by observations made in the Pohnpei Island group, Micronesia (Nunn et al., 2017).

As corals, mangroves and seagrasses disappear, so do fish and other dependent organisms that directly benefit industries such as tourism and fisheries (Cinner et al., 2016; Graham et al., 2015) (*high confidence*). These impacts are sometimes exacerbated by tropical storms (Sainsbury et al., 2018), which physically destroy habitats and hence the resources upon which coastal fisheries depend. There is *high confidence* that climate change impacts, together with local human disturbances, will continue to denude coastal and marine ecosystem services in many small islands with serious consequences for vulnerable communities (Elliff and Silva, 2017; Bindoff et al., 2019).

15.3.3.2 Impacts on Freshwater Systems

Freshwater ecosystems on small islands are exposed to dynamic climate impacts and are considered to be among the most threatened on the planet (Settele et al., 2014; IPCC, 2018; Butchart et al., 2019; Key Risk 3 in Box 15.1). Hoegh-Guldberg et al. (2019) estimated that with a warming of 1.5°C or less, freshwater stress on small islands would be 25% less as compared to 2.0°C. While some island regions are projected to experience substantial freshwater decline, an opposite trend is observed for some western Pacific and northern Indian Ocean islands (Holding et al., 2016; Karnauskas et al., 2016). Island topography and ecophysiology influence water storage capacity and rainfall response potential on high volcanic and granitic islands with small and steep river catchments generally responding more rapidly (Dunn et al., 2018). On these types of islands, freshwater ecosystems are often closely connected with coastal spaces, and changes in freshwater supply from river systems have direct implications for salinity and sediment loads (Yang et al., 2015; Zahid et al., 2018) (*high confidence*).

SLR undermines the long-term persistence of freshwater-dependent ecosystems on islands (Goodman et al., 2012) and is one of the greatest threats to the myriad of goods and services these environments provide (Mitsch and Hernandez, 2013; Cross-Chapter Box DEEP in Chapter 17). Hoegh-Guldberg et al. (2019) posit that as sea level rises, managing the risk of salinisation of freshwater resources on small islands will become increasingly important. On Roi-Namur, Marshall Islands, Storlazzi et al., (2018) found that the availability of freshwater is impacted by the compounding effect of SLR and coastal flooding. In other Pacific atolls, Terry and Chui (2012) showed that freshwater resources could be significantly affected by a 0.40-m SLR. Similar impacts are anticipated for some Caribbean countries with worst-case scenario (RCP8.5) indicating a 0.5-m SLR by the mid-century (2046-2065) and 1-m SLR by the end-of-century (2081–2100) (Stennett-Brown et al., 2017). Such changes in SLR could increase salinity in estuarine and aquifer water, affecting ground and surface water resources for drinking and irrigation water (Mycoo, 2018a) across the region (*high confidence*). SLR also affects groundwater quality (Bailey et al., 2016), salinity (Gingerich et al., 2017), and water-table height (Masterson et al., 2014). Salinisation of exposed soils impacts microbial communities (Zheng et al., 2017), carbon quality (Ruiz-Fernandez et al., 2018), and soil quality in general.

The influence of climate change spans several variables for atoll islands with multiple, interacting forces that exacerbate impacts on freshwater ecosystems (Connell, 2016). On atoll islands, groundwater and freshwater supply are highly susceptible to climate impacts (Warix et al., 2017). Analysis of groundwater resources on Roi-Namur, in the Marshall Islands, reveals that the extent of salinisation of fresh groundwater lenses varies with the scale of the overwash. Alsumaiei and Bailey (2018) estimated an 11-36% reduction in the fresh groundwater lens volume of the small atoll islands (area < 0.6 km²) of the Maldives due to SLR. Small overwash events lead to saline conditions that last for a month while severe rainfall events during the wet season can salinize freshwater for up to 3 months (Oberle et al., 2017). These findings suggest likely implications for long term impacts of climate change on groundwater resources of atolls. On inhabited islands of the outer atolls of the Marshall Islands, available groundwater exceeds freshwater demand by more than an order of magnitude (Warix et al., 2017). Similarly, on Nauru, the characterisation of groundwater aquifers revealed the presence of only a few drought resilient thin freshwater lenses, taking place in low conductivity sandy deposits, unexpectedly next to the seashore (Alberti et al., 2017).

Projected changes in aridity are expected to impose freshwater stress on many small islands, especially SIDS *(high confidence*). Karnauskas et al. (2018) found that these changes are likely to have pronounced impacts across the Caribbean. These changes are congruent with drought risk projections for Caribbean SIDS (Lehner et al., 2017; Taylor et al., 2018) and aligned with observations from the Shared Socio-Economic Pathway (SSP) 2 scenario, where a 1°C increase in temperature (from 1.7°C to 2.7°C) could result in a 60% increase in the number of people projected to experience a severe water resources stress in 2043–2071, (Schewe et al., 2014; Karnauskas et al., 2018). Analysis from a new high-resolution drought atlas for the Caribbean spanning 1950–2016 indicates that the region-wide 2013–2016 drought was the most severe event during the multi-decadal period (Herrera and Ault, 2017). In Puerto Rico, the island experienced 80 consecutive weeks of moderate drought, 48 weeks of severe drought and 33 weeks of extreme drought conditions between 2014 and 2016 (Álvarez-Berríos et al., 2018). Further analysis by Herrera et al. (2018) suggested that anthropogenic warming accounted for ~15–17% of the 2013-2016 drought's severity and ~7% of its spatial extent.

In Puerto Rico, multi-model mean projected total flow decreases by 49–88% of historical amounts from the 1960s to the 2090s for the high emissions scenarios (Van Beusekom et al., 2016) and by 39–79% for the low emissions scenarios. The intensification and displacement of the North Atlantic Subtropical High (NASH), which is projected for this century, can decrease Caribbean and South-eastern American rainfall on seasonal and annual timescales is projected to cause a decrease in precipitation over the Bahamas (van Hengstum et al., 2018) that can have implications for freshwater supply. In the Mediterranean region, changes in average climate conditions will increase groundwater stress notably because of a 10–30% decline in freshwater resources (Koutroulis et al., 2016) *(medium confidence)*. For example, analysis of annual and seasonal streamflow data on the island of Mallorca shows a decreasing trend during spring and summer, with flows reduced by up to 17% in some basins (Garcia et al., 2017).

15.3.3.3 Impacts on Terrestrial Biodiversity Systems

Despite encompassing approximately two percent of the Earth's terrestrial surface, oceanic and other islands (with high endemicity) are estimated to harbour substantial proportions of existing species (e.g., ~ 25% extant global flora, ~ 12% birds and ~10% mammals) (Alcover et al., 1998; Wetzel, 2013; Kumar and Tehrany, 2017). Islands also have higher densities of critically endangered species, hosting just under half of all species currently considered to be at risk of extinction (Spatz et al., 2017), hence making the loss of terrestrial biodiversity and related ecosystem services a Key Risk (KR1) in small islands (Box 15.1). As such, impacts from developing synergies between changing climate and other natural and anthropogenic stressors (Cross-Chapter Box DEEP in Chapter 17) could lead to disproportionate changes in global biodiversity. The most prominent of these drivers for terrestrial ecosystems of small islands include: rising sea levels, increasing intensities of extreme events together with human activities — especially continuing/accelerating habitat destruction, degradation and fragmentation, and the introduction of invasive alien species (IAS) (Tershey et al., 2015). When further coupled with characteristic small island traits such as spatial and other resource limitations, such synergies play a critical role towards increasing the vulnerability of these insular ecosystems. This is likely to hinder the adaptation response of terrestrial biota ─ increasing the risk of biodiversity loss and in turn, impairing the resilience capacity of ecosystem functioning and services (Heller and Zavaleta, 2009; Ferreira et al., 2016; Vogiatzakis et al., 2016) (*high confidence*).

Current observations of insular species response to climate change generally report on geographic range shifts and reductions for both species and vegetation associations as well as the resulting impacts on local ecology (Virah-Sawmy et al., 2016; Vogiatzakis et al., 2016; Koide et al., 2017; Maharaj et al., 2019). Some of these include changes in plant and animal phenology such as for the common Mediterranean island species *Quercus ilex* and *Ficus carica* in addition to resulting community alterations. Species have been shifting greater distances to access not only suitable climate conditions but also by association, suitable breeding conditions and seasonal food. Examples include: migratory birds such as *Coturnix coturnix* now having earlier spring arrival dates in the Mediterranean compared to 6 decades ago; a significantly higher abundance of thermophilic species found at tree-line summits on the mountains of Mediterranean islands and also the increased mortality of the iconic *Argyroxyphium sandwicense* as result of warmer drier trends at Hawaiian high altitudes (Krushelnycky et al., 2013; Taylor and Kumar, 2016; Vogiatzakis et al., 2016).

Recorded alterations of ecological interactions include increased competition, changes to migratory routes (Harter et al., 2015) and mismatches between species, such as increased pathogen attacks on Mediterranean forest species (Vogiatzakis et al., 2016). Also, in some areas of Madagascar there has been increased vulnerability to fire, due to the replacement of succulents by less fire resilient species (Virah-Sawmy et al., 2016). Further, the low functional redundancy of island ecosystems implies a comparatively higher proportion of keystone species than continents, many of them being endemics (Harter et al., 2015), with potentially unpredictable system consequences due to climate-induced ecological changes. For example, Caribbean land crabs have been observed to alter their food intake as a response to drying conditions (McGaw et al., 2019) and Aldabra giant land tortoises have reduced their activity in response to increasing temperature and decreasing precipitation (Falcon and Hansen, 2018), thus changes in both these ecosystem engineers are of potential consequence for seed dispersal, among other ecological functions.

There have been numerous projections of climate change impacts on island species and ecosystems, although the caveats identified about data uncertainty in AR5 remain largely unchanged. The majority of studies modelling geographical range changes of small island species, to even the most optimistic 21st century climate change scenarios imply a reduction in climate refugia (Table 15.1 and Box CCP1.1 in Cross-Chapter Paper 1) via projected strong shifts, reductions or even complete losses of climatic niches for some species (e.g., (Maharaj and New, 2013; Fortini et al., 2015; Struebig et al., 2015b) (*high confidence*). Because of the high proportion of global endemics hosted within small islands, the resulting increased extinction risk of these species could lead to disproportionate losses in global biodiversity (Harter et al., 2015) (m*edium to high confidence*).

SLR has been projected to impact the terrestrial biodiversity of low-lying islands and coastal regions via large habitat losses both directly (e.g., submergence) and indirectly (e.g., salinity intrusion, salinisation of coastal wetlands and soil erosion) at even the 1m scenario (*medium to high confidence*). However, these impacts vary depending on the islands' topographical differences. In a study of SLR impacts on insular biodiversity hotspots, Bellard et al. (2013a) reported that the Caribbean islands, Sundaland and the Philippines were projected to suffer the most habitat loss while the East Melanesian islands were predicted to be the least affected. The most threatened of these, the Caribbean, was projected to have between 8.7% to 49.2% of its islands are entirely submerged respectively from 1°m to 6°m SLR (Bellard et al., 2013a). However, many current projection studies consider marine flooding directly and seldom incorporate other indirect impacts such as increased habitat losses from horizontal erosion loss, increased salinity levels, tidal ranges and extreme events. As such, these projections are considered to be conservative, underestimating the extent of habitat loss to terrestrial biodiversity (Bellard et al., 2013b).

Resulting marine flooding is expected to destroy habitats of coastal species, particularly range-restricted coastal and/or single-island endemics (including many already listed as *at least* threatened by the International Union for Conservation of Nature [IUCN]) within the limited terrain on atoll islands. These species have limited opportunities to accommodate such direct impacts of climate change apart from shifting inland towards the hinterland or to other neighbouring atolls which might have favourable habitat. However, fragmentation of habitat due to anthropogenic activity may hinder migration further inland, while shifting to neighbouring islands is not a viable option due to the expanse of ocean between islands (Bellard et al., 2013b; Wetzel et al., 2013; Kumar and Tehrany 2017) (*high confidence*). Additionally, migratory birds, which use small islands such as those of atolls for stopovers or breeding/nesting sites, are projected to become impacted. Within the Mediterranean and Caribbean, significant losses to coastal wetlands - critical habitat for migratory birds has already been observed, with further significant habitat losses, redistribution and changes in quality being projected across island systems such as the Bahamas (Caribbean) and Sardinia (Mediterranean) (Wolcott et al., 2018; Vogiatzakis et al., 2016).

Additionally, indirect impacts of SLR may potentially result in equal or more biodiversity loss than direct impacts (*medium confidence*). The relocation of displaced coastal human population and associated intensive agriculture and urban areas inland to the hinterland may result in greater biodiversity loss than direct impacts – especially on islands with large coastal populations and urban centres (Wetzel et al., 2012; Bellard et al., 2013b). Given the dense population of insular hotspots (~31.8% of existing humans within ~ 15.9% of inhabited global land area) and the fact that many islands have large proportions of human populations living within coastal regions, it has been suggested that immense impacts from such relocations should be factored into projection and adaptation studies (Wetzel et al., 2012).

Tropical island systems are uniquely vulnerable to extreme weather events such as TCs, due to their small size, unique ecological systems and often low socio-economic capacity (Box 15.2, Goulding et al., 2016; Schütte et al., 2018) (*high confidence*). Growing evidence suggests high resilience of forest habitats (Keppel et al., 2014; Luke et al., 2016), especially within intact forest ecosystems to hurricanes and cyclones (Goulding et al., 2016). Within the Caribbean in particular, high resilience of forest types have been associated with the *present* intensity and return rate of hurricanes over the last 150 years. While initial damage can be high, relatively fast recovery rates have been reported for both floral and faunal components of these ecosystems (Cantrell et al., 2014; Shiels et al., 2014; Monoy et al., 2016; Richardson et al., 2018).

It should however be underscored that these relatively fast recovery rates are associated with the *present* intensity and return rate of TCs. They do not reflect the impacts of increasingly intense events such as Hurricane Dorian (2019), which resulted in the almost complete inundation of several low-lying islands of the Bahamas from storm surges. Severe weather events affecting islands not only have direct effects on biodiversity, but also interact synergistically with other stressors, such as increased invasion by non-native species and land use change. For example, TCs within Papua New Guinea resulted in the destruction of subsistence gardens, which led inhabitants to clear forest areas for new farming areas and for harvesting of timber resources to rebuild (Goulding et al., 2016).

The most recent projections suggest that TC intensity is predicted to increase as climate continues to change (Marler, 2014; Taylor and Kumar, 2016; Walsh et al., 2016). There are too few projections available to suggest potential future response trends of these ecosystems to this increased intensity, however it seems plausible that present resilience capacities may be adversely impacted (Marler, 2014) (*medium confidence*). Further, the potential for stressors such as forest fragmentation/degradation or IAS combining with these increasingly intense events to cause precipitating ecosystem cascades is a real concern (Goulding et al., 2016).

Continued high rates of habitat loss, fragmentation and degradation have been reported for many small islands as natural habitat continues to be cleared to facilitate increasing demands upon natural resources from rising human populations, agriculture, urbanisation, unsustainable tourism, overgrasing and fires. This increases the vulnerability of ecosystems within especially oceanic islands — where isolation has given rise to high levels of endemism but simple biotic communities with low functional redundancy (Box CCP1.1 in Cross-Chapter Paper 1). There is *high confidence* that climate change may exacerbate the effects of this habitat loss upon the biodiversity of these islands as upslope shifts of range-restricted, dispersal-limited and poorly competitive species, confined within narrow latitudinal (and decreasing altitudinal) gradients, are hindered by fragmented and degraded landscapes (e.g., Struebig et al., 2015a). This may ultimately increase the risk of multiple extinctions, negatively impacting upon global biodiversity levels (Taylor and Kumar, 2016) (*high confidence*).

IAS are considered to be the second greatest cause of biodiversity loss worldwide (Bellard et al., 2014), and analyses of historical and current threats indicate that IAS and disease have been the primary drivers of insular extinctions in modern history (Bellard et al., 2016). Impacts of IAS on islands are projected to increase with time due to synergies between climate change and other traditional drivers such as increasing global trade, tourism, agricultural intensification, over exploitation and urbanisation (Bellard et al., 2014; Russell et al., 2017). Changing climate conditions may not necessarily increase the rate of IAS introductions but is expected to improve chances of IAS establishment via (i) altering IAS transport and introduction mechanisms, (ii) increasing the impacts and distributions of existing IAS and (iii) altering the effectiveness of existing control strategies (Hellmann et al., 2008; Russell et al., 2017). These are likely to enhance IAS impacts on islands including: restructuring of ecological communities leading to declines and extinctions/extirpations in flora and fauna, habitat degradation, declining ecosystem functioning, services and resilience, and in extreme cases, potential community homogenisation (Russell and Blackburn, 2017;

IPBES, 2018) (*high confidence*). Given the high degree of endemicity within oceanic islands and their associated vulnerabilities, such exacerbation by changing climate pose a serious threat to decreasing global biodiversity (van Kleunen et al., 2015) (*medium to high confidence*).

There is also *high confidence* that compared to continents, terrestrial IAS are disproportionately prevalent on islands (almost three-quarters of global species currently threatened by IAS and disease are found on islands) and also generate stronger impacts (e.g., within alpine ecosystems of high islands) than on continents (Bellard et al., 2014; Bellard et al. 2016; Frazier and Brewington, 2019). Russell and Blackburn (2017) suggested a correlation between small island size and increased numbers of IAS. SIDS within the Indian Ocean and in particular the Pacific SIDS region were reported to have significantly more IAS (*medium confidence*), while the Caribbean and Atlantic SIDS have fewer numbers but faster accumulation of IAS. Finally, while there have been developments in the eradication of IAS on islands (Jones et al., 2016a), there is sparse evidence and hence assessment of the degree to which measures designed to prevent introduction and to manage invasion pathways and establishment have been successful.

Table 15.1: Climate Refugia Burning Embers. Percentage of selected islands classified as refugia for biodiversity at increasing levels of warming. There is a burgeoning literature on the extinction-mitigation potential of highly heterogeneous landscapes within islands and associated local climate micro-refugia (e.g., Médail, 2017; Le Roux et al., 2019). This table demonstrates the difficulty of protecting lands which might be 'more resilient' to climate change under increasing levels of warming and current land use practices (Price et al. submitted Mapping the Planet for conservation) – by illustrating how much potential refugia space may already have been lost due to habitat conversion. For each island or island chain, there are two columns-sets, the first column-set is the percentage of the island, or island chain, that is a refugia based on *climate alone*, assuming all areas are equally suitable. The second column-set illustrates the percent of natural land projected to be a climate refugia based on the ESA CCI 2015 satellite derived land-cover data (treating bare rock/sand, ice and water as no data, and agricultural urban land cover as being unsuitable). This second column-set provides a measure of *how much of potential refugia 'space' might have already been lost owing to habitat conversion*. Colour coding: > 50% of the land as refugia – white; 30%-50% of the land yellow; 17%-30% of the land red and <17% dark red. These thresholds were chosen based on the current CBD 2020 (Aichi) targets of 17%, proposed or inspirational targets of 30% of land protected, and suggested goals of setting aside "half-for-nature". Results were derived from the current and future projected distributions of ~130,000 terrestrial fungi, plants, invertebrates and vertebrates (Warren et al. 2018a).;with refugia classified as areas remaining climatically suitable for >75% of the species modelled (Warren et al. (2018b Implications)and Price et al. (submitted Biodiversity Losses)). Projections are based on the mean impacts from 21 CMIP5 climate model patterns with no dispersal. The modelled spatial resolution was 20km - which was subsequently elevationally downscaled to 1km following the methods in Price et al.(Submitted increasing risks). Warming levels were originally derived from the RCP 2.6, 4.5, 6 and 8 scenarios and subsequently interpolated on a cell-by-cell level to the temperatures listed. Details of the modelling undertaken can be found in Warren et al. (2018a).

[INSERT TABLE 15.1 HERE]

15.3.4 Observed Impacts and Projected Risks on Human Systems

15.3.4.1 Island Settlements and Infrastructure

The impact of sea-level changes on the settlements and infrastructure of small islands is proportionately greater than larger land masses in part because of their longer coastlines per unit of land area (Kumar et al., 2018). In small islands, many settlements and infrastructure are highly exposed to climate-related hazards as they tend to be located on the coast, making the risk of destruction of such human settlements, buildings and physical facilities a Key Risk (KR5 in Box 15.1). For example, major settlements of the insular Caribbean are located on the coast and the majority are port cities (Cashman and Nagdee, 2017). A similar settlement pattern exists in the Pacific (Dowling and McGuirk, 2016). Further, high density coastal urban development is a common trend as documented in the cases of the Pacific such as Fiji and Kiribati (Duvat et.al. 2013), and in the Caribbean, Jamaica and Trinidad (Mycoo and Donovan, 2017; Mycoo et al., 2018b).

Small islands face several climate change-related hazards which place their resources, population and assets at serious risk (Hay et al., 2019). Their settlements have been impacted by climate risks such as SLR, heavy precipitation events, TCs, and storm surges. Studies by Rasmussen et al. (2018) explain that comparatively small changes in mean sea-level can result from large increases in the frequencies of ESL events and therefore increase the risk of coastal flooding. Coastal flooding has affected major settlements in the Caribbean, Pacific, and Indian Ocean. Flooding occurs in coastal settlements such as Port of Spain (Trinidad and Tobago), Georgetown (Guyana) (Mycoo, 2014b; Mycoo 2018a), Viti Levu (Brown et al., 2017) and other parts of Fiji's coast (McAneney et al., 2017) and Male' (Maldives) (Wadey et al., 2017). In the Seychelles, as a result of new patterns of rainfall distribution, increasing coastal development, blocked drainage and land reclamation, flash flooding lasting two to three days occurred in Mahé in 2019 (Etongo, 2019).

Shoreline erosion, lowland flooding and groundwater salinisation have also been documented for numerous non-urban coastal island settlements. On Vanua Levu (Fiji) and the reef islands off the coast of Choiseul (Solomon Islands) and erosion has occurred in villages (Albert et al., 2016; Barbier, 2015; Charan et al., 2017). In the future, many areas of small islands may become uninhabitable well before the time of permanent inundation (Storlazzi et al., 2018; Shope and Storlazzi, 2019). As an example, in Fiji it is noted that lowland areas are likely to become less readily habitable as sea level rises causing shoreline retreat and frequent lowland flooding in such places (Martin et al., 2018).

The risk of flooding in small islands is expected to be higher in the future because of the high percentage of population living in the Low Elevation Coastal Zone (coastal areas below 10 metres of elevation) (Kulp et al., 2019) (See Figure 15.3). Approximately 14 million persons in the Caribbean currently live below 3 metres elevation and 22 million below 6 metres (Cashman and Nagdee, 2017). Approximately 50% of the population of the Pacific resides within 10 km of the coast but this increases to 97% when Papua New Guinea is excluded. In the Solomon Islands and Vanuatu over 60% of the population live within 1 km of the coast and in Fiji 27% of the population live 1 km from the coast (Andrew et al., 2019). Excluding PNG, 90% of Pacific Islanders live within 5 km of the coast (Andrew et al., 2019). The majority of people living in the Pacific region reside in the LECZ (Andrew et al., 2019). Furthermore, four coral atoll countries (Kiribati, Tuvalu, Marshall Islands and Tokelau) and many populated atolls and reef islands in other Pacific islands (e.g., Carteret atoll in PNG, Ontong Java in Solomon Islands, and Ouvea in New Caledonia) are located entirely within the LECZ (Andrew et al., 2019). In the Indian Ocean, 80% of the land area of the Maldives is below sea level making it one of the world's most vulnerable countries to climate change. A 1-meter high increase in sea level could inundate two-thirds of the country's land (Ahmed and Suphachalasai, 2014).

In the Caribbean and Pacific, a growing percentage of the population live in informal settlements which have been impacted by risks, such as SLR, coastal and riverine flooding, ETCs and landslides (Butcher-Gollach, 2015; Chandra and Gaganis, 2016; Mycoo, 2017). In both Caribbean and Pacific settlements, land use planning and building guidelines exist but enforcement is difficult and results in the proliferation of informal settlements (Butcher-Gollach, 2018; Mecartney and Connell, 2017; Mycoo, 2017; Mycoo 2018b; Trundle et al., 2018). Anthropogenic pressures resulting from the growing numbers of persons living in informal settlements in small islands are expected to exacerbate impacts of these risks (Mycoo and Donovan, 2017).

Key infrastructure to support the increasing population inhabiting coastal urban areas is often located in risk-prone areas of small islands (Mycoo, 2017). For example, approximately 57% of built infrastructure in the Pacific is located in risk-prone coastal areas (Kumar and Taylor, 2015). Most Pacific Island Countries have ≥50% of their infrastructure within 500 metres of the coast. In the case of Kiribati, Marshall Islands and Tuvalu, >95% of their infrastructure is located in this area (Andrew et al., 2019). The increasing intensity of category 4 and 5 TCs in recent years has already caused far more damage to coastal areas, including infrastructure, than SLR (Eckstein et al., 2018; Nalau et al., 2017). Examples of intense TCs, which have already severely impacted small islands, include TC Winston in Fiji in 2016, TC Maria in Dominica in 2017 and TC Dorian in the Bahamas in 2019. Losses per unit of GDP resulting from TC damage totalled US$1.7 billion in Dominica with nearly all its infrastructure destroyed (Eckstein et al., 2018). The Fijian government estimated destruction from TC Winston amounted to US$0.9 billion and accounted for more than 20% of current GDP (Cox et al., 2018; World Bank, 2017). Many small islands already face high flood damages relative to their GDP specifically through TCs (Cashman and Nagdee, 2017). Under the SLR Expected

Annual Damage (EAD) this damage can account for a higher percentage of GDP in 2100, as highlighted in AR5 (Wong et al., 2014).

Based on SLR projections, it is predicted that in the Caribbean almost all port and harbour facilities will suffer inundation in the future (Cashman and Nagdee, 2017). In Jamaica and St Lucia, SLR and ESLs are projected to threaten transport system infrastructure at 1.5°C unless further adaptation is undertaken (Monioudi et al., 2018). Climate-driven impacts on island infrastructure have been experienced for some time and are likely to become more widespread and more economically challenging in the next few decades (Robinson, 2017).

15.3.4.2 Human Health and Well-being

Small islands face disproportionate health risks associated with changes in temperature and precipitation, climate variability, and extremes (Cross-Chapter Box INTERREG in Chapter 16; Key Risk 4 in Box 15.1). Climate change is projected to increase the current burden of climate-related health risks (Weatherdon et al., 2016; Ebi et al., 2018; Schnitter et al., 2019). Health risks can arise from exposures to extreme weather and climate events, including heatwaves; changes in ecological systems associated with changing weather patterns that can result, for example, in more disease vectors, or in compromised safety and security of water and food; and exposures related to disruption of health systems, migration, and other factors (McIver et al., 2016; World Health Organisation (WHO), 2018; Mycoo, 2018a).

Extreme weather and climate events, particularly TCs and floods regularly cause injuries, deaths and increase in some diseases (Schütte et al., 2018) (Box 15.1). For example, category 5 TC Winston hit Fiji on 20 February 2016. During the national state of emergency (7 March and 29 May 2016), indicator-based surveillance recorded 34,113 cases of the nine syndromes among 326,861 consultations in a population of about 900,000; 48% of cases were influenza-like illnesses, 30% were acute watery diarrhoea, and 13% were suspected cases of dengue. There also were 583 cases of Zika-like illness (1.7% of all cases) and two large outbreaks of viral conjunctivitis (total of 880 cases).

Mortality rates following TC Maria in Puerto Rico were higher for individuals living in municipalities with the lowest socioeconomic development and for men 65 years of age or older (Santos-Burgoa et al., 2018); this excess risk persisted for at least a year after the event. Heat-related mortality and risks of occupational heat stress in small island states are projected to increase with higher temperatures (Hoegh-Guldberg et al., 2018; Mendez-Lazaro et al., 2018).

Tropical and sub-tropical islands face risks from vector-borne diseases, such as dengue fever and the Zika virus. El Niño events can increase the risk of diseases such as Zika virus by increasing biting rates, decreasing mosquito mortality rates, and shortening the time required for the virus to replicate within the mosquito (Caminade et al., 2017). Combining disease prediction models with climate indicators that are routinely monitored and evaluation tools can be used to generate probabilistic dengue outlooks in the Caribbean and early warning systems (Oritz et al., 2015; Lowe et al., 2018). Projections suggest that more individuals will become at risk of dengue fever by the 2030s and beyond because of an increasing abundance of mosquitos and larger geographic range (Ebi et al., 2018). A study in New Caledonia found that projected increases in mean temperature could double the dengue burden by 2100 (Teurlai et al., 2015). In the Caribbean, Saharan dust transported across the Atlantic can interact with Caribbean seasonal climatic conditions to become respirable and contribute to asthma presentations at the emergency department (Akpinar-Elci et al., 2015) (See Table 15.1).

Ciguatera fish poisoning (CFP) is a foodborne illness caused by toxins that can contaminate reef fish; symptoms can remain for a few weeks to months. CFP occurs in tropical and subtropical regions, primarily in the South Pacific and Caribbean, but wherever reef fish are consumed (Traylor and Singhal, 2020). In the Caribbean Sea, increasing ocean temperatures are expected to stabilize or slightly decrease the incidence of CFP because of shifts in species distribution of dinoflagellates associated with CFP (Kibler et al., 2015). CFP is endemic in the Cook Islands and French Polynesia, where incidence is associated with sea surface temperature anomalies (Zheng et al. 2020). In the Canary Islands, tropicalization trends due to climate change are expected to increase CFP occurrence in the future (Rodriguez et al., 2017).

Climate driven changes in the ability to access locally grown or harvested food, either through environmental degradation or changes in extreme event magnitude and/or frequency, can increase dependence on imported food and increase rates of non-communicable diseases (Springmann et al., 2016; WHO, 2018). Projections suggest that local food accessibility could be reduced by 3.2% in the low- and middle-income countries of the Western Pacific (including the Philippines, Fiji, Papua New Guinea, Solomon Islands, and other Pacific islands) by 2050, with approximately 300,000 associated deaths possible (Springmann et al., 2016). A climate change-related 20% decline in coral reef fish production in some Pacific island countries by 2050 could exacerbate the population growth-driven gap between volume of fish needed for food security and fish available through sustained harvest (Bell et al., 2013). TCs also can affect treatment and care for people with non-communicable diseases, including exacerbation or complications of illness and premature death (Ryan et al., 2015).

Heavy reliance on aquifers and rainwater harvesting in small islands, particularly atolls, coupled with overcrowding, population growth, and contamination increase the risk of waterborne disease (McIver et al., 2014). For example, seasonal rainfall in Kiribati is associated with waterborne disease (such as diarrhoea, cholera, and typhoid fever). Future projections indicate increases in the number of days of heavy rainfall by 2050, suggesting future increases in risk in heavily populated areas (McIver et al., 2014). Damage to water and sanitation services can cause disease outbreaks, as occurred when outbreaks of cholera occurred in Haiti following TC Matthew (Raila and Anderson, 2017; Hulland et al., 2019).

Many major health care facilities in small island states are located in exposed coastal areas and have limited ability to provide health services during disasters when services are most needed (WHO, 2018). For example, in Vanuatu, TC Pam in 2014 severely damaged two hospitals, 19 health care centres, and 50 healthcare dispensaries in 22 affected islands (Kim et al., 2015). A Smart Hospital Initiative in the Caribbean focuses on improving hospital resilience, strengthening structures and operations, and installing green technologies to reduce energy consumption and provide energy autonomy during extreme events and disasters (https://www.paho.org/en/health-emergencies/smart-hospitals).

15.3.4.3 Water Security

Climate change impacts on freshwater systems frequently exacerbate existing pressure, especially in locations already experiencing water scarcity (Section 15.3.3.2 and Cross-Chapter Box INTERREG in Chapter 16; Schewe et al., 2014; Holding et al., 2016; Karnauskas et al., 2016), making Water Security a Key Risk (KR3 in Box 15.1) in small islands. Small islands are usually environments where demand for resources related to socio-economic factors such as population growth, urbanisation and tourism already place increasing pressure on limited freshwater resources. In many small islands, water demand already exceeds supply. For example, in the Caribbean, Barbados is utilising close to 100% of its available water resources and St. Lucia has a water supply deficit of approximately 35% (Cashman, 2014). On many Mediterranean islands, water demand regularly outstrips supply as a result of low average precipitation coupled with increasing water demand from economic activities such as irrigated agriculture and tourism (Hof et al., 2014; Papadimitriou et al., 2019).

Population growth plays a strong role in projected future water stress (Schewe et al., 2014). Combining projected aridity change (fractional change compared to historical climatology) with population projections derived from SSP2, shows that the SIDS with high projected population growth rates are expected to experience the most severe freshwater stress by 2030 under a 2°C warming threshold scenario (Karnauskas et al., 2018). For several countries (e.g., Guinea-Bissau and Belize), increasing aridity change is a prominent exacerbating factor, but for others (e.g., the Solomon Islands and Comoros) population growth is the main factor. A 1°C increase in temperature (from 1.7°C to 2.7°C) could result in a 60% increase in the number of people projected to experience a severe water resources stress in 2043–2071 (Schewe et al., 2014; Karnauskas et al., 2018). Research on Jamaica concluded that the ability of rainwater harvesting to meet potable water needs between the 2030s and 2050s will be reduced based on predicted shorter intense showers and frequent dry spells (Aladenola et al., 2016).

The Caribbean and Pacific regions have historically been affected by severe droughts (Peters, 2015; FAO, 2016; Barkey and Bailey, 2017; Paeniu et al., 2017; Trotman et al., 2017; Anshuka et al., 2018) with significant physical impacts, as well as negative socio-economic outcomes. The highest land disturbance percentages have coincided with major droughts in Cuba (de Beurs et al., 2019). Drought has been shown to have an impact on rainwater harvesting in the Pacific (Quigley et al., 2016) and Caribbean (Aladenola et al., 2016), especially in rural areas where connections to centralised public water supply have been difficult. Increasing trends in drought are apparent in the Caribbean (Herrera and Ault, 2017) although trends in the western Pacific are not statistically significant (McGree et al., 2016).

Areas where a freshwater lens is thinner are most likely to be impacted by multiple climate stressors, and these areas tend to be in coastal zones where populations are likely to be most concentrated (Holding et al., 2016). In Barbados, where groundwater is relied upon for food production, urban use, and environmental needs, higher food prices are expected in the future if informed land use management and integrated water resources policy implementation are not put in place to manage groundwater in the short term, even with modest climate change threats (Gohar et al., 2019).

15.3.4.4 Fisheries and Agriculture

Fisheries provide small islands with opportunities for economic development, revenues, food security and livelihoods (Bell et al., 2013). For some islands in the Pacific, up to 40% of their revenues derive from taxes on sales of fishing licenses and for some, up to 25% of their GDP comes from industrial fishing (Bell et al., 2013). Additionally, fish play an important role in meeting food security in many islands. In the Pacific, fish protein is estimated to make up 50-90% of animal protein consumption in rural areas, and 40-80% in urban areas (Hanich et al., 2018). Many studies of future fisheries productivity in a changing climate suggest that yields will fall as a result of productivity reductions (fewer smaller fish), species extinction, and migration (Nurse, 2011; Asch et al., 2018; Hanich et al., 2018; Robinson et al., 2019).

Asch et al. (2018) provided future projections for biodiversity, and fisheries maximum catch potential in Pacific Island countries and territories under climate change. These authors concluded that 9 of 17 Pacific Island entities (Kiribati, Tuvalu, the Cook Islands, the Marshall Islands, the Federated States of Micronesia, the Solomon Islands, Papua New Guinea, Niue, and Guam) could experience ≥ 50% declines in maximum catch potential by 2100 relative to 1980–2000 under RCP 8.5. These changes were associated with rates of local species extinction of > 50% in many regions as fishes and invertebrates decreased in abundance or migrated away to regions with conditions more suitable to their particular bio-climate envelope. Similar projections have now been performed for all countries worldwide, including Pacific, Caribbean, Atlantic, Mediterranean and Indian Ocean small islands (Cheung et al., 2018). The small islands that show the largest anticipated decrease in fisheries maximum catch potential by the end of the century (according to a RCP 8.5 scenario) included Nauru, Kiribati, Tuvalu, Palau, the Federated States of Micronesia, Tokelau, São Tomé and Príncipe, whereas some other small islands such as Easter Island (Chile), Pitcairn Islands (UK), Bermuda, and Cabo Verde may actually witness increases in fish catch potential (Cheung et al., 2018). Using improved vulnerability assessment methods, Monnereau et al. (2017) showed that for the fisheries sector, small island states are generally more vulnerable to climate change impacts compared to the least developed countries or coastal states. Small island fisheries can be severely impacted by extreme events such as tropical cyclones, however access to resurgent pelagic fisheries can also help to alleviate immediate food insecurity pressures in some circumstances (Pinnegar et al., 2019).

Projected impacts of climate change on agriculture and fisheries pose serious threats to dependent human populations (Hoegh-Guldberg et al., 2019; Ren et al, 2018), making the risk caused to livelihoods a Key Risk in small islands (KR8 in Box 15.1). On small islands, despite biophysical commonalities (e.g., size and isolation), differences in economic status and level of dependence on agriculture and fisheries produce dynamic climate impacts (Balzan et al., 2018). Climate change is impacting agricultural production in small islands through slow-onset stressors such as rising average temperatures, shifting rainfall patterns, sea level rise and extreme events like TCs. For example, TC Pam, a Category 5 cyclone, devastated Vanuatu in 2015 and caused losses and damages to the agriculture sector valued at USD 56.5 million and TC Winston in 2016 incurred losses and damages on the agriculture sector in Fiji valued at USD 254.7 million (Iese et. al, 2020a). Losses and damage in agriculture often led to people eating imported processed foods affecting their diet and nutrition (Emily et. al, 2020). Small Islands' communities are also witnessing the indirect effects of the covid-19 pandemic on agricultural systems (Hickey and Unwin, 2020). In Fiji and Solomon Islands, households appear to have responded positively to Covid-19 by increasing food production from home gardens, particularly root crops, vegetables and fruits and households are also consuming what they are producing. However, the limited diversity of agriculture production and reduced household incomes are contributing to low diet diversity (Iese et al., 2020b). Bell and Taylor (2015) assessed the effects of climate change on specific sectors of agriculture in the Pacific islands region and found that, by 2090, staple food crops of taro, sweet potato, and rice are expected to sustain moderate to high impact. Of export crops, coffee is expected to sustain the most significant impact due largely to increased temperatures in the highland areas of Papua New Guinea – a high production area (Bell et al., 2016). Livestock is an important protein source in small islands and is particularly vulnerable to changes in temperature through heat stress (Bell and Taylor, 2015; Lallo et al., 2018). With the concentration of island people along (often reef-fringed) coasts, there is a comparatively large dependence on nearshore marine foods and coastal agricultural systems (Ticktin et al., 2018).

In the Caribbean, additional warming by 0.2°–1.0°C, could lead to a predominantly drier region (5%–15% less than present-day), and a greater occurrence of droughts (Taylor et al., 2018) along with associated impacts on agricultural production and yield in the region (Hoegh-Guldberg et al., 2019; Gamble 2017). Rhiney et al. (2018) conducted crop suitability modelling on several commercially important crops grown in Jamaica and found that even an increase less than + 1.5°C could result in a reduction in the range of crops that farmers may grow. Farmers on small islands have utilised Indigenous knowledge systems built on local ontology and cosmovision to sharpen their sensitivity to environmental conditions (Shah et al., 2018). However, the projected climate changes across the region could undermine climate-sensitive agricultural livelihoods and exacerbate food insecurity challenges (McCubbin et al., 2017).

The projected climate impacts on island agroecosystem services could accentuate a myriad of social and ecological risks. For example, Arnold et al. (2018) studied the pollinator population on farms across three Caribbean countries and found that without proactive farm management practices, the projected impacts of climate change on drought patterns is a major threat to cocoa pollination services. In general, many tropical island agroforestry crops are completely dependent on insect pollination and it is therefore important to understand the climatic drivers of changing conditions related to pollinator abundance. Coastal agroforest systems in small Pacific islands are important to national food security but native biodiversity is rapidly declining (Ticktin et al., 2018). Such biodiversity loss from traditional agroecosystems has been identified as one of the most serious threats to food and livelihoods security in SIDS (UNEP, 2014a). Additionally, while coastal-lowland salinization and more-frequent flooding attributable to SLR have impacted coastal agriculture on some islands (Wairiu, 2016; Cruz and Andrade, 2017), stronger TCs can sometimes shock island terrestrial food production to the point that it subsequently needs reconfiguration (Mertz et al., 2010; Duvat et al., 2016; Chakrabarti et al., 2017). Calls to conserve associated environments and, more broadly, to make terrestrial food production on islands more resilient to climate-driven shocks underscore concern about future food security (Connell, 2013; de Scally, 2014). Implicit in the latter is reversing the decades-long loss of local and traditional knowledge about food production in many island societies and incorporating it into future strategies (Janif et al., 2016; Mercer et al., 2014b).

15.3.4.5 Economies

Small-island economies vary greatly in their nature, history/trends, and viability under a changed climate. As elsewhere, few small island economies are overseen by governments that are adequately prepared for the economic impacts of climate change over the next few decades (Connell, 2013; Hay, 2013). In particular, the lack of diversity that characterizes most small-island economies means they are especially vulnerable to global (climate-driven) shocks (Cross-Chapter Box DEEP), be these the impacts of extreme events or more gradual longer-term change, which makes the maintenance of traditional mechanisms for coping with such shocks in many island societies all the more important (Granderson, 2017; Wilson and Forsyth, 2018; Nunn and Kumar, 2019). As a result, the risk from climate change to economies constitutes a Key Risk (KR8 in Box 15.1) in small islands.

Many island environments have been commercially exploited by external interests for much of their recent history. This is especially common for timber, the wholesale removal of forests, especially on tropical islands, exposing land to heavy rain that leads to denudation and increases lowland sedimentation (Eppinga and Pucko, 2018; Wairiu, 2017). Negative aspects of both processes will be exacerbated by climate change, demonstrating the practical need for reforestation in many island contexts (Thomson et al., 2016). Some small-island economies are sustained by extractive industries such as mining, creating dependencies that lead to their environmental impacts being downplayed (Tserkezis and Tsakanikas, 2016; Shepherd et al., 2018). It is important to address these impacts as they will add to negative impacts of climate change (Clifford et al., 2019).

Many small-island economies are sustained by tourism and have invested heavily in associated infrastructure and capacity building (Cannonier and Burke, 2018). Some rural island communities have become dependent on tourism to the point that it would be difficult to revert to subsistence living (Lasso and Dahles, 2018). Coast-focused (beach-sea) tourism in island contexts is already being impacted by beach erosion, elevated high SST causing coral bleaching, and associated marine-biodiversity loss, as well as more intense TCs (Tapsuwan and Rongrongmuang, 2015; Parsons et al., 2018; Wabnitz et al., 2018). The Covid-19 pandemic travel disruption significantly affected Caribbean islands tourism sector by reducing incomes that would have been used to enhance climate resilience (Sheller, 2020). Many tourism interests downplay the impacts and future risks from climate change (Shakeela and Becken, 2015), a position that may be borne out by sustained/rising demand for small island vacationing in some locales (Katircioglu et al., 2019). A way forward is for island tourism to emphasize its low-carbon and sustainable attributes, and to encourage smaller-scale eco-friendly holiday opportunities (Lee et al., 2018).

Given the high cost of imported goods, especially foodstuffs, larger island jurisdictions are striving to transform their economies to favour locally produced or locally constituted materials that employ local people and reduce their cost of living. The exposure of this component of island economies varies, yet manufacturing/commercial operations are usually found in the lowest-lying areas, often on reclaimed lands. This makes them especially vulnerable to rising sea level, part of a larger issue around the disproportionate exposure of infrastructure on small islands to climate change (Fakhruddin et al., 2015; Kumar and Taylor, 2015).

It is challenging to disentangle the role of climate change from that of globalisation and development in recent changes to human livelihoods on small islands, given that the latter have characterised many – especially SIDS – within the last few decades. However, recent climate change is clearly implicated in livelihood deterioration in many island contexts (Hernandez-Delgado, 2015; Nunn and Kumar, 2018). For example, livelihood impacts of climate-driven stressors (including shoreline/riverbank erosion, flooding and erratic rainfall) in three Mahishkhocha island-chars (river-mouth sand islands of Bangladesh) have been amplified by inadequate/misguided policy (Saha, 2017). The subordination of IK & LK in favour of external adaptation strategies has accelerated livelihood decline in many island contexts (Wilson and Forsyth, 2018). Although economic and financial development has the potential to reduce environmental (and livelihood) degradation in SIDS (Seetanah et al., 2018), it is also clear that uneven development can steepen core-periphery disparities, especially in archipelagic contexts, resulting in deteriorating rural/peripheral livelihoods at the expense of improving urban ones (Wilson, 2013; Sofer, 2015) and increased rural-urban migration (Birk and Rasmussen, 2014; Connell, 2015).

15.3.4.6 Migration

Climate-related migration is considered to be a particular issue for small islands because changes in extreme events and slow-onset changes affect increasingly highly exposed and vulnerable low-lying coastal populations, therefore causing a threat to small island habitability (Key Risk 9 in Box 15.1) (Storey and Hunter, 2010; Kumar and Taylor, 2015; Duvat et al., 2017a; Weir and Pittock, 2017; Hoegh-Guldberg et al., 2018; Rasmussen et al., 2018, Mycoo, 2018a). A typology of climate-related migration is provided in Cross-Chapter Box MIGRATE in Chapter 7. It is assumed that climate-related migration will increase in small islands, however, as is the case globally, the causes, form and outcomes are highly context specific. Types of climate-related migration occur across a continuum of agency from involuntary displacement at one end to voluntary movement to strategically reduce risks and planned resettlement at the other end (15.5.1, also see Chapter 7) (Birk and Rasmussen, 2014; Betzold, 2015; McNamara and Des Combes, 2015; Gharbaoui and Blocher, 2016; Stojanov et al., 2017; Weir, 2020).

Studies do not provide sufficiently robust evidence to attribute the various forms of migration to anthropogenic climate change directly on small islands or to accurately estimate the current number of climate-related migrants (see Chapter 7). Mobility is rarely due exclusively to climate-driven environmental change; rather, climate events and conditions strongly interact with other environmental stressors and economic, social, political and cultural reasons for migrating (*high evidence, high agreement*) (Laczko and Piguet, 2014; Birk and Rasmussen, 2014; Campbell and Warrick, 2014; Marino and Lazrus, 2015; Connell, 2016; Weber, 2017; Stojanov et al., 2017; Cashman and Yawson, 2019). In the Maldives, a survey conducted by Speelman et al. (2017) found that environmental factors did not strongly influence people's intention to migrate, either internationally or internally, when compared to perceived employment and educational opportunities and access to services.

Despite difficulties with attribution, the literature establishes that climate variability and extreme events and broad environmental pressures have contributed to some degree to human mobility on small islands over time (Birk and Rasmussen, 2014; Campbell and Warrick, 2014; Donner, 2015; Kelman, 2015a; Connell, 2016; Stojanov et al., 2017; Barnett and McMichael, 2018; Martin et al., 2018; Campbell, 2014) (*medium evidence, high agreement*) and these studies can provide analogues from which to inform climate-migration responses (Birk and Rasmussen, 2014; Kelman, 2015a; Connell, 2016).

Similarly, studies do not provide robust evidence to project how the full range of climate drivers may influence migration patterns on small islands into the future, although studies are emerging that estimate populations affected as a consequence of projected SLR. Rasmussen et al. (2018) estimated current populations of the world that are potentially subject to permanent inundation from projected local mean SLR associated with global mean surface temperature stabilisation targets of 1.5°C, 2.0°C, and 2.5°C occurring at 2100. The methods (after Kopp et al., 2014) involved the integration of the various components affecting sea level at the global scale (for example, oceanic thermal expansion, land ice melt), dynamic ocean processes that affect sea level regionally, and local vertical land movements that cause local relative sea levels to differ from the global mean. For the affected land area and population, this analysis included a subset of 58 small islands and other associated territories, as defined by the United Nations, for which the results are shown in Table 15.2.

Table 15.2: Global mean sea level rise (SLR) projections and associated population of SIDS exposed to permanent inundation for global mean surface temperature stabilisation targets of 1.5°C, 2.0°C and 2.5°C. (From Rasmussen et al., 2018)

Stabilised warming at 2100[a]	1.5°C		2.0°C		2.5°C	
Percentile	*50*	*5th–95th*	*50th*	*5th–95th*	*50th*	*5th–95th*
Global-mean SLR (cm) by percentile	48	28–82	56	28–96	58	37–93
SIDS population exposure (thousands) by percentile	400	300-560	420	300-640	430	320-630

(a) Above pre-industrial level.
(b) Values are centimeters above 2000 current era baseline.
(c) Potentially affected population due to local mean SLR. Local mean SLR projections used for individual SIDS take account of variations from the global mean due to factors such as glacial isostatic adjustment, gravitational changes from ice melting, deltaic subsidence and tectonic movements.

The aggregate figures of population that could potentially be affected by permanent inundation shown in Table 15.2 and Figure 15.3 mask important differences in relative exposure between individual SIDS and analyses for non-SIDS small islands are not available. Further, population affected by permanent inundation does not take into account the change in the frequency of ESL events and associated water-level attenuation (as per Vafeidis et al., 2019), nor does it account for adaptation measures that may alleviate impacts, future population growth, or the extent to which populations could adaptively migrate (see Section 15.5.3). However, Rasmussen et al.'s (2018) analysis shows that comparatively small changes in mean sea level can result in large increases in the frequencies of ESL events and, hence, the risk of coastal flooding of inhabited land, suggesting many areas of SIDS may become uninhabitable well before the time of permanent inundation (see also studies referenced in 15.3.3.1.1). A similar conclusion is drawn by Kulp and Strauss

(2019) who show that land area home to 10% or more of the population of many SIDS is at risk of chronic coastal flooding or permanent inundation by 2100.

Physical sites for settlement, particularly on atoll islands may be made marginal or uninhabitable by coastal inundation, wave-driven flooding and coastal erosion (15.3.3.1.1, 15.3.3.1.2, 15.3.4.1*)*. Livelihood security may be decreased by degradation of terrestrial and ocean ecosystems, necessitating increased mobility as people seek to diversify economic and food security options. Several studies from the Pacific show that in some instances, climate drivers potentially exacerbate environmental degradation leading to livelihood-related mobility, but do not singly drive it (Birk and Rasmussen, 2014; Connell, 2016; Wairiu, 2016; Allgood and McNamara, 2017).

Even where settlement locations and livelihoods remain secure, an increase in health diseases, decrease in the availability of potable water, and increasing exposure to extreme events may reduce habitability (Campbell and Warrick, 2014; Storlazzi et al., 2018) (Box 15.2). For example, the Fijian coastal village of Vunidogoloa made the decision to relocate in response to regular inundation during high tides. Raising houses on stilts and constructing a seawall failed to prevent regular flood damage to buildings and the entire community eventually relocated as a 'last resort' adaptation measure to a site within customary land. The availability of customary land for the new site was a key factor of success in this relocation example (McNamara and Des Combes, 2015; Piggot-McKellar et al., 2019).

15.3.4.7 Culture

Small island societies have developed IK & LK based responses to living in dynamic environments susceptible to climate variability and extremes, which are based in broader systems of culture and heritage (Barnett and Campbell, 2010; Lazrus, 2015; Nunn et al., 2017; Bryant-Tokalau, 2018b; Nalau et al., 2018b; Perkins and Krause, 2018) (*high confidence*). Cultural resources including aspects such as IK & LK, collective action, social cohesion, reciprocity and kinship networks, common pool resource governance systems, religious and spiritual values, tangible and intangible cultural heritage, practices, rituals, innovations and identity, are thought to play an important role in climate change adaptation on small islands through contributing to adaptive capacity and resilience (McMillen et al., 2014; Petzold and Ratter, 2015; Nunn et al., 2015; Nunn et al., 2017; Warrick et al., 2017; Falanruw, 2018; Mondragón, 2018; Parsons et al., 2018; Neef et al., 2018; Perkins and Krause, 2018; Hagedoorn et al., 2019) (Section 15.6.5) (*high evidence, medium agreement)*.

Climate change exacerbates risks to cultures (Cross-Chapter Box INTERREG in Chapter 16; Key Risk 9 in Box 15.1) and contemporary responses fail to address cultural aspects of life at risk (Adger et al., 2014). In Yap State, Federated States of Micronesia, protocols and cultural norms that have traditionally provided social resiliency via systems of reciprocity and exchange may be tested by population movement from outer islands to main islands as a result of reduced habitability contributed to by sea level rise and salt water intrusion (Perkins and Krause, 2018). Similar examples can be found in Papua New Guinea and Fiji due to relocation of communities (Gharbaoui and Blocher, 2016, 2018).

Climate-migration due to loss of land habitability (15.3.4.6) can have particularly severe cultural implications in a small island context where community solidarity and cohesion linked to place-based identity are important aspects of adaptive capacity (Hofmann, 2014; Lazrus, 2015; Warrick et al., 2017). In Federated States of Micronesia, land is owned through the matrilineal system and hence puts women in the centre of decision-making. The deterioration and loss of land (through salt water intrusion, flooding, drought, erosion) not only can lead to economic deprivation but it also compromises cultural identities: "Where land signifies political, social, and economic well-being, becoming bereft of land cuts off an important thread of people's sense of belonging" (Hofmann, 2017, p. 82) particularly for Chuuk women. Land degradation and loss involves the "interruption to the matrilineal transmission of land" (Hofmann, 2017: p. 82), the loss of identities, relationships, and their customary authority.

The unquantifiable and highly localised cultural losses resulting from climate drivers are less researched and less acknowledged in policy than physical and economic losses (Karlsson and Hovelsrud, 2015; Thomas and Benjamin, 2018). In the Bahamas, prolonged displacement of the entire population of Ragged Island following Hurricane Irma (2017) highlighted the cultural losses that can result from climate-induced displacement from ancestral homelands. Threats to identity, sense of place and community cohesion resulted from displacement, although all were important foundational features of the Islanders' self-initiated rehabilitation efforts and eventual return. Nonetheless, non-economic losses were not accounted for by policy addressing displacement (Thomas and Benjamin, 2018). In the case of Monkey River Village in Belize, coastal erosion is threatening the community's cemetery. Residents place significant spiritual and emotional value on the cemetery which serves important community functions, and thus, threats to it are perceived to be serious and necessary to be taken into account in any planned response (Karlsson and Hovelsrud, 2015). A similar situation exists on Carriacou in the West Indies where culturally and historically significant archaeological sites are being lost due to coastal erosion caused by a combination of sand mining and extreme climate-ocean events exacerbated by SLR (Fitzpatrick et al., 2006).

Population and settlement concentration in coastal areas and high exposure to climate-driven coastal hazards on small islands (15.3.1, 15.3.2, 15.3.3.1.1, 15.3.3.1.2, 15.3.4.1) mean that threats to tangible cultural heritage (archaeological sites, buildings, historic sites, UNESCO World Heritage Sites etc.) are high (Marzeion and Levermann, 2014; Reimann et al., 2018), although few studies examine this issue specifically in a small island context. On the island of Barbuda in the Lesser Antilles Islands chain, archaeological sites containing important information on historical ecology and climatic shifts are at risk from coastal erosion and hurricanes. This loss of heritage represents identity loss, as "learning about the past is a crucial exploration of self that grounds and connects people to places" (Perdikaris et al., 2017 p. 145). Loss and damage to heritage sites may also impact tourism and thus have significant economic impacts for narrow small island economies (15.3.4.5).

15.3.4.8 Transboundary Risks/Issues

Inter-regional transboundary impacts are those generated by processes originating in another region or continent well beyond the borders of an individual archipelagic nation or small island. Intra-regional transboundary impacts originate from a within-region source (e.g., the Caribbean). Some transboundary processes may have positive effects on the receiving small island or nation, though most that are reported have negative impacts (Table 15.3).

Table 15.3: Summary of inter- and intra-regional transboundary risks and impacts on small islands

[INSERT TABLE 15.3 HERE]

[START BOX 15.1 HERE]

Box 15.1: Synthesis of Key Risks in Small Islands.

Climate-ocean changes, including slow onset climate and ocean changes, and changes in extreme events, are projected to cause and/or amplify nine Keys Risks in small islands, through both direct (e.g., change in rainfall patterns will cause water insecurity) and indirect, that is, cascading effects (e.g., loss of terrestrial biodiversity and ecosystem services will increase water insecurity, which will cause health degradation). KR1 to KR7 are interconnected (as shown by arrows), with risk accumulation (from KR1 to KR7) causing overarching Key Risks (KR8 and KR9).

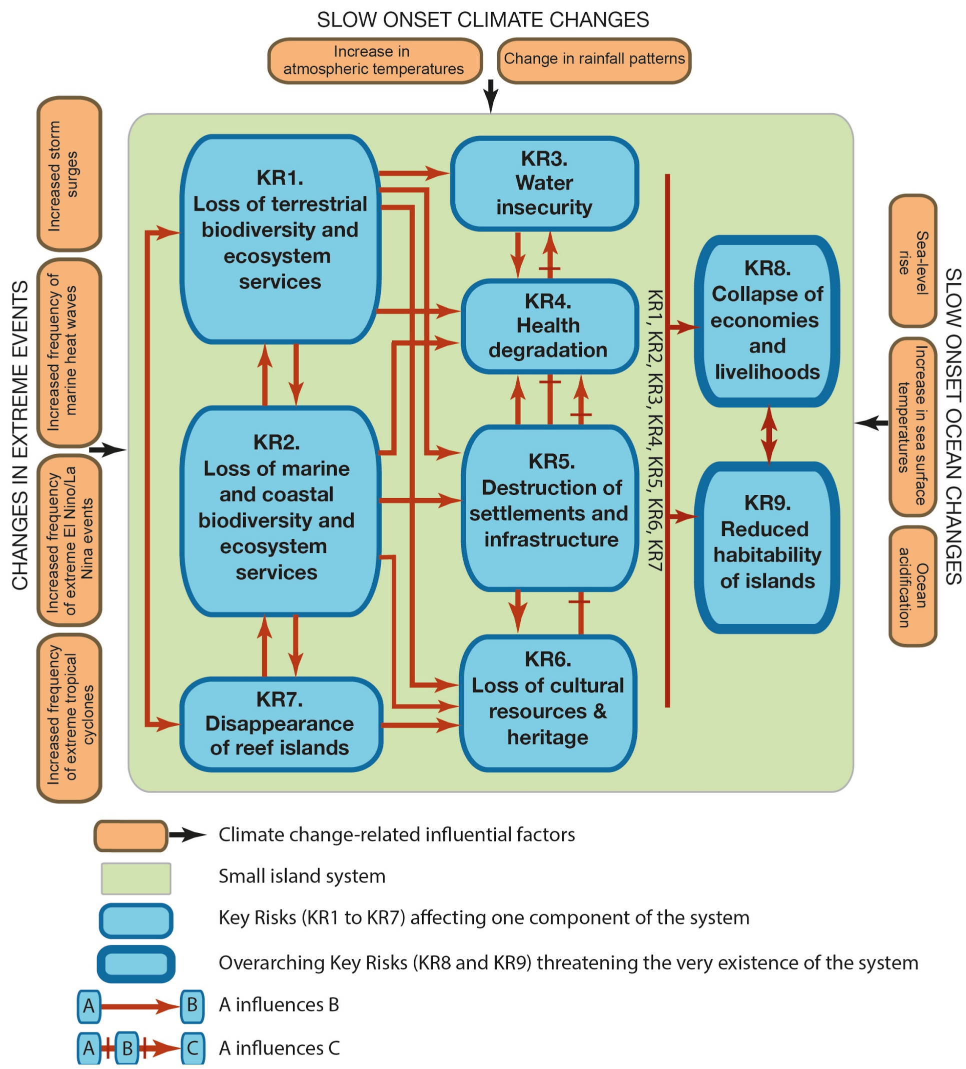

Figure Box15.1.1: Key Risks from climate change in small islands.

[END BOX 15.1 HERE]

[START BOX 15.2 HERE]

Box 15.2: Key Examples of Compound Events: Maldives Islands and Caribbean Region

Cumulative Impacts of the Compound Events of the 1998-2016 Period in the Maldives Islands

Between 1998 and 2016, the Maldives Islands were successively affected by three major climate events, including the 1997–1998 ENSO event, the 2007 flood event and the 2016 ENSO event, and by one tectonic event, i.e. the 2004 Indian Ocean Tsunami (Morri et al., 2015). The 1997–1998 ENSO event was particularly severe in the Maldives, as a result the living coral cover dropped to <10% (Bianchi et al., 2003). Recovery was still in progress in 2004 when the tsunami caused further - although not quantitatively assessed (Gischler and Kikinger, 2006) damage to the reef ecosystem. Post-1998 recovery took 15 years, i.e. longer than following the 1987 ENSO event (after which recovery had only taken a few years) and longer than in the neighbouring undisturbed Chagos atolls, thereby suggesting the alteration of the recovery capacity of the reef ecosystem by human-induced reef degradation and climate change (Morri et al., 2015; Pisapia et al., 2017). Mid-2016, a new ENSO event occurred, which reduced living coral cover by 75% (Perry and Morgan, 2017). The future recovery of the reef ecosystem, which is critical to both current livelihoods and economic activities (especially diving-oriented tourism and fishing) and long-term island persistence will mainly depend first on the frequency and magnitude of future bleaching events, which are expected to increase due to ocean warming, and second on the highly variable effects of anthropogenic disturbances locally (Perry and

Morgan, 2017; Pisapia et al., 2017; Duvat and Magnan, 2019). Additionally, the 2004 Indian Ocean tsunami (Magnan, 2006) and the 2007 flood (Wadey et al., 2017) caused disproportionate damage equalling to 62% of the country's GDP (Luetz, 2017). The tsunami downgraded the Maldives (now a middle-income country) to the Least Developed Countries category and caused massive within-country migration with 30,000 people (9.6% of the country's population) displaced (RoM, 2009). These successive events, which had cumulative devastating effects on the reef ecosystem and cascading effects on health and well-being, livelihoods and economy, highlighted the risk posed by limited recovery time to the whole social-ecological system as well as the detrimental effect of local human disturbances on reef recovery. This case thus illustrates the cumulative and cascading risks that a series of events may cause in reef-dependent atoll contexts.

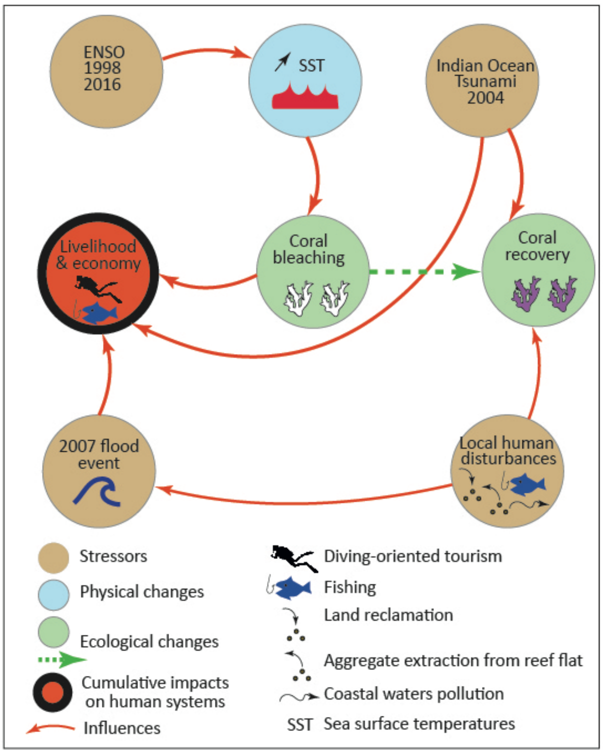

Figure Box15.2.1: Cascading and cumulative impacts of the compound events of the 1998-2016 period in the Maldives Islands. [PLACEHOLDER FOR FINAL DRAFT aesthetics will continue to be improved]

Cumulative Impacts of the 2017 Hurricanes in the Caribbean Region

Among the 29 Caribbean SIDS, 22 were affected by at least one TC in 2017, 4 of which were hit by one TC, 13 by two TCs and 5 by three TCs. Nine SIDS experienced direct landfall of Category 4–5 TCs Irma and/or Maria, including Dominica, Antigua and Barbuda, Anguilla, Saint-Martin/Sint Maarten, the British Virgin Islands, the U.S. Virgin Islands, Puerto Rico, Turks and Caicos, and Cuba (Shultz et al., 2018). Due to the 2017 TCs, Puerto Rico and Dominica respectively ranked first and third among the countries and territories that were the most affected by climate-related events worldwide in 2017 (Eckstein et al., 2018). Losses per unit of GDP respectively reached US$ 82,315 and US$1,686 billion losses in Puerto Rico and Dominica, which suffered almost complete infrastructure destruction and a reversal of their socioeconomic development (Eckstein et al., 2018).

Beyond TC impacts (i.e. fatalities and effects on public health, buildings and infrastructure, utilities and public services... (Pasch et al., 2018; Shultz et al., 2018)), these events especially highlighted how the pre-cyclone high exposure and vulnerability of these islands has caused a "cumulative community vulnerability" (Lichtveld, 2018, p. 28) that has amplified the impacts of these TCs, which will in turn increase the long-term vulnerability of affected islands. Caribbean islands exhibit a high exposure to TC impacts due to the combination of a small island size with a 360° perimeter exposing them respectively to cyclone-induced rainfall and winds over their entire surface, and to storm waves along their entire coastline. This high exposure, combined with a high vulnerability due to the concentration of human assets (people, infrastructure, utilities and public services) in low-lying coastal areas, inadequate housing, limited access to healthy food and transportation, and unpreparedness explains the widespread-to-total devastation of the nine SIDS on which the cyclones made landfall (Shultz et al., 2018; Briones et al., 2019). This either caused or exacerbated (e.g., in the case of Puerto Rico) long-lasting socio-economic crises, which was further deepened by high social inequalities. The remoteness of islands and destruction of transport systems (Lopez-Candales et al., 2018) and island supply chains (Kim and Bui, 2019) which heavily depend on ports, roads, power and communications, made rescue logistically complex, explaining the lack of freshwater, food supplies, medications and fuel on some islands during several weeks after the event. The heterogeneity of Caribbean governments, including independent sovereign states, territories or protectorates of other countries, led to the involvement of a diversity of international partners from a range of nations in disaster response, which made crisis management more complicated (Lopez-Candales et al., 2018; Shultz et al., 2018). This cumulative vulnerability caused "cascading public health consequences" (Shultz et al., 2018, p.9), including delayed mortality, physical injury during the clean-up and recovery phase, heat-related injury, and increased the risk of chronic, vector-borne, contaminated water-related diseases, and mental sequelae (Ferré et al., 2018; Kishore et al., 2018).

Furthermore, these TCs will increase the vulnerability of the most affected small islands for an extended time through "depopulation" (Melendez and Hinojosa, 2017), illustrated by an expected loss of ~470,000 people representing 14% of Puerto Rico's population in only two years as a result of emigration to the US mainland, and the considerable aggravation of the 2006-2016 chronic economic crisis that had already pushed >500,000 people to migrate to the USA. As a result, Puerto Rican incomes are expected to decrease by 21% over the next 15 years (Melendez and Hinojosa, 2017). This economic crisis is exacerbated by the loss of ecosystems, such as mangroves (Branoff, 2018; Walker et al., 2019; Taillie et al., 2020) and terrestrial forests (Eppinga and Pucko, 2018; Feng et al., 2018; Hu and Smith, 2018; Van Beusekom et al., 2018) that are the support to livelihoods and tourism, as well as fisheries resources and infrastructure (Pinnegar et al., 2019). Cyclone-induced loss of tourist income will be especially high in SIDS (Seraphin, 2018). For example, Dominica is expected to lose more than a year of its tourist income due to the loss of 95% of its vegetation and damage to hotels. In the most affected islands, the physical destruction of buildings and outmigration have respectively generated a significant loss of tangible (e.g., museums, monuments, etc.) and intangible (traditional artistry, festivities, etc.) cultural heritage (Boger et al., 2019). The prolonged displacement of entire island populations (e.g., Ragged Island, the Bahamas; Barbuda) has caused "non-economic loss and damage", including threats to health and wellbeing, and loss of culture, sense of place and agency (Thomas and Benjamin, 2019), which are likely to further exacerbate the long-term vulnerability of concerned communities.

In early 2020, while island communities were still recovering from the 2017 hurricanes, the COVID-19 pandemic caused the closure of global transportation, with devastating socioeconomic impacts on tourism-dependent Caribbean economies (Sheller, 2020). Both the long-lasting impacts of the 2017 hurricanes on community vulnerability and the additional (and not yet fully understood) effects of the Covid-19 pandemic illustrate how compounding crises increase island vulnerability to both climate and non-climate related events.

[END BOX 15.2 HERE]

15.4 Detection and Attribution of Observed Impacts of Climate Change on Small Islands

As highlighted in AR5, detection of climate change impacts in small islands fragile environment is challenging because of other non-climate drivers that affect small islands. Determination of attribution to incremental change of climate drivers is also challenging because of the natural climate variability. Therefore, there is limited scientific literature on observed impacts and attribution. Synthesis of findings on the impacts of climate change shows that there is more information on impacts on ecosystems compared to human systems. There is *high confidence* in attribution to climate change of impacts on the coastal and marine as well as terrestrial ecosystem (Cramer and Hansen, 2015; Duvat et al., 2016; Shope et al., 2016; van Hooidonk et al., 2016; Hoegh-Guldberg et al., 2017; Hughes et al., 2017; Mentaschi et al., 2017; Shope et al., 2017; Vitousek et al., 2017; Wadey et al., 2017; Ford et al., 2018; Hughes et al., 2018; IPCC, 2018; Storlazzi et al., 2018; Bindoff et al., 2019) and *medium confidence* in attribution to climate change of impacts on livelihoods, economics and health (McIver et al., 2016; Eckstein et al., 2018; Santos-Burgoa et al., 2018; Schütte et al., 2018; WHO, 2018, Burger et al., 2020) (Figure 15.5). The *limited robust evidence* on attribution of observed impacts to climate change in small islands does not indicate that no such impacts have occurred.

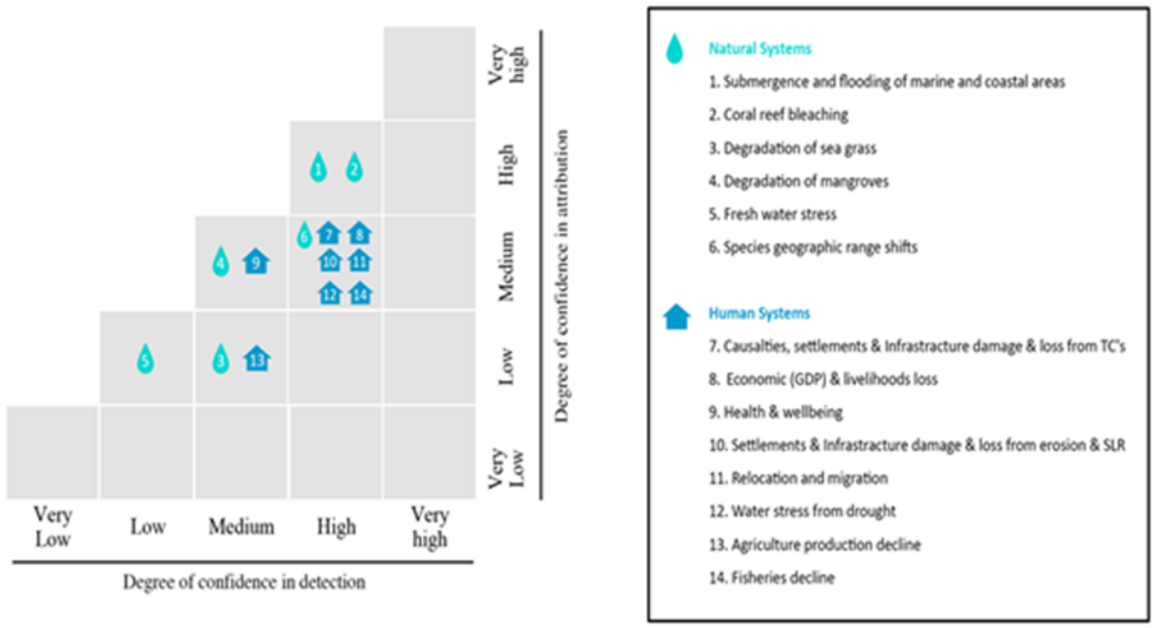

Figure 15.5: A comparison of the degree of confidence in the detection of observed impacts of climate change on tropical small islands with the degree of confidence in attribution to climate change drivers at this time. For example, the green symbols No. 1 and No. 2 (submergence and flooding of marine and coastal areas, and coral reef bleaching) indicate there is very high confidence in both the detection of "sea level rise" and its attribution to climate change drivers, whereas the blue symbols No. 7 (casualties, settlements & infrastructure damage and loss from TCs, and No. 8 (economic (GDP) & livelihood loss) indicate that although confidence in detection is high, there is at present medium confidence in the attribution to climate change. It is important to note that medium confidence in attribution frequently arises owing to the limited research available on small island environments.

15.5 Assessment of Adaptation Options and Their Implementation

This Section covers most adaptation actions and approaches across small islands. In the context of small islands, it is recommended that adaptation options should be "multi-scale, multi-component, multi-sector, multi-actor initiatives' (Robinson, 2017, p. 671) and meet multiple vulnerabilities in order to promote effective adaptation while also meeting sustainable development and disaster risk reduction goals. In an analysis of SIDS National Communications, most adaptation strategies continue to fall into five categories: 1) Observation and assessments; 2) Planning, institutions and policies; 3) Implementation and Management; 4) Monitoring and Evaluation; 5) Education and Knowledge Management (Robinson, 2017). Since AR5, small islands have experimented with new adaptation options, which has increased the lessons learnt from on-the-ground practices in these settings. Figure 15.6 shows the adaptation options that are being experimented with in small islands.

15.5.1 Hard Protection

Seawalls have been a popular coastal protection measure on islands (Figure 15.6). An analysis of National Communications shows that 28% of coastal protection actions are seawalls, followed by breakwater structures and coastal protection units (Robinson, 2017). Coastal protection infrastructure has been heavily invested, for example in the Caribbean region and especially Barbados (Mycoo, 2014a), Cuba and Guyana (Mycoo, 2014b). Yet, the case of who pays for expensive structures, especially under the 1.5°C warming scenario, requires immediate discussions on financial commitments (Mycoo and Donovan, 2017; Mycoo, 2018a). A similar situation applies in many Indian Ocean islands, where coastal protection strategies are manifested in many small islands by hard shoreline structures, many of which are proving increasingly challenging to maintain (Naylor, 2015; Betzold and Mohamed, 2017; Magnan and Duvat, 2018). The situation in much of the Pacific is different given that many islands have been occupied for millennia by Indigenous communities with extant knowledge for coping with adversity (Granderson, 2017). The latter generally favours 'soft' shoreline structures for coastal protection although the building of seawalls has been rapid, especially in urban islands (Duvat, 2013; Magnan et al., 2018; Morris et al., 2018; Umeyama, 2012), but not only (e.g., Tubuai, French Polynesia, Salmon et al., 2019).

Many rural communities have uncritically emulated structures in urban contexts built and maintained with outside funds. As a result of which in many such SIDS seawalls have collapsed without additional funding available for repairs (Nunn and Kumar, 2018; Piggot-McKellar et al., 2020). Similar cases have been recorded along the coast of Puerto Rico (Jackson et al., 2012) while on Indian Ocean islands, the shorelines are littered with broken seawalls and groynes (Duvat, 2009). In Samoa, seawalls close to Apia need constant investments to remain viable and at some point, there are economic limits to such adaptation strategies (Crichton and Esteban, 2018).

On small islands, another widespread issue with seawalls and other hard shoreline structures is that they invariably shift problems of shoreline erosion and lowland inundation elsewhere (Donner and Weber, 2014). Even surrounding entire islands with such structures, as has happened on Male' (Maldives), is not a long-term solution because of incidences of localised seawall collapse that can spread quickly if not addressed immediately (Naylor, 2015). It is clear that, except for iconic/urban coasts, hard structures for coastal protection will become increasingly ineffective in the future, demonstrating the need for adaptation along most island coasts to become more transformative than has been the case over the past few decades. In the Bahamas, it has been suggested that coastal protection structures and strategies are implemented through "a rather piecemeal approach of single projects and small patches, partially resulting in maladaptation by further increasing processes of erosion" (Petzold et al., 2018, p. 95). In the village of Lalomalava, Samoa, national adaptation funding was spent on erecting a seawall to protect the village, but the wall was not long enough to protect the whole village, leading some families and properties to face increasing impacts from large waves (Crichton and Esteban, 2018).

15.5.2 Accommodation: "Staying Put" and Advance as Strategies

In most small island contexts, the costs of adaptation through accommodation are prohibitive so that it has in most cases not been contemplated as a widespread option. However, accommodation measures such as the raising of dwellings and key infrastructure (like coastal roads) above ground level have been implemented to reduce the impacts of flooding in some islands (Figure 15.6). In the most populous islands of the north-western Tuamotu atolls, French Polynesia, where between 48 and 98% of dwellings have already experienced flooding since the 1980s, elevated houses with floors built 1.5 m above ground level are subsidised by the Government as part of Risk Prevention Plans (Magnan et al., 2018). Despite this incentive, the opposition of the local authorities and population to these plans (which also include constraining setback guidelines) considerably limited implementation, hence elevated houses only represent 7% of the total housing stock. In some small and low-lying islands of the Philippines (Tubigon) and of Indonesia (Jakarta area) facing increased flooding, residents have elevated their houses by building stilted houses or raising the floor using coral stones (Jamero et al., 2017; Esteban et al., 2020). Also, in Guyana (Mycoo, 2014b), Suriname and Belize houses have been built on stilts to address flooding (Mycoo and Donovan, 2017).

In some small island settings, land reclamation (i.e. land gain through infilling) has been implemented for decades to allow for infrastructure construction and to address land shortages arising from high population growth. For example, land reclamation in Port of Spain, the capital city of Trinidad, has long been used as a solution space to meet land for housing, industrial development and infrastructure provision (Mycoo, 2018b). Likewise, one third of the land area of Malé, the capital island of the Maldives, results from land reclamation (Naylor, 2015). Land reclamation is also common in Pacific atoll countries and territories, where it occurs in both urban islands facing high population pressure (e.g., South Tarawa, Kiribati (Biribo and Woodroffe, 2013); Funafuti Atoll, Tuvalu (Onaka et al., 2017); Rangiroa Atoll, French Polynesia (Duvat et al., 2019) and rural islands (e.g., Takapoto and Mataiva atolls, French Polynesia; Duvat et al., 2017b)). In some cases, land reclamation has paved the way for land raising, which is increasingly considered to adapt to SLR in small islands contexts. For example, since the 1990s, the capital area of the Maldives has been expanded through the construction of a large new island, Hulhumale', which is still under construction and is built 60 cm higher than Male' (max. elevation of ~2.2 m against ~1.6 m) to take into account SLR (Hinkel et al., 2018; Brown et al., 2020). The 2004 Indian Ocean Tsunami has boosted land reclamation combined with island raising as part of the "safe island development programme" in Maldives (Shaig, 2008). Recent studies suggest that land and island raising have some potential in small islands, especially in urban high-value areas where it can generate substantial revenues through the sale or lease of new land, and therefore leverage public adaptation finance (e.g., Maldives Islands; Bisaro et al., 2019).

15.5.3 Migration

Migration, including planned resettlement, is increasingly occurring in small islands to intentionally respond to or prepare for climate change impacts (Magnan et al., 2019). However, the extent to which migration reduces risk – and is therefore 'successful' and adaptive - for migrants and receiving communities is highly dependent on contextual socioeconomic, political, legal, cultural and psychological factors (de Coninck et al., 2018; Weir et al., 2016). There is currently *limited evidence* and *low agreement* in the literature as to whether migration of various types is an effective strategy to adapt to localised impacts of climate change, (Donner, 2015; McNamara et al., 2016; Hermann and Kempf, 2017; Tabe, 2019; McMichael et al., 2019; Bertana, 2019; Piggot-McKeller, 2019; Weir, 2020). Despite this, studies undertaken to date (mainly in the Pacific) reveal a number of contextual characteristics that commonly influence whether migration can be deemed adaptive or not, including cost effectiveness, land tenure, distance, availability of financial and technical support, consideration of specific local socio-cultural context, migration participation and the presence/absence of strong governance frameworks or policy (McNamara et al., 2016; Hino et al., 2017; Nalau and Handmer, 2018; Albert et al., 2017; Piggot-McKellar, 2019; Gharbaoui and Blocher, 2016).

In small islands, there is *medium evidence* and *high agreement* that the degree of migrant agency and choice in decisions about whether to move, where, when and how is an important determinant of success (McNamara and des Combes, 2015; Hino et al., 2017; Bertana, 2019; Piggot-McKellar, 2019; McMichael et al., 2019) (see Cross-Chapter Box MIGRATE in Chapter 7). Two case studies of community relocation in Fiji (Denimanu and Vunidogoloa villages) revealed that participatory inclusion of all social groups in the relocation planning process, including in planning for livelihood sustainability in new locations, should be ensured in future planned community relocation to foster adaptive outcomes (Piggot-McKellar et al., 2019). Forced relocation, involuntary displacement and low-agency migration (for example, due to low migrant financial resources, or limited participation in migration planning) is commonly associated with unsuccessful outcomes and can therefore be considered an impact of climate change rather than an adaptation strategy (Weber, 2016; Tabe, 2019; Thomas and Benjamin, 2018). For all forms of climate-related migration, placing affected people are at the centre of decision making and equipping them with resources and power to shape their own migration pathways is an important success factor (Bertana, 2019; Piggot-McKellar et al., 2019).

The role of formal government relocation policy as a success determinant is highlighted in the Pacific literature. In the Solomon Islands, households from the community of Nuatambu Island have relocated to customary land in separate locations across south-eastern Choiseul Province to retreat from shoreline change. Relocation has reduced exposure to climate-driven risk, but having occurred outside any formal governance framework, has come at a significant economic cost to households, impacted social capital and reduced access to infrastructure and services – all of which are drivers of vulnerability (Albert et al., 2017). In contrast, relocation of another coastal risk-prone provincial town in the Solomon Islands, Taro, has been planned under government guidance for many years. This planned relocation would enable a community to move as an intact unit. However, lack of policy and legislation enabling sufficient land to become available for relocation has impeded efforts (Albert et al., 2017). In December 2018, Planned Relocation Guidelines drafted by the Fiji Government came into effect, providing a framework to undertake climate change related relocation and equipping communities with rights in the planned relocation process (McMichael and Katonivualiku, 2019). Yet, McMichael and Katonivualiku (2019) caution that even with guidelines in place, the socio-cultural complexities of relocation challenge strong planning. In many documented cases, relocation – both planned and autonomous – is an adaptation option of last resort due to high economic and socio-cultural cost (McNamara and Des Combes, 2015; Laurice Jamero et al., 2017).

There are few examples of highly 'successful' and therefore adaptive international resettlement or relocation in response to environmental pressures in history. For example, the experiences of Gilbertese resettled in the Solomon Islands highlight that tensions with host communities over land and resource rights and limited knowledge of new environments can create new vulnerabilities (Donner, 2015; Tabe, 2019; Weber, 2016). Even where gradual international relocation is supported and planned through policy as in the case of Kiribati's "migration with dignity" strategy, strong cultural connection to land and uncertainty about life in receiving communities in Australia and New Zealand means that many remain opposed to indefinite or permanent migration (Allgood and McNamara, 2017; Hermann and Kempft, 2017). However, planned migration at this scale can reduce exposure in sending locations and spread risk through expanding economic opportunities and providing remittances, thus having inadvertent adaptation outcomes (Campbell, 2014a). An example is Nanumea in the atoll nation of Tuvalu, where circular migration to the capital Funafuti and locations overseas for labour and education opportunities reduces pressure on limited freshwater availability, thus reducing exposure to drought. The maintenance of a home community on customary land on Nanumea is fundamental to this type of mobility being considered 'adaptation' (Marino and Lazrus, 2015). Additionally, research from the Maldives suggests that women and men do not possess equal capacities to use mobility as a strategy to adapt to climate change, with women less able to employ migration as an adaptation strategy due to gender roles, social expectations, economic structures, political laws and religious doctrines, and gender norms and cultural practices (Lama, 2018).

The option to migrate as an adaptive strategy should be considered as one option among many (Barnett and O'Neill, 2012; Kelman, 2015a). Migration may become a reality when the biophysical thresholds, for example more frequent flooding, elevated sea levels and frequent wave-over wash (Storlazzi et al., 2018) make it impossible to remain and return to the place of living (Campbell, 2014a; Nalau and Handmer, 2018). In countries like the Marshall Islands, discussions on relocation and migration, and limits to adaptation, are increasingly being tied to frameworks like the Reimaanlok Conservation Area Management Planning Framework that combines Indigenous community-based planning with empirical scientific evidence in identifying atoll habitability thresholds (Stege, 2018). This kind of proactive and empirically based tracking of impacts can assist in opening up conversations about local and global change and enable communities to proactively plan for adaptation (Stege, 2018).

Table 15.4 summarises the feasibility assessment of planned relocation as an adaptation option using evidence presented in sub-Section 15.5.3 in this chapter. The feasibility assessment was done using its six dimensions with levels of evidence and agreement and indicates how the feasibility of planned relocation may be differentiated by certain contextual factors (last column).

Table 15.4: Feasibility assessment of planned relocation adaptation option, with moderate shading indicating that, on average, the dimension does not have a positive or negative effect on the feasibility of the option, or the evidence is mixed, and light shading indicating the presence of potentially blocking barriers. No shading means that sufficient literature could not be found to make the assessment. Abbreviations of the six feasibility dimensions used: Ec.: Economic Tec: Technological Inst.: Institutional – Soc.: Socio-cultural – Env.: Environmental/Ecological - Geo: Geophysical[PLACEHOLDER FOR FINAL DRAFT: to be updated with the feasibility assessment of other adaptation options in Section 15.5]

	Adaptation Option	Evidence	Agreement	Ec	Te	Inst	Soc	Env	Geo	Context
Overarching Adaptation Options	Planned relocation	Limited	Low							The adaptiveness of planned relocation is highly context dependant and influenced by cost effectiveness, land tenure, distance, availability of financial and technical support, consideration of specific local socio-cultural context, migrant participation and the presence/absence of strong governance frameworks or policy.

15.5.4 Ecosystem-based Measures

Small islands have focused increasingly on ecosystem-based adaptation (EbA) approaches that bring benefits both for the ecosystems and communities (Giffin et al., 2020) (See Figure 15.6). There is *robust evidence* on implementation of EbA approaches across small islands, yet *medium agreement* on the exact benefits of these activities (Mercer et al., 2012; Doswald et al., 2014; Nalau et al., 2018) given the difficulties in quantifying benefits and the absence of monitoring and evaluation frameworks (Doswald et al., 2014). Traditionally, EbA activities, especially at national and regional scales, have predominantly focused on restoring or conserving coastal and marine ecosystems (e.g., coral reefs, mangrove forests and seagrass meadows), with less emphasis upon the services provided by natural inland forests (Mercer et al. 2012). Incorporation of forests is however increasing, in most cases as components of ridge to reef (Figure 15.4) (or DDR) projects (*low to medium evidence*), and is usually geared towards integrated watershed management to establish downstream water security, erosion control and ultimately to protect the health of coral reef ecosystems (Förster et al., 2019). Such watershed management schemes, especially across the Caribbean and Pacific are increasingly incorporating key adaptation strategies such as prevented deforestation/degradation together with reforestation (Mycoo and Donovan, 2017; Mcleod et al. 2019; McMillen et al. 2016) (*low to medium evidence*).

Additionally, some islands are constructing climate-smart development plans such as improved management of existing and newly established protected areas, restoration of riparian zones, urban forests/trees, sub urban and peri urban home gardens, and improved agroforestry practices towards increasing resilience to changing climate conditions, wildfires as well as decreasing food insecurity (e.g., McLeod et al., 2019; Pedersen et al., 2019). There is also now increasing evidence that land use is a key driver of coral reef health, with human development and associated flooding at times outweighing the benefits of marine protected areas (Lamb et al., 2016, Suchley and Alvarez-Filip, 2018) (*low to medium evidence, high agreement*). Further, paired terrestrial and marine protected areas have shown that forest conservation and rehabilitation yield better outcomes for coral health as forests stabilize soils and prevent erosion and sequester groundwater pollutants (Carlson et al., 2019) (*low to medium evidence, high agreement*). Ridge to reef studies are currently focused on regions such as the Caribbean and Pacific (e.g., Brown et al., 2017; Delevaux et al., 2018 a, b), however, not so much within the Indo-Pacific islands (Rude et al., 2016; Brown et al., 2017). The success of protected areas is undermined by weak governance due in part to limited financial resources which undermine management and the enforcement of regulations governing activity within them (Schleicher et al., 2019). In the Caribbean, fiscal instruments are used such as environmental taxes and levies but there is limited evidence of direct reinvestment in conservation and management (Attzs, 2014; Caribbean Natural Resources Institute (CANARI), 2019).

Since the 1990s, artificial reefs have been increasingly used in small islands to support reef restoration and reduce beach erosion, in particular in the Caribbean region (e.g., Dominican Republic, Antigua, Grand Cayman) and Indian Ocean (Maldives, Mauritius) (Fabian et al., 2014). They have been more or less successful in reducing the destructive impacts of extreme events, depending on their technical characteristics and the local context. For example, while it resisted the waves generated by hurricanes Georges and Mitchell in 1998, the artificial reef (Reef Ball breakwater type) implemented at Gran Dominicus Resort, in the southeast of Dominican Republic, did not prevent significant beach erosion. In contrast, the coral reef restoration project implemented to "build a beach" on the resort island of Ihuru, North Male' Atoll, Maldives, was successful as it allowed beach expansion and prevented the erosive impacts of the 2004 Indian Ocean Tsunami on the beach (Fabian et al., 2014).

Over the past decades, beach nourishment has been implemented in small islands either to reduce beach erosion (e.g., in tourist areas), or to protect critical human assets such as coastal roads that are highly exposed to storm waves. For example, beach nourishment has been increasingly used to maintain beaches in the resort islands of the Maldives, while it has scarcely been implemented in inhabited islands where the local population is more favourable to engineering structures (Shaig, 2011). It has also been used in Barbados for the same reason (Mycoo, 2014b). In some contexts, cooperation agencies play an important role in the promotion of beach restoration. For example, the Japan International Cooperation Agency (JICA) recently supported beach restoration projects in Mauritius and Tuvalu. At Grand Sable, Mauritius, the project aimed to protect the coastal road and residential area from wave impact (Onaka et al., 2015). On the northern coast of Fongafale, Funafuti Atoll, Tuvalu, beach nourishment was aimed at protecting a densely populated area from coastal erosion and flooding (Onaka et al., 2016). At this site, it proved to be successful as the 20 m-wide newly created beach resisted TCs Ula and Winston in 2015-2016 (Onaka et al., 2017).

In designing and implementing EbA, IK & LK have high relevance especially amongst Pacific small islands as many communities are remote and still rely on ecosystems for their livelihoods (Nalau et al., 2018). In Fiji, IK & LK have informed EbA projects by identifying native species suitable to strengthen the coastal environment to reduce coastal erosion and flooding in the villages (Nalau et al., 2018). Good practice can also be found from Haiti and Belize where IK & LK have been included in EbA projects (Mercer et al., 2012). In the Caribbean, EbA approaches are somewhat absent in national and regional programmes and plans, yet at the local scale EbA strategies are used increasingly with implementation mostly led by NGOs (Mercer et al., 2012). In Samoa, EbA approaches include planting "native coastal trees such as coconuts, tropical almonds and other salt-tolerant species" (Crichton and Esteban, 2018, p. 296). Yet, the success of replanting is not straightforward: pigs and chickens often damage the seedlings, rising sea levels might introduce too high levels of salinity for particular species to survive, and community ownership needs to stay constant to care for the species after official project completion (Crichton and Esteban, 2018, p. 862).

Other adaptation challenges include dominant preferences for hard infrastructure given that e.g., seawalls provide an immediate outcome and have higher costs, making it easier to use the allocated finance for adaptation (Nalau et al., 2018). In the Caribbean, many local EbA projects are not well documented, making it difficult to evaluate how much and what kind of knowledge are used in these projects (Mercer et al., 2014b). Whole-of-island approaches, like Lomanu Gau in the Gau Island in Fiji, try to foster integrated management practices in small islands that are based on shared governance of resources, and understanding the interlinkages between sectors and ecosystems (Remling and Veitayaki, 2016). In the South Pacific, the concept of Blue Economy has been suggested as a conceptual framework that describes the connectedness of people's livelihoods with the ocean, and sustainable development aspirations with five core components of "ecosystem resilience, economic sustainability, community engagement, institutional integration and technical capacity" (Keen et al., 2018, p. 335) that are underpinned by customary resource management and cultural relationships.

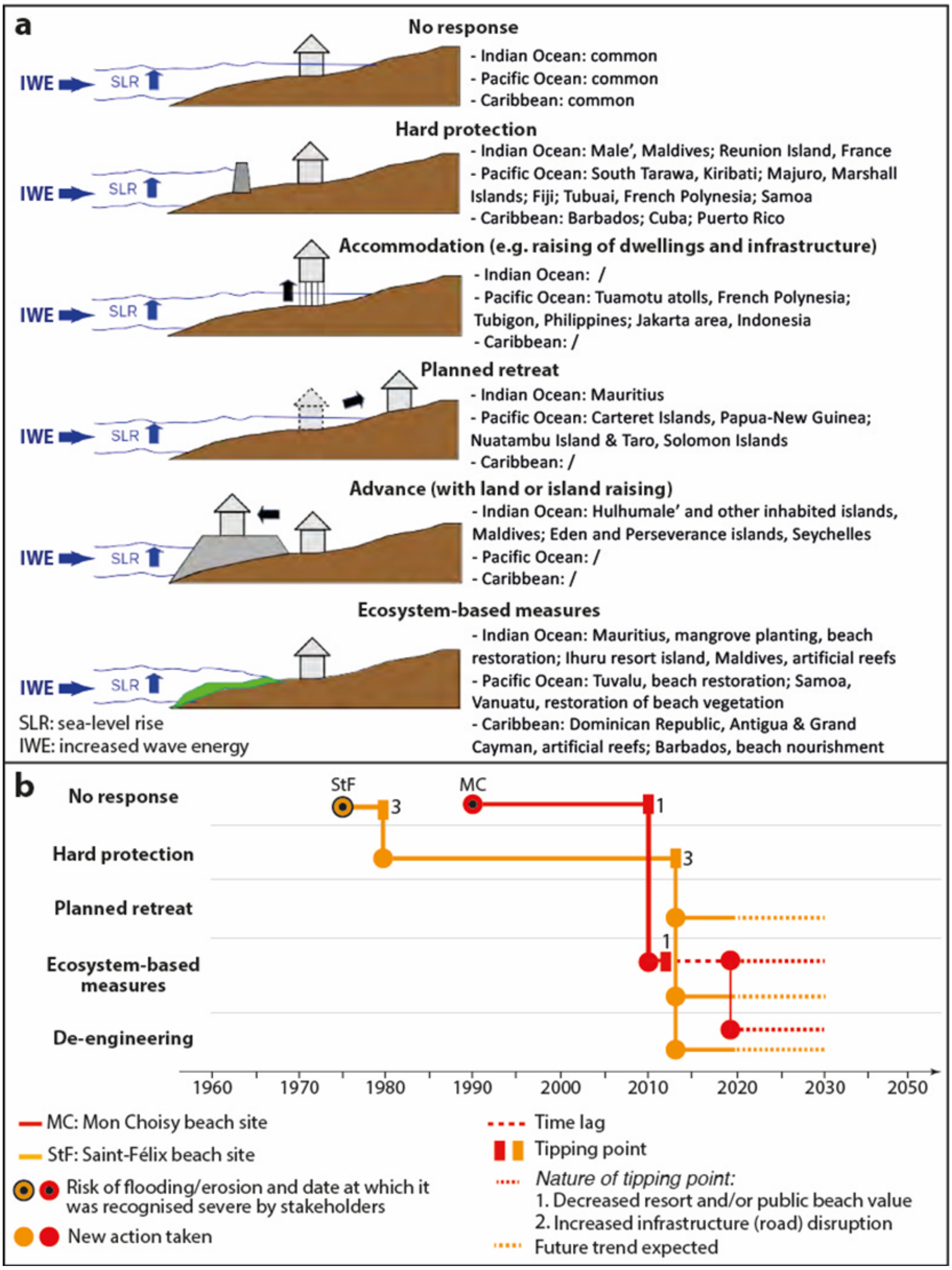

Figure 15.6: Adaptation measures implemented to reduce coastal risks in small islands. Panel provides examples of implementation of different types of measures aimed at reducing climate-driven coastal risks, namely coastal erosion and flooding. The measures include various strategies: no response (no intervention, widespread in small islands), hard protection through the construction of engineering-based structures, accommodation through dwelling and infrastructure raising, planned retreat, advance (i.e. especially island raising) and ecosystem-based measures, in three small island regions, the Indian and Pacific Oceans and Caribbean. It highlights the prevalence of no response, hard protection and the increasing use of ecosystem-based measures. Based on the example of two beach sites in Mauritius (Mon Choisy in the north and Saint-Félix in the south), panel b shows that the measures used at a given coastal site evolve over time (here, from no response to hard protection, and then planned retreat and ecosystem-based measures) and that recent DRR (Saint-Félix) and adaptation (Mon Choisy) projects often combine several types of measures, including retreat, ecosystem-based measures and de-engineering (removal of hard structures that have failed in containing risks) (Duvat et al., 2020). Together, panels a and b emphasize the diversity and increasing complexity of the measures implemented in small islands. [PLACEHOLDER FOR FINAL DRAFT: aesthetics will continue to be improved]

15.5.5. Community-based Adaptation

Community-based Adaptation (CBA) is best described as "community-led process based on meaningful engagement and proactive involvement of local individuals and organisations" (Remling and Veitayaki, 2016, p. 380). Enabling CBA projects to succeed relies on gaining a good understanding of the socio-political context within which the communities operate, including such key issues as land tenure arrangements and ownerships, gender, and decision-making processes that operate on the ground (Crichton and Esteban, 2018; Nunn et al., 2013; Buggy and McNamara, 2015; Parsons et al., 2018; Nalau et al., 2018; Piggot-McKellar et al. 2020; McNamara et al., 2020). This also includes the broader and often more urgent development issues that impact on communities' wellbeing (Piggot-McKellar et al. 2020). Community-based projects demonstrate in the Pacific that communities' vulnerabilities, priorities and needs might be a better and more effective entry point for climate adaptation than framing projects solely around climate change (Remling and Veitayaki, 2016; Weir, 2020). This is supported by a recent review of 32 community-based adaptation initiatives in the Pacific where initiatives that were locally funded and implemented were more successful than those with external international funding (McNamara et al, 2020). Initiatives that integrated EbA and climate awareness raising performed also better (McNamara et al., 2020).

While CBA approaches to adaptation projects can increase community ownership and commitment to project implementation, yet these can also face challenges. In Pele Island, Vanuatu, implementation of CBA projects has experienced significant failures due to elite capture of project management, internal power dynamics within communities, and different priorities of communities living across the island that were supposed to be all responsible for implementing whole-of-island projects (Buggy and McNamara, 2015). Similarly, in Samoa, consultations with community leaders led to the misplacement of a revetment wall that increased flooding in the area against engineering advice (McGinn and Solofa, 2020).

15.5.6 Livelihood Responses

Communities across small islands are adapting to the impacts to climate change across a range of livelihood activities. Coastal fishers have adapted by employing a wide range of activities ranging from diversification of livelihoods to changing fishing grounds and considering weather insurance (Blair and Momtaz, 2018; Karlsson and McLean, 2018; Lemahieu et al., 2018; Turner et al., 2020). Such perceived climate change impacts as increases in both air and ocean temperature, increases in wind and changes in rainfall have led a number of fishermen to undertake adaptation strategies in Antigua (Antigua and Barbuda) and Efate (Vanuatu). In Antigua, adaptation strategies have included investments in improved technologies and equipment, changing fishing grounds, and seeking better training and education, (Blair and Momtaz, 2018). In Efate (Vanuatu) the majority (87%) of the fishermen who were surveyed used livelihood diversification as an adaptation strategy whereas 53% have also sought new fishing areas as a result of the changing conditions (Blair and Momtaz, 2018). In Southwest Madagascar, due to deteriorated reef conditions, coastal fishermen now go further offshore to catch fish or have adapted their fishing techniques while others, closer to the tourism markets, have opted for livelihood diversification (Lemahieu et al., 2018). Coastal fishers in the Dominican Republic have also diversified their livelihoods and use local knowledge in changing fishing practices and locations depending on environmental conditions (Karlsson and McLean, 2018). In the future, increased inland rainfall could for example provide new areas for inland aquaculture in the Solomon Islands as an adaptation strategy and reduce also pressure from coastal fishing (Dey et al., 2016).

In the agricultural sector in Jamaica, adaptation strategies include varying expenditure on inputs (e.g., fertilizers, chemicals, labour), diversifying cropping patterns, expanding or prioritising other cash crops (e.g., fruits and vegetables), engaging in small-scale livestock husbandry (Guido et al., 2017), and investing in irrigation technologies due to increased drought and infrequent rainfall (Popke et al., 2016). In many higher elevation islands within the Pacific, including islands of Vanuatu and Fiji, communities continue to use (to varying degrees) traditional adaptive strategies (designed to reduce their vulnerability to tropical cyclones). These include planting a diversity of different crops within household and communal gardens, locating gardens in different areas within their customary lands (to ensure that not all crops are destroyed due to extreme event), and the storage, and preservation of certain foodstuffs (so-called famine foods) (Campbell, 2014b; McMillen et al., 2014; Le Dé et al., 2018).

Given changes in climatic conditions, in Puerto Rico women in the coffee industry are now forming their own "micro-clusters" of complementary activities, such as rebuilding of public spaces, running environmental education programmes for children, and opening new commercial enterprises (e.g., coffee shops, and food products) that do not rely on traditional coffee supply chains or government assistance (Borges-Méndez and Caron, 2019). Such strategies parallel those undertaken by Pacific women working on various local-level climate change adaptation and environmental projects throughout small island nations of the Pacific. Women report how they are testing and using adaptive strategies, which are informed by IK & LK, but which are being modified to suit the changing environmental conditions they are encountering (and those projected in the future). This includes harvesting rainwater during droughts, planting native plants along coastlines to prevent erosion and flooding, developing plant nurseries, experimenting with growing salt-tolerant (taro) crops, and relocating crop cultivation inland (McLeod et al., 2018).

The tourism sector is increasingly a major source of cash-based livelihoods across small islands. Despite the high vulnerability and sensitivity of island tourism to climate change at a national scale (Scott et al., 2019), there is evidence from the South Pacific that local tourism operators' adaptive capacity is high due to socio-cultural factors. In Samoa, adaptive capacity consisted of accommodation providers' social networks, resources, past experiences and understanding of environmental conditions, and remittances as a form of informal insurance (Parsons et al., 2017). Tongan tour operators' adaptive capacity is strengthened by high climate change awareness, strong social networks and remittances as well as perceived high resilience against climate change (van der Veeken et al., 2016). In Fiji, hotels use social media for crisis communication, in particular to mobilise resources through donations and fundraising to enable faster disaster recovery (Möller et al., 2018).

Evidence from Vanuatu shows that climate risk to tourism destinations is influenced by multiple, interconnected economic, socio-cultural, political, and environmental factors suggesting that holistic approaches are needed to reduce risk and avoid negative knock-on effects (Loehr, 2020). Tourism can contribute to strengthening mechanisms which reduce vulnerability and increase adaptive capacity of the wider destination, such as providing adaptation finance, investing in education and capacity building, and working with nature rather than against it (Loehr, 2020). Examples include for example numerous Ecosystem-based Adaptation initiatives (Mycoo, 2018a). In Vanuatu, tourism businesses are engaged in establishing Marine Protected Areas to address multiple risks from climate change, population growth and development (Loehr et al., in press). In the Seychelles, coral restoration programmes and mangrove reforestation are promoted through public-private partnerships, generating opportunities for wetland-tourism (Khan and Amelie, 2014).

The willingness of tourism businesses to finance adaptation measures varies. Islands have developed building codes considering impacts from sea level rise; however, these are often not enforced (Hess and Kelman, 2017). In cases where tourist resorts have been part of climate adaptation projects, such as funding for hard coastal protection infrastructure, the resort owners find that these diminish the aesthetics of the beach destination (Crichton and Esteban, 2018). Adaptation taxes and levies imposed on tourism can provide funding (Mycoo, 2018a), as British Virgin Islands' The Environmental Protection and Tourism Improvement Fund Act, 2017 shows (Government of the British Virgin Islands, 2017). A lack of interaction between tourism and climate change decision makers is a commonly identified issue (Mahadew and Appadoo, 2018; Becken, 2019; Scott et al., 2019). A number of adaptation measures are recommended in the literature such as increasing climate change research, education and institutional capacities; product and market diversification away from coastal tourism to include terrestrial-based experiences and heritage tourism, and mainstreaming adaptation in tourism policies and vice versa, e.g., to include appropriate planning guidelines for tourism development, coastal setbacks and environmental impact assessments (Becken et al., 2020; Mycoo, 2018a; Thomas & Benjamin, 2020; van der Veeken et al., 2016). However, there is limited evidence of whether interventions such as product diversification have been successfully implemented, and longitudinal studies on the effectiveness of adaptation measures implemented in island tourism are still limited. Further research in this sector is needed given its increasing significance to small islands as a livelihood option and a major part of their economies overall.

15.5.7 Disaster Risk Management, Early Warning Systems and Climate Services

Given their particular exposure and vulnerability to a range of fast- and slow-onset hydro-meteorological and ocean extreme events (15.3.2), disaster risk management (DRM) investments in small islands are commonly framed as reducing climate change-driven risk and contributing to sustainable development (Mercer et al., 2014a; Kuruppu and Willie, 2015; Gero et al., 2011; Johnson, 2014). Some DRM–related approaches have been confirmed to increase adaptive capacity in some small islands regions, including strengthening the capacity of National Meteorological and Hydrological Services (NMHS) to deliver effective warnings (WMO et al., 2018); nurturing inclusive, participatory and community-based processes that build social capital (De Souza and Clarke; Blackburn, 2014; McNaught et al., 2014; Handmer and Iveson, 2017; Chacowry et al., 2018; Currenti et al., 2019; Cvitanovic et al., 2019; Hagedoorn et al., 2019; Gero et al, 2015), as well as processes that integrate Indigenous knowledge (IK) and local knowledge (LK) with science (Hiwasaki et al., 2014; Carby, 2015; DeGraff and Ramlal, 2015; Bryant-Tokalau, 2018a; CANARI, 2020).

In the Pacific, integration of previously disparate DRM, adaptation and sustainable development planning has advanced considerably since AR5 at both national (SPREP, 2013) and regional level (SPC, 2016), as has institutional reform (White, 2015; Nalau et al., 2016), and mainstreaming of multiple DRM and adaptation oriented applications across the water and food security, sanitation, infrastructure development, risk assessments, communications, youth and community portfolios at regional, national and local scales (SPC, 2013; SPC, 2015; SPC, 2017). By contrast, very little has been published on the Caribbean context or in other small island regions on successful DRM for adaptation, making a robust statement on progress difficult.

Although many small island countries operate Early Warning Systems (EWS) for various hazards, the governmental priority, stage of development and overall effectiveness of these EWS at national to local levels, vary widely. Many small islands, especially those with the highest risks and the least resources, remain highly challenged in building and sustaining integrated, people-centred, end-to-end early warning systems that are fully functional across the four inter-related components of EWS. Past (WMO, 2011b) and more recent (WMO et al., 2018; Mahon et al., 2019) assessments of early warning capabilities in the Caribbean highlight improvements in EWS for weather, water and climate over time. However, progress has been uneven across hazards, governance levels and spatial and temporal scales, with more advanced development of some sub-systems and EWS pillars than others. As an example, whilst significant progress has been made in the area of detection, monitoring, analysis and forecasting of severe weather systems, there is a need to strengthen this area for other climate-related hazards such as wildfires, localised intense rainfall, floods, as well as heatwaves and droughts which become more important in a changing climate.

The movement towards an integrated multi-hazard early warning system has also been slow, and the harmonisation and development of a standardised and inter-operable, multi-hazard EWS that addresses climate-related hazards across multiple spatial and timescales remains a challenge (Mahon et al., 2019). Assessments also point to specific deficiencies including significant gaps in the area of disaster risk knowledge - particularly the development of risk assessments, the variable capacity for interpreting scientific warning products across states, as well as effective communication of warning messages to populations at risk (Lumbroso et al., 2016) (WMO, 2011b; WMO et al., 2018).

There is increasing recognition and commitment at global (WMO, 2011a; WMO, 2014; UN, 2015c; UN, 2015b; UN, 2015a), regional (CCCCC, 2011; CDEMA, 2014; SPC, 2016; SPREP, 2017; CIMH et al., 2019; see also Chapter 3, Section 3.6.3.2.4) and national levels (SPREP, 2016a; WMO, 2016a) of the importance of climate services in supporting adaptation decision making in small islands (*medium evidence, high agreement*). A number of SIDS-focused climate service programmes have emerged, especially in the Caribbean and Pacific (CIF, 2015; Martin et al., 2015; SPREP, 2016b; WMO, 2016b; WMO, 2018a; WMO, 2018b; WMO, 2017) and at least one SIDS – Dominica - has been prioritised as a pilot implementation country under the Global Framework for Climate Services (WMO, 2016a). The majority of these programmes aim to improve climate data quality, management and associated observation, modelling and information services (e.g., Martin et al., 2015; Hermes et al., 2019), enhance sectoral and multi-sectoral climate early warning systems (e.g., Smith et al., 2017; Mahon et al., 2018), and provide user-tailored products and services through knowledge co-production processes (e.g., Kruk et al., 2017 and see SPREP (2016a) for examples of Pacific climate services). As is the case globally (Vaughan et al., 2018), climate services focused on decision-making at seasonal (3–6 month) and weather timescales has thus far been the focus of investment in small islands, with less investment in climate services for decision making at longer timescales.

Despite the development of some climate services evaluation methodologies (Vaughan and Dessai, 2014; Newth and Gunasekera, 2018), studies assessing the effectiveness and value of climate services in small islands are lacking, particularly those evaluating the contribution of climate services to adaptation to longer term climate change (Vaughan et al., 2018). One of the few evaluations available assessed the outcomes of a Caribbean agro-meteorological initiative, highlighting shortcomings in dissemination by National Meteorological and Hydrological Services (NMHSs), as well as uptake and use by farmer communities of climate outlook bulletins that communicate a three-month seasonal forecast (Vogel et al., 2017). This aligns with other studies from the Caribbean (Mahon et al., 2019; Dookie et al., 2019) and Indian Ocean (Hermes et al., 2019), which have found that NMHSs and regional intergovernmental bodies face key capacity challenges in translation, transfer, and facilitation of the use of climate information to various end user groups. As identified by Dookie et al., 2019, in many small island contexts a gap remains between investments in data quality and information services and uptake and use in risk reduction by policy and decision makers. Bringing policy makers and users into discussions about how to shape investments in climate information services is recommended, as is provision of dedicated resources to translate data and information services into decision support tools and products (Dookie et al., 2019; Haines, 2019)

15.6 Enablers, Limits and Barriers to Adaptation

Since AR5, more literature has emerged on barriers and limits to climate change adaptation across small islands. Adaptation is not only about choosing between technical options but is also "a social and political challenge" (Petzold and Ratter, 2015) illustrating the more fundamental barriers and limits but also enabling conditions that underpin adaptation processes in different small island contexts. The resource bases of most small islands are restricted by the geographical size of the islands, but also by governance arrangements and financial and human resource capacity to implement adaptation actions on the ground (Cvitanovic et al., 2016; Scobie, 2016; Beckford, 2017; Ha'apio et al., 2018). Currently, the institutional and legal systems remain ill-prepared for managing relocation and other planned and/or autonomous responses to climate threats in the region (Mycoo, 2018a), limited local resources are creating a push for temporary and/or permanent migration to other islands (Betzold, 2015) although some governments have already developed relocation guidelines (Government of Fiji, 2018).

15.6.1 Governance

Specific governance-related barriers for effective adaptation have been identified to include: lack of coordination between government departments and sectors and limited policy integration (Scobie, 2016; Robinson, 2017), lack of ownership of adaptation implementation in cases where communities or national governments have not been part of the adaptation decision process (Conway and Mustelin, 2014; Kuruppu and Willie, 2015; Nunn and Kumar, 2018; Parsons and Nalau, 2019; Prance, 2015), and difficulties in integrating IK & LK as part of adaptation initiatives. Specific barriers to effective sustained adaptation in the Pacific include variable climate change awareness among decision-makers, and the preference for short-term responses rather than longer-term transformative ones (Nunn et al., 2013). Barriers to effective adaptation implementation at country level also stem from donors' preferencing their own priorities that do not necessarily fit the country priorities or context (Conway and Mustelin, 2014; Kuruppu and Willie, 2015; Prance, 2015), something that has led to increasing calls for effective community/cultural engagement in adaptation, especially through CBA and EbA (Ensor et al. 2018; Nalau et al. 2018b). In cases where recovery efforts are framed as purely a matter of infrastructure other important aspects, such as livelihoods and gender, are more easily overlooked in adaptation (Turner et al., 2020).

Several other governance related barriers also persist. In the Caribbean small islands such as Jamaica and St. Lucia, and also in the Pacific, barriers to mainstreaming adaptation include competing development priorities, the absence of planning frameworks or 'undetected' overlaps in existing frameworks, serious governance flaws linked to the prevalence of corruption and corrupt people in political and public life, and insufficient manpower and human resources, linked to countries' financial capacity (Robinson, 2017). An analysis by Gourlie et al., (2018) of Pacific coastal fisheries legislation found only a few countries where climate change adaptation was embedded in existing legislation despite the overall agreement to *A New Song for Coastal Fisheries - Pathways to Change: the Noumea Strategy*', a regional strategy to improve coastal fisheries management in a changing climate. Many climate change specific initiatives across small islands have a unidirectional focus on climate risks and shift limited resources away from other important development objectives (Baldacchino, 2018). Local level plans are often overlooked: for example, in Mauritius, local level climate adaptation plans are currently nearly non-existent while district councils have rarely been successful in even accessing international adaptation finance (Williams et al., 2018). In Samoa, several national level programs on adaptation have had difficulties in engaging with the local level even if the decision-making powers on actual land management sit within the communities (McGinn and Solofa, 2020). In the Caribbean, the lack of strong governance mechanisms for urban planning have contributed to urban sprawl and expansion that has increased the number of informal settlements, and population growth are driving Caribbean small islands to their limits (Enriquez-de-Salamanca, 2018; Mycoo, 2018a; Mycoo 2018b).

Adaptation governance is also complicated further by the multitude of stakeholders involved, with differing agendas and priorities. In the Bahamas, private properties have significant say in how and what adaptation measures they decide to pursue and are not well regulated, with the tourism sector in particular dominated mainly by external investors (Petzold et al., 2018). Social organisations, such as the churches, that have significant influence in many Oceanic countries, have begun to engage in climate change discussions and governance. Many churches report, however, being constrained to act on climate adaptation due to lack of financial resources, low levels of professional knowledge on the issue, and their members not perceiving climate change as an urgent risk (Rubow and Bird, 2016). Actors such as military services in the Indian and Pacific Oceans also control a high number of assets in vulnerable locations and will need to integrate climate information into adaptive planning in the future (Finucane and Keener, 2015) even if these fall outside of the conventional sphere of adaptation policy and planning.

For policymakers in the Caribbean and Indian Ocean, the difference between an adaptation limit and an adaptation barrier/constraint in a small island context is marginal (Robinson, 2017). Some policymakers view them as being one and the same—a key conceptualisation is that an adaptation barrier pushes a small island to its limit (Robinson, 2017).Low technical capacity, and poor data availability and quality are reported as limiting adaptation in Caribbean small islands such as Dominica, and St. Vincent and the Grenadines (Smith and Rhiney, 2016; Robinson, 2018a). These factors are, however, secondary to the lack of finances, which is seen as a fundamental limit (Charan et al., 2018; Robinson, 2018a; Williams et al., 2018). This was also reported in the Seychelles, despite its success with innovative financing streams and being a leader in the Indian Ocean in this regard (Robinson, 2018b). In the Caribbean context, key barriers to adaptation in Indigenous and rural communities in St. Vincent and the Grenadines consist of "low socio-economic status of households, limited training, low access to technology, poor access to road especially in mountain lands, limited market opportunities and lack of or limited institutional support" (Smith and Rhiney, 2016, p. 29). Yet, Le Cornu et al. (2018) assessed spatial management and climate adaptation practices in small-scale fisheries in the Pacific Islands and found that effective ocean management can advance climate action and provide the necessary spatial data in doing so.

Limited regional cooperation across sub-national island jurisdictions (jurisdictions with semi-autonomous status) along with limited regional-scale climate information are also stymying action (Petzold and Magnan, 2019). This is a concern given the need for pooled governance in response to capacity constraints across small jurisdictions (Dornan and Newton-Cain, 2014; Kelman, 2016). Coupled with this, there is insufficient understanding of the role of regional and international actors such as the Caribbean Community Climate Change Centre and the Global Environment Facility, respectively (Middelbeek et al., 2014). However, sometimes external pressure and, for example, trans regional trade agreements are "useful for reducing unsustainable local socio-political arrangements" as seen in the Solomon Islands regarding fisheries management within the concept of Blue Economy (Keen et al., 2018, p. 338). Similarly, in Samoa, the World Bank's Pilot Program for Climate Resilience (PPCR) and Adaptation Fund's Enhancing Resilience of Samoa's Coastal Communities to Climate Change, illustrate successful examples of multi-level governance due to their programmatic and pragmatic approaches versus project-based approaches (McGinn and Solofa, 2020). Enabling factors in these funding programmes relate to strategic placements of funds and responsibilities in the relevant ministries, alignment with national priorities and pre-existing plans, pooling funding to fill existing finance gaps, and increased awareness across scales and departments of synergies and gaps between different initiatives (McGinn and Solofa, 2020). Initiatives also like the Pacific Adaptive Capacity Framework (Warrick et al., 2017) and regional strategies such as the Framework for the Disaster and Climate Resilient Development in the Pacific (FRDP) enable the localising of climate adaptation into cultural contexts in an integrated manner (SPC, 2016).

Countries like the Seychelles and Maldives have developed national climate change plans that recognize linkages to food security, health and disaster risk reduction, although these-face significant resourcing issues when it comes to implementation (Techera, 2018). National level plans, such as National Adaptation Plans of Action (NAPAs), increasingly could include local government engagement and have a stronger focus on urban centres and adaptation (Mycoo, 2018a). Building codes act as supportive enablers for adaptation governance: requiring more hurricane-resistant housing in the Caribbean, including incentives for informal settlements to build in a more resilient manner, can achieve multiple development and adaptation outcomes (Mycoo, 2018a). In Dominica, a Climate Resilience Executing Agency of Dominica (CREAD) established in 2019, aims to enable stronger climate resilience by bringing all sectors and services together for more effective coordination (Turner et al., 2020). A range of mechanisms also exists in the tourism industry: adaptation taxes and improved building regulations could reduce risk drastically for example in the Caribbean region (Mycoo, 2018a). However, empirical evidence from Maldives suggests that the tourism industry in particular is not investing in long-term climate adaptation strategies but pursuing short-term measures such as sand replenishment of beaches on a daily basis and desalination plants to combat water shortages (Shakeela and Becken, 2015).

15.6.2 Health-Related Adaptation Strategies

The term 'health systems' refers to the organisation of people, institutions, and resources that work to protect and promote population health. The two components of health systems are public health and health care; adaptation is needed in both to develop climate-resilient health systems (WHO, 2015). Adaptation measures focus on each of the building blocks of health systems, including leadership and governance; a knowledgeable health workforce; health information systems; essential medical products and technologies; health service delivery; and financing. Many small island states have policies to manage these health risks, although management efforts are inadequate in many settings (McIver et al., 2016). Ministries of Health are largely unprepared to adapt to a changing climate because few programmes take climate change into account.

Different kinds of diseases pose threats to island communities. A vulnerability and adaptation assessment conducted in Dominica identified vector-, water- and food-borne diseases and food security as priority threats from climate change (Schnitter et al., 2019). Short-term adaptation options include strengthening solid waste management and enforcing current legislation; increasing public awareness, with a particular focus on unemployed youth; providing training to health sector staff; improving the reliability and safety of water storage practices; improving climate change and health data collection methods and enhance environmental monitoring; enhancing the integration of climate services into health decision-making; strengthening the organisational structure of emergency response; and ensuring sufficient resources and surge capacity. Longer-term adaptation options build on these and include developing early warning and response systems for climate-sensitive health risks; enhancing data collection and information flow; increasing the capacity of laboratory facilities; and developing emergency plans. Further, many healthcare facilities in Small Island states are located in coastal regions that are subjected to flooding and storm surges. Healthcare facilities need to adapt and strengthen their infrastructure (e.g., to prevent flooding) and to increase their capacity to continue to provide services to critical services during extreme events and typhoons.

15.6.3 Adaptation Finance and Risk Transfer Mechanisms

In the majority of small island developing states there is a high dependence on international financing to support adaptation to slow and rapid onset events (Robinson and Dornan, 2017; Petzold and Magnan, 2019). However, funds tend to be geared towards supporting sectoral-level adaptation initiatives for vulnerable natural resource sectors such as water, biodiversity and coastal zones (Kuruppu and Willie, 2015). Considering low income small islands such as Comoros, Haiti, and São Tomé and Príncipe, international modalities do little to address the root causes of vulnerability or to support system-wide transformations

(Kuruppu and Willie, 2015). Although countries like Trinidad and Tobago have amassed oil wealth, the profits are not invested in a way that benefits environmental goals (Middelbeek et al., 2014). In Mauritius, a lack of financial resources for climate change adaptation has been recognised as a specific impediment in district council level (Williams et al., 2018).

Although small island jurisdictions have seen increased flows of adaptation finance through mostly top-town arrangements, they face large implementation difficulties (Weir and Pittock, 2017; Magnan and Duvat, 2018). There are growing concerns among policy- and decision-makers in small islands about the current levels and forms of adaptation finance, and about countries' experience with accessing it (Robinson and Dornan, 2017). In the Caribbean, 38% of flows were concessional loans and 62% were grants (Atteridge et al., 2017); the situation in the Atlantic and Indian Oceans is starkly different—nearly 75% of the flows were in the form of concessional loans and grants accounted for the remaining 25% (Canaleset et al., 2017). This raises questions about fairness and justice for small islands having to finance adaptation to climate impacts to which they made a negligible contribution. In the Pacific, 86% of aid was delivered as project-based support (Atteridge and Canales, 2017), which further raises concerns about the long-term sustainability of adaptation interventions. Direct budget support was rare (Atteridge and Canales, 2017), signalling the importance of works such as Rambarran (2018) that support cross-regional lesson-learning by, for example, showcasing the experience of Seychelles with successfully devising innovative financing mechanisms for supporting adaptation and conservation goals, and reducing its public debt.

Microfinance is increasingly viewed as a positive mechanism to improve access to climate adaptation funding (Di Falco and Sharma, 2018). In the Caribbean, a significant barrier in accessing climate finance relates to bureaucratic structures, which means that money intended for communities does not reach them (Mycoo, 2018a). Many adaptation projects even at the community level have upfront costs that need to be supported, especially in communities where there is little hard cash in use (Remling and Veitayaki, 2016). Attention to both short- and longer-term funding remains crucial although many donors only finance short projects instead of longer programmes (Atteridge and Canales, 2017; Conway and Mustelin, 2014; Remling and Veitayaki, 2016). Despite such challenges, communities in the Pacific region have used "cashless adaptation" for a long time that involves trading of services and items as a form of Indigenous microfinance (Nunn and Kumar, 2019). Social networks also function as a source of informal microfinance. Extended family members who have migrated elsewhere often send back remittances to their families and communities especially after disasters. This is evident in Samoa where Indigenous tourism operators receive remittances from overseas family members (Crichton and Esteban, 2018; Parsons et al., 2018), with similar processes observed among atoll communities in the Solomon Islands (Birk and Rasmussen, 2014), Vanuatu (Handmer and Nalau, 2019) and in Jamaica (Carby, 2017). However, the role of migration and remittances is still poorly understood; it is difficult to quantify the informal flows and understand the extent they support effective adaptation (Campbell, 2014a; Parsons et al., 2018; Handmer and Nalau, 2019).

In Old Harbour Bay, Jamaica, the largest fishing village, a high number of community members engaged in the fishing industry, particularly vendors and scalers, do not own the material assets needed to fully benefit from these livelihood activities (Baptiste and Kinlocke, 2016). In Zanzibar, the majority of fishers do not own the boats or fishing gear and hence have to rent the equipment leading to increased costs and dependence on other people (Suckall et al., 2014). Developing a broader asset portfolio by increasing access to such assets via adaptation finance investments could reduce vulnerability across the community, and in particular function as an effective livelihood-based adaptation strategy for the most vulnerable such as women, who are part-time employed and in peripheral roles in the fishing industry (Baptiste and Kinlocke, 2016). In Belize and Dominican Republic, many coastal fishers for example use informal credit from food stores or captains to enable them to withstand financial losses that are often incurred during bad weather and extreme events (Karlsson and McLean, 2018).

In Vanuatu, discussions are ongoing on increasing insurance availability for TCs and droughts, but standardisation of housing designs to get insurance can become difficult where the costs make it prohibitive and run counter to traditional building designs and materials (Baarsch and Kelman, 2016). Empirical evidence from Belize, Grenada, Jamaica and St. Lucia indicates that there are also other factors why people do not take insurance, including the cost of premiums (44 %), lack of trust in insurance companies (27 %), having never considered insurance (26 %), a lack of need for insurance (25 %) and a lack of knowledge of insurance (22 %)" (Lashley and Warner, 2013, p. 108). Increasing trust could be addressed by seeking out domestic banks or credit unions with whom people are already engaging with, while also using social marketing campaigns to raise awareness of weather-related insurance to address knowledge gaps and lack of awareness of these kinds of alternative financial risk management tools (Lashley and Warner, 2013). In Dominica, many coastal fishers are however suspicious of insurance schemes given past experiences of not being paid out on time or having to disclose catch data (Turner et al., 2020). Yet, insurance is not capable of addressing all kinds of loss and damage accruing from climate impacts and should be used as an adaptation strategy across many (Lashley and Warner, 2013).

Insurance cover is a critical question in small islands. For example, in Vanuatu, one company's "insurance policy does not cover storm damage from the sea or high tides…which is not helpful for properties damaged by a tropical cyclone's storm surge" (Baarsch and Kelman, 2016, p. 6). There are also such regional initiatives as the Caribbean Catastrophe Risk Insurance Facility and the Pacific Catastrophe Risk Assessment and Insurance Initiative that offer countries increased access to data and funds, but these funds are still rather small compared to the needs across the countries (Handmer and Nalau, 2019). There is also limited access to insurance schemes due to lower demand in small markets (Petzold and Magnan, 2019) especially when "it is not clear that any premium level would be affordable for Pacific islanders, given the low rates of cash income and high rate of subsistence living" (Baarsch and Kelman, 2016, p. 8). In south-western Jamaica, small holder farmers are constrained in their capacity to adapt to increased drought conditions due to lack of access to finance, new irrigation technology and greenhouse production as these require significant upfront investments, leading to "widening disparity in the ability of different farmers to deploy specific strategies in response to climate risk" (Popke et al., 2016, p. 78). In Saint Lucia and Grenada (via the Caribbean Oceans and Aquaculture Sustainability Facility), but also in Dominica, discussions are ongoing on national level parametric fisheries insurance given the high vulnerability and dependence on fishing gear, shared infrastructure and assets amongst coastal fishers (Sainsbury et al. 2019; Turner et al., 2020).

15.6.4 Education and Awareness-Raising

A significant barrier to effective climate adaptation is the lack of education and awareness around climate change both among the general public (for example in the Bahamas; (Petzold et al., 2018) and among decision-makers in the more remote rural communities (Nunn et al., 2013; Mycoo, 2015). Increasing knowledge on adaptation options and needs can increase adaptive capacity that is underpinned by "the ability of individuals to access, understand and apply the knowledge needed to inform their decision-making processes" (Cvitanovic et al., 2016, p. 54). Workshops and trainings are seen as crucial at the local scale to build communities' capacity to take action and to integrate climate change considerations to the broader development processes (Remling and Veitayaki, 2016), although workshop-based capacity building in adaptation has been questioned (Conway and Mustelin, 2014; Lubell and Niles, 2019). More interactive community engagement strategies could include "participatory three-Dimensional modelling (P3DM), participatory video, development of photo journals, and civil society plans" (Beckford, 2017, p. 46) that enables broader engagement. In Fiji, Laje Rotuma youth EcoCamps have been used to engage younger Fijians to understand adaptation and increasing environmental stewardship with good outcomes (McNaught et al., 2014). Vanuatu's Volunteer Rainfall Observer Network in turn engages volunteers to record their rainfall observations, demonstrating the use of IK & LK that can be integrated with contemporary weather forecasting (Chand et al., 2014).

In Fiji, a study on adaptive behaviour and intention to invest in more adaptive portfolios found that the intent for adaptive behaviour increased with the supply of climate information (Di Falco and Sharma, 2018). In the Pacific, high performing CBA initiatives included climate awareness raising that equipped people with knowledge to understand occurring environmental changes and what to do (McNamara et al., 2020). Lack of information has the potential likewise to increase community vulnerability. Remote Indigenous farming communities in St Vincent, in the Caribbean, for example have already observed decreased rainfall and increases in temperatures, but they have been largely excluded from agricultural training that includes information in how to improve agricultural strategies in times of climatic shocks and how to prepare for changing climatic conditions (Smith and Rhiney, 2016). Petzold et al. (2018, p. 97) found that in the Bahamas, "ethnic backgrounds and inequalities in income and education, are reflected in people's awareness of climate change risks". In Dominica, access to information critical to fisheries is noted as a significant challenge, including data collection, its management and human resources in building capacity to process and use this information for evidence-based decision making (Turner et al., 2020).

Successful implementation of adaptation can be mis-framing the scale of the needed action. Framing adaptation projects only at a community-scale, like in the CBA approach, might prove problematic if the best scale to leverage adaptation is across catchment or whole-of-island scale (Buggy and McNamara, 2015; Remling and Veitayaki, 2016). The Risk and Vulnerability Assessment Methodology (RiVAMP) developed for Jamaica focused on local and state government officials and their understanding of the role ecosystems can play in adaptation and risk reduction. However, the RiVAMP process did not engage communities who use the ecosystems and need to be aware of the linkages between adaptation and ecosystems (Mercer et al., 2012). In the Caribbean, the Caribbean Climate Online Risk and Adaptation tool has been developed to assist the tourism industry in producing "climate-sensitive developments" (Mackay and Spencer, 2017, p.55). Though some authors conclude on the low climate awareness/understanding among small islanders (Middelbeek et al., 2014; Betzold, 2015; Petzold et al., 2018), others indicate that many Caribbean islanders are acutely aware of past storm events (i.e. social memory) and have a certain degree of self-reliance, which creates the capability to multi-task and cope with limited resources (Petzold and Magnan, 2019). There is, however, a disconnect between knowledge, attitudes and practices—knowledge sharing and learning need to be improved along with the take-up of an evidence-based decision-making approach (Lashley and Warner, 2013; Petzold et al., 2018; Saxena et al., 2018).

15.6.5 Culture

Culture can be defined as "material and non-material symbols that express collective meaning" (Adger et al., 2014, p. 762) and includes worldviews and values, how individuals and communities relate to their environment, and what they perceive to be at risk and in need of adaptation (McNaught et al., 2014; Nunn et al., 2014; Nunn et al., 2016; Remling and Veitayaki, 2016; Granderson, 2017; Neef et al., 2018; Oakes, 2019). In small islands, culture plays an important role in individual and community decision-making on adaptation both as an enabling factor and as a barrier (Nunn et al., 2016; Parsons et al 2017; Neef et al., 2018; Piggot-McKellar et al., 2020). In Samoa, the principles of *Fa'asamoa* (the Samoan way of life) impacts on how decisions are made, including the role of the *aiga* (extended family) that is a web of local, national and transnational kinship networks (Parsons et al., 2018). Enabling factors include the role of social capital in effective climate adaptation (Petzold and Ratter, 2015; Parsons et al., 2018) as indigenous resilience and adaptive capacity are increased by social networks. In Dominica, in the aftermath of Hurricane Maria (2017), social capital in the form of transboundary nearby island networks enabled some communities to recover faster from the disaster including access to more livelihood opportunities and assets (Turner et al., 2020).

Researchers have found that culture is often overlooked in adaptation policies and plans. For example, in the National Communications of 16 SIDS, only one country (Cook Islands) reported adaptation actions that addressed social issues, culture, and heritage (Robinson, 2017). The widespread failure of externally-driven adaptation solutions to be either effective or sustainable in rural small-island communities is that they often exclude community priorities, ignore or undervalue IK & LK, and are based on secular western/global worldviews (Nunn et al., 2016; Piggott-McKellar et al., 2019; Prance, 2015; McNamara et al. 2017; Nunn and McNamara 2019; Donner and Webber, 2014; Schwebel, 2018). Externally driven adaptation initiatives focus on large-scale projects that are not necessarily underpinned by local knowledge and community driven strategies (Prance, 2015; Mallin, 2018). The World Bank Kiribati Adaptation Program (KAP) for example builds mainly on western knowledge and science despite consultations with the Kiribati communities (Prance, 2015). This is problematic in those small island nations where most land and knowledge is embedded in traditional governance and culture but where adaptation plans and decisions are made elsewhere, how that land should be used, and what knowledge is used or discarded in the process (Nunn et al., 2013; Charan et al., 2018; Parsons et al., 2018; Nalau et al., 2018a; Prance, 2015; McGinn and Solofa, 2020).

In Kiribati, communities often use different timescales to evaluate the need for adaptation. I-Kiribati culture's core concept of time is short- and medium term (Prance, 2015), which should be considered in adaptation policy and planning processes especially at the household and community level (Donner and Webber, 2014). This requires changes in the ways that 'problems' and 'barriers' are framed and overcome in island contexts and ultimately requires that key stakeholders, especially community leaders, are empowered to help design and sustain adaptation (Baldacchino, 2018; Weiler et al. 2018). Focusing on values-as-relations (e.g., island communities' relationship with the environment and each other) could diversify the values considered in decision-making processes where economic values are but one of those values (Parsons and Nalau, 2019). Kelman (2018) further emphasizes the importance in ensuring that efforts to build resilience are contextualised within the four domains of islandness (boundedness, smallness, isolation and littorality) to effectively capture subjective nuances associated with climate development efforts on islands. Indeed, those Pacific islands with more island-centric approach to climate adaptation tend to have overall more successful adaptation policies in place (Schwebel, 2018).

The cultural context and sources of knowledge are myriad and diverse in small islands. Community members often use both IK & LK as well as western scientific-based weather forecasts to take actions to prepare for extreme weather events and reduce their vulnerability (Chand et al., 2014; Johnston, 2015; Janif et al., 2016; Granderson, 2017; Kelman et al., 2017), with specific examples from Niue, Tonga, Vanuatu and the Solomon Islands (Chand et al., 2014; Chambers et al., 2017; Chambers et al., 2019). IK & LK cover a wide range of knowledge (including worldviews) and can both enable and constrain adaptation. IK & LK encompass knowledge across "1) weather and climate observations; 2) resource use and management; 3) social networks; 4) local leadership; and 5) beliefs and values" (Granderson, 2017, p. 551). IK & LK are often used especially before and during disasters: in Samoa, for example, people keep particular areas reserved for disaster times such as TC seasons (Kuruppu and Willie, 2015). In Vanuatu, IK & LK indicators for tropical cyclones include "heavy flowering of Nakavika trees or early flowering of mango trees" and turtles going further inland to lay their eggs (Chand et al., 2014, p. 448). IK & LK are however not evenly distributed within communities: these can be traditional intellectual property of particular roles in the villages (e.g., weathermen in Vanuatu), and not available to other community members or external actors directly (Chand et al., 2014; Prance, 2015). In Tongoa Island, Vanuatu, communities are finding that their IK & LK-based seasonal calendars are out of sync given the changes in climatic conditions (Granderson, 2017). Erosion of IK & LK remains a concern across small island nations (Kuruppu and Willie, 2015; Beckford, 2017; Granderson, 2017).

Yet, not all IK & LK are necessarily helpful and can in some cases even lead to maladaptation (Beckford, 2017; Mercer et al., 2012). Elders from the Chuuk State (Federated States of Micronesia, (Elders.from.Atafu.Atoll, 2012), for instance, assign blame for changeable weather patterns, destructive typhoons, and loss of biodiversity to people's failure to maintain and employ their IK & LK. This also includes the shift from traditional religious beliefs to those of Christianity, and the broader adoption of Western knowledge, development, and lifestyles (Hofmann, 2017; Perkins and Krause, 2018). Fatalism (belief that disasters are God's will) is still reported as a major barrier to adaptation: In Maldives fatalism decreases direct adaptation action and influences perceptions of climate risks (Shakeela and Becken, 2015). Similar views have been expressed by Indigenous communities in St Vincent why they do not prepare for hurricanes or climatic shocks (Smith and Rhiney, 2016). In Oceania, Christianity and the church play an important role in how issues, such as climate change, are communicated and thought about (Nunn et al., 2016; Rubow and Bird, 2016), including the Noah and flood story that is taken literally to mean that there is no need to worry about sea level rise (Rubow and Bird, 2016). New forms of eco-theology (theology that connects humans with land, sea and sky) are however emerging that situate climate change as part of environmental stewardship (Rubow and Bird, 2016) and make churches active partners in caring for the environment.

Rather than seeking to integrate IK & LK into a singular form and ensure that Indigenous and local peoples' understandings of climate change are in accordance with western scientific knowledge and worldviews, many studies demonstrate the value in allowing for multiple systems of knowledge through collaborative and co-production projects and strategies, which allow for culturally-situated knowledge, values, and practices to be positioned at the heart of sustainable climate change adaptation (Beckford, 2017; Chambers et al., 2017; Plotz et al., 2017; Malsale et al., 2018; Parsons et al., 2018; Suliman et al., 2020). In the Caribbean context, Beckford (2017) suggests the establishment of Caribbean Local and Traditional Knowledge Network that would function as a shared platform on key knowledge across the region and make IK & LK more available for climate adaptation and community resilience projects where appropriate. Likewise, Indigenous research methodologies are only starting to emerge to the mainstream that introduce more culturally grounded concepts and methods into how research is conducted and enable the decolonisation of mainstream research conducted for example in the Pacific Islands (Suaalii-Sauni and Fulu-Aiolupotea, 2014).

Despite widespread international evidence that the impacts of climate change and disaster events often negatively affect women (and gender minorities) more than men (Aipira et al., 2017; Gaillard et al., 2017; McSherry et al., 2015), attention to gender equality as a concept is still only "embryonic in climate change adaptation in the Pacific" and although recognised in theory (in some policies and project designs), it is not well supported by on-the-ground actions or well monitored (Aipira et al., 2017, p. 237). Many Pacific small island climate change adaptation policies do not mainstream gender across the activities (Aipira et al., 2017), with women's groups being excluded from climate grants due to patriarchal formal and informal governance structures, lack of resources, lower access to educational and training schemes, and no track record (or receiving grants or meeting grant milestones) (Mcleod et al., 2018). However, Pacific women identify several strategies that enable them to adapt to climate change more effectively. These include the recognition and support of women's IK & LK by governments, researchers, and NGOs; increasing women's access to climate change funding and support from organisations to allow them to meet the requirements of international climate change grants; and specific education and training to women's groups to allow them to develop strategic action plans, mission statements, learn financial reporting requirements, as well as general leadership and institutional training (Mcleod et al., 2018). Such measures are likely to enable a broader representation and participation in adaptation processes despite cultural constraints (See Table 15.5). On enabling conditions).

Table 15.5: Enabling Conditions and Factors for Adaptation in Small Islands

[INSERT TABLE 15.5 HERE]

15.7 Climate Resilient Development Pathways and Future Solutions in Small Islands

Development pathways and adaptation possibilities in small islands are shaped by colonial histories the ability of governance systems (Sealey-Huggins, 2017; Baldacchino, 2017) and where the use of concepts, such as transformation and resilience, can be interpreted as a form of neo-colonialism (Parsons et al., 2016; Baldacchino, 2017). Synergies exist between climate resilient development pathways and implementation of Sustainable Development Goals in small islands because development decisions and outcomes are strengthened by consideration of climate and disaster risk (Hay in press; Robinson, 2019). Monitoring progress of SDGs is proving challenging for small islands, in part due to large numbers of indicators in the renewed development goals; this is the case for health indicators in the Pacific (Hall et al., 2019) and water indicators in the Caribbean (Roopnarine et al., 2019). To ensure greater efficiency and effectiveness of SDG implementation, Belize for example is taking a systems-based approach to work across the SDGs (Allen et al., 2018). Yet, literature on SDG implementation is generally lacking for small island states as is the integration of climate risk into infrastructure decisions.

In the Pacific region, 67% of infrastructure is located within 500 metres of coastline and commercial, public and industrial infrastructure are particularly vulnerable due to the location of urban centres (Kumar and Taylor, 2015). Despite this level of vulnerability, the Fiji Vulnerability Assessment (World Bank, 2017) found that climate risks are not being routinely incorporated into infrastructure decisions across the country. The Parliamentary Complex redevelopment in Samoa highlights also that despite strong evidence that suggested the need to relocate the site, numerous cultural and historical factors led to the decision to redevelop at the original site (Hay et al., 2019). Decisions that are optimal for adaptation therefore may therefore not be acceptable in the wider development context within which they operate. Despite this whole-of-island and ridge-to-reef approaches are being considered that can support more interconnected and holistic development pathways in small islands (Brown et al. 2017; Delevaux et al., 2018 a,b; Rude et al., 2016; Mycoo and Donovan, 2017), including designing coastal protection that uses green infrastructure, ecosystem-based adaptation and hard infrastructure in combination (Mycoo, 2014b; Mycoo and Chadwick, 2012).

Tourism system transitions can enable the sector to contribute to climate resilient development pathways through managing climate risks and improving ecological, economic and social outcomes for small islands (Loehr, 2020; Loehr et al., 2020; Sheller, 2020; Mahadew and Appadoo, 2019) (*medium evidence, high agreement*). The decisions and mobilisation of local level government is also an important factor in realising climate resilient development in urban areas, yet there are severe constraints, including economic, legislative and technical capacity barriers to local governments undertaking this role (Mycoo, 2018a, b; Trundle et al., 2019; Williams et al., 2020). For example, many cities and local governments in the Pacific region are severely resource constrained (Kiddle et al., 2017; Keen and Connell, 2019; McNamara and Nunn, 2019; Kelman, 2014). Despite successive Pacific Urban Forums, Pacific local governance literature highlights the gap between commitment and practise and regional responsibility for urbanisation remains unclear (Kiddle et al., 2017; Keen and Connell, 2019; Trundle, 2019). Innovation in climate resilient development policy making however has taken place in the Caribbean (Mycoo, 2018a) and the Pacific (Hay, in press). For example, the Pacific region has been at the forefront of efforts to better integrate climate change and disaster management with broader development planning and implementation (Hay, in press). This region is bringing together disaster risk management, low carbon growth and climate change adaptation with broader development efforts for the first time (Pacific Community et al., 2016). A similar approach is being adopted in the Caribbean with the pursuit of integrating building back better using disaster resilient building techniques and codes with robust land use planning policy in the post-disaster period (Twigg et al., 2017). More effort, however, is needed in implementing this approach in the Caribbean (Wilkinson and Twigg, 2018). Climate risk insurance is also increasingly discussed across small island contexts as a way to support development and adaptation processes (Quesne et al., 2017; Handmer and Nalau, 2019; Morten, 2020; Mycoo, 2018a; Surminski et al., 2016). Research by Climate Analytics on climate risk adaptation and insurance for the Caribbean commenced in 2019. The objective is to incorporate findings into a broader framework of disaster risk reduction to assist farmers, fishers and crafts people in the tourism sector develop resilience and protect their livelihoods. Improvements in cross sectoral and cross agency coordination are creating opportunities for improved disaster preparedness and resilience measures in small islands (Webb et al., 2016; Nalau et al., 2016). However, further integration between aid, public financial management and climate finance is necessary, as is continued investment in coordination mechanisms (Hay, in press).

Early research on the response to COVID-19 indicates that existing disaster response mechanisms in the Pacific and Caribbean islands, and a history of regional collaboration through regional governance mechanisms such as Pacific Islands Forum and CARICOM have assisted in rapid responses to COVID-19 and demonstrate the inherent adaptive capacity of small islands (Hambleton, 2020; Kelman, 2018). The collective efforts of SIDS have also advanced their sustainable development interests on the global stage, contributing to global climate mitigation ambitions and incorporating an oceans focus in the UN SDGs for example (Quirk 2016; Schwebel 2018). Many small islands are highly dependent on tourism for their economies and are facing worsening crises associated with climate-related disasters and more recently COVID-19 disruptions of travel (Sheller, 2020). The re-establishment and re-building of tourism infrastructure and services is often a critical priority for development aid and for government responses post-disasters. Emergent research undertaken during the COVID-19 pandemic highlights the vital importance of SIDS considering the different development pathways available beyond those centred primarily on 'extractive' international tourism. Indeed, the adaptive capacity and innovations demonstrated by SIDS during COVID-19 demonstrates the potential benefits of diversified and sustainable economies (and ecologies) would mean for the resilience of both human and ecological communities (Sheller, 2020). Alternative visions for disaster reconstruction for Caribbean SIDS, for instance, include those centred on agro ecology, food sovereignty, and regenerative economies that promote community- and locally-based economic activities (Sheller, 2020).

In the context of small islands, climate justice research is expanding beyond the initial debates about nation-states responsibilities for the causes and responses to climate change, with studies increasingly demonstrating the complex and dynamic intergenerational and multiscalar dilemmas of climate justice (Baptiste and Devonish, 2019; Douglass and Cooper, 2020; Ferdinand, 2018; Sheller, 2018, 2020). In Caribbean SIDS research highlights how intersecting external and internal socio-economic and political processes (most notably those associated with colonisation and globalisation) are creating a situations where marginalisation populations are becoming increasingly socially and -economically disadvantaged and politically marginalised, which are in turn heightening climate vulnerability and impeding sustainable development efforts (Baptiste and Devonish, 2019; Gahman and Thongs, 2020; Moulton and Machado, 2019). In Barbuda, following Hurricane Irma, the Barbudan Government, supported by various international development and disaster aid institutions and actors, sought to revoke Barbudans' communal land rights on that basis that communally-held land was a barrier to the nation's reconstruction and development efforts (centred exclusively on foreign investment in tourism) (Baptiste and Devonish, 2019). Scholars similarly note how elsewhere in the Caribbean, the negative consequences of Hurricane Irma as well as Hurricane Maria and Hurricane Harvey in 2017 were not confined to financial, physical, and socio-cultural damages and losses from the hurricanes, but extended to how development aid and disaster aid was coordinated and distributed within various nations. The (neo) colonial entanglements and structural violence negatively affected the recovery efforts of many communities and contributed to heightened vulnerability and new climate injustices (Gahman and Thongs, 2020; Moulton and Machado, 2019; Sheller, 2018). Linking with climate justice are also the notions of limits to adaptation and loss and damage. SIDS are already reporting significant losses and damages in particular from tropical cyclones/hurricanes and increases in sea level rise (Thomas and Benjamin, 2017). Yet, the methods and mechanisms to assess climate-induced losses and damages are still largely undeveloped and the issue is rarely integrated into small island national policies (Talakai, 2015; Thomas and Benjamin 2017; Handmer and Nalau, 2019).

15.8 Research Gaps

Assessment of the Post-AR5 literature reveals progress on some of the research gaps and data gaps identified in the previous IPCC assessments of small islands, while other gaps still require more attention. Despite intensive study, significant uncertainties remain with many knowledge gaps arising from the complexity of biophysical and social interactions, and the local and regional heterogeneity of small islands. The literature assessed to date revealed research and data gaps in four general areas: island-scale data availability; ecosystem services data; vulnerability and resilience and; adaptation.

15.8.1 Island-scale Data Availability

Small island regions face unique data availability and capacity development challenges. The small size of the islands affects the availability and accuracy of downscaled climate data and projections (Gould et al., 2018). Small islands are projected to remain vulnerable to SLR, however, there is a lack of oceanographic (e.g., tidal), meteorological, high resolution topographic and bathymetric data, as well as future sea-level and wave climate projections for most islands, which severely constrain modelling studies and therefore improved understanding of future coastal flooding and erosion (Giardino et al., 2018). There is also a need for further developing context-specific numerical models, especially through the inclusion of sediment transport (Shope and Storlazzi, 2019), coastal and marine ecosystems' responses (Beetham et al., 2017), and various societal responses (e.g., engineering and ecosystem-based solutions (Giardino et al., 2018) in simulations. The complexity and specificities of small island environments and unavailability of robust baseline data considerably challenge modelling studies in small islands contexts, as reflected by the serious limitations of global modelling impact studies for these settings (Mentaschi et al., 2018, p. 9; Vousdoukas et al., 2020). Data and model developments are therefore urgently needed to assess the future habitability or exploitability of the islands that are the most critical to small island countries and territories, and to help identify and promote appropriate (especially in technical terms) solutions.

Downscaled climate data at the terrestrial small island scale is also required to conduct modelling assessments. This is particularly needed for islands with complex topography which could be important in providing much-needed climate refugia for the survival of narrow range species such as endemics (Balzan et al., 2018). Such spatial data could be used to maximize the potential of islands to deliver critical ecosystem services (Balzan et al., 2018; Katovai et al. 2015). Thomas and Benjamin (2017) highlighted the lack of data as an area of concern related to assessing loss and damage at 1.5°C. Understanding loss and damage also requires more detail on island-specific losses and damages accruing from anthropogenic climate change impacts. At the moment, such assessments are limited, and most of the small islands have not yet documented these factors in their national adaptation plans or policies (Handmer and Nalau, 2019). There is a need for specific studies also on biophysical variables and species (e.g., impact of temperature rise on mangroves); long term impacts of ocean acidification on species, including relationship to disease outbreaks, and changing breeding grounds of marine species and impacts on fisheries and marine-based livelihoods; incorporating biophysical feedback and interconnectivity of environments into models; and more detailed datasets (e.g., bathymetry, coastal assets) (World Bank, 2016; McField, 2017; Wilson, 2017).

15.8.2 Vulnerability and Resilience

Studies on the variability of vulnerability within and between islands and states, typologies of best practice actions (Oculi and Stephenson, 2018), frequency of knowledge sharing among islands and regions (Foley, 2018), identification of regional framework mechanisms, and mapping the complex impact and hazard interactions at a regional scale (Duvat et al., 2017a; Scandurra et al., 2018; Thiault et al., 2018; Neef et al., 2018) are required for a deeper understanding of vulnerability and resilience. Kelman (2018) emphasised the importance of ensuring that resilience-building efforts are contextualised within the four domains of islandness (boundedness, smallness, isolation, and littorality) to effectively capture subjective nuances associated with climate development efforts on islands. Baldacchino (2018) review of climate change-related initiatives in small island states highlights the potential ontological trap associated with a unidirectional focus on climate risks and the shifting of limited resources away from other important development objectives.

Research gaps in place-based assessments of social service bundles coupled with policy actions (Balzan et al., 2018) highlight the need for new knowledge to strengthen communication between academia, donors, the private sector, community and government as a challenge to climate change adaptation in small islands to address vulnerability challenges. More research is needed to fill the gap created by ineffective collaborations and networks, especially among academia, industry, and government (Allahar and Brathwaite, 2016; Schipper et al., 2016; Mycoo and Donovan, 2017). At a regional scale, small islands sub-groups like the Caribbean, Pacific, and AIMS have two seemingly contrasting characteristics, of being both transboundary (regions), but also highly variable (between SIDS and between regions). Both of these characteristics require further exploration in the literature to improve decision making (Blair and Momtaz, 2018).

There is a paucity of research on the vulnerability of island ecosystem services to climate change (Balzan et al., 2018). While there is a relatively rich scientific history on the pressures of habitat loss and degradation, impacts of natural hazards and invasive species, far less is known about the interactions with adaptive capacity and livelihood conditions on islands. In small island contexts, there is a specific need for assessing the effectiveness and cost of ecosystem - and community-based solutions where the latter have been implemented. The design of generic assessment methods and tools is required to allow for comparative analyses that will, in turn, provide useful guidance for the promotion of context-specific adaptation strategies (Blair and Momtaz, 2018). For many of the small islands, especially SIDS, the economic valuation of marine and coastal ecosystem services coastal protection, fisheries, tourism is of great importance, as well as the subsequent losses in these sectors and related livelihoods due to climate change impacts (Waite et al., 2014; Schuhmann and Mahon, 2015; World Bank, 2016; Layne, 2017). There are few integrated modelling studies that can inform future habitability of differentiated small island types and populations affected. Existing studies (Rasmussen et al., 2018) have progressed knowledge since AR5, but island-specific analyses are required to robustly estimate the future ability of land to support life and livelihoods, taking into account multiple climate-drivers, future population exposure, and adaptation responses.

Research into those ecosystem services that provide benefits to human wellbeing (including slow-onset hazards), the ability of an ecosystem to be restored to a service-able extent in a changing climate, and modelling to predict an ecosystem's ability to adapt to climate change impacts are limited (Biggs et al., 2015; Bank, 2016; Cashman and Nagdee, 2017; Layne, 2017; Wilson, 2017). More work is also needed in understanding how the ecosystem benefits are modified under changing climate conditions and how these benefits can be quantified (Doswald et al., 2014). There is also a need to conduct more scientific research on designs of EbA (including the development of design standards), including the costs or benefits of multiple methods (Comte and Pendleton, 2018; Reguero et al., 2018). Balzan et al. (2018) highlight the importance of quantifying the role of biodiversity in delivering key ecosystem services and demonstrate how such data could provide insights on the interrelatedness of island ecosystems and transboundary service benefits.

15.8.3 Adaptation

In the last decade or so, there has been a significant increase in climate-related financing for small island states. However, monitoring and tracking of funding and metrics to evaluate overall impact are lacking (Boyd et al., 2017; Mallin, 2018). Research into adaptation costs could benefit from the inclusion of indirect effects of climate change such as psychological costs (Gibson et al., 2019; Vincent and Cull, 2014) but to date this research is missing. Greater effort could also be placed on the quantification of the relationship between adaptation costs and adverse events (Adelman, 2016). The usefulness and utility of insurance mechanisms for building resilience to climate hazards require further exploration as these are increasingly proposed as an adaptation measure but remain ill understood in small island contexts (Baarsch and Kelman, 2016). There is also a need to examine differences between theoretical adaptation practices and observed results from actual implementation, along with the integration of IK, LK and external knowledge (Mercer et al., 2014b; Kelman, 2015b; Saint Ville et al., 2015; Robinson and Gilfillan, 2016; Robinson, 2017). In particular, understanding the changing nature of IK & LK, in particular early warning indicators for extreme events and slow-onset events, in a changing climate is a research gap (Chand et al., 2014; Chambers et al., 2017; Chambers et al., 2019). Greater efforts overall should be spent in capturing experience-based knowledge of implementation of adaptation projects and programs including identification of factors that enable adaptation implementation in small island contexts.

Although studies examining the association between climate and weather extremes, events and conditions and mobility in small islands have increased since AR5 (Birk and Rasmussen, 2014; Kelman, 2015a; Connell, 2016; Stojanov et al., 2017; Barnett and McMichael, 2018), few studies robustly examine attribution of migration of small island populations, communities and individuals to anthropogenic climate change and other non-climate migration drivers. The biophysical, socio-economic, and in-situ adaptation thresholds at which small island populations experience impacts to the extent that migration is necessary, remains under-explored (Barnett, 2017; Handmer and Nalau, 2019). The implications of forced and voluntary immobility (Allgood and McNamara, 2017; Farbotko, 2018; Suliman et al., 2020), the socio-economic, health, psychological and cultural outcomes of climate migrants, and gender dimensions of climate migration all remain under-researched. Similarly, much of the climate change related small island research is published by developed country authors rather than Indigenous island scholars (Robinson, 2020). Likewise, research is still missing on comparative studies that focus on cross-regional scales that provide more in-depth understanding of the differences and similarities that arise in different contexts and scales (Robinson, 2020) including the interlinkages between slow onset processes and sudden extreme events and associated loss and damage (Handmer and Nalau, 2019; Thomas and Benjamin, 2019; Thomas et al., 2020).

Limits to adaptation is still a largely under-researched topic globally (Leal Filho and Nalau, 2018) and specifically in the small island context, as are the linkages between adaptation limits, loss and damage and transformative adaptation (Thomas et al., 2020). In terms of projected risks and adaptation responses, further work is needed to improve knowledge of commonalities, differences, successes, and failures of natural and human adaptation responses (Kuruppu and Willie, 2015). One of the failings of current literature on limits to adaptation revolves largely on the use of barriers for sector-specific or small-scale scenarios, that provide an understanding only for that particular scenario and does not identify common constraints (Kuruppu and Willie, 2015). Research gaps on loss and damage include: how to assess the economic costs of losses and damages; mechanisms to develop robust policies in small island contexts; specific data on experienced loss and damage across socio-economic groups and demographics; monitoring and tracking of slow onset events (Thomas and Benjamin, 2017; Thomas et al., 2020) and the non-economic aspects including sense of place, health and community cohesion (Thomas and Benjamin, 2019). More studies are needed on the role that organisations (international, national and regional) play in adaptation efforts – their effectiveness at achieving desired outcomes, roles and accountability (Robinson and Gilfillan, 2016; Scobie, 2017; Mallin, 2018). It is also important that the impacts of socio-political relations inter-state are researched (Belmar et al., 2016) and more focus on climate justice (Baptiste and Devonish, 2019; Gahman and Thongs, 2020; Moulton and Machado, 2019) and gender are similarly needed (Mcleod et al., 2018). The importance of approaching governance in a flexible and innovative manner needs to be also emphasised more in the literature (Chung Tiam Fook, 2015). Given the high number of place-specific case studies in adaptation literature, more reviews are needed that synthesise key lessons and principles of adaptations in small island contexts from this knowledge. Further research is also needed to capture the lessons from COVID-19 response in small islands and how these could enable more robust adaptation and climate resilient development transitions as has been suggested at a broader scale by Schipper et al. (2020). There is also little to no information on impacts upon terrestrial and freshwater biodiversity from the relocation of coastal human populations inland due to SLR.

Frequently Asked Questions

FAQ 15.1: How is climate change affecting nature and human life on small islands, and will further climate change result in some small islands becoming uninhabitable for humans in the near future?

Climate change has already affected and will increasingly affect biodiversity, nature's benefits for people, settlements, infrastructure, livelihoods and economies on small islands. In the absence of ambitious human intervention to reduce emissions, climate change impacts are likely to make some small islands become uninhabitable in the second part of the 21st century. By protecting and restoring nature in and around small islands as well as implementing anticipatory adaptation responses, humans can help reduce future risks to ecosystems and human lives on most small islands.

Observed changes – including increases in air and ocean temperatures, increases in storm surges, heavy rainfall events, and possibly more intense tropical cyclones - are already causing a loss of services provided by ecosystems, the disruption of human livelihoods, damage to buildings and infrastructure, and loss of economic activities and cultural heritage on small islands. Widespread observed impacts include severe coral reef bleaching events, such as that associated with the 2015–16 El Niño event which caused the most damaging worldwide coral reef bleaching on record. Additionally, the 2017 Atlantic hurricane season was unusually characterised by sequential severe tropical cyclones that resulted in widespread cyclone-induced damage to ecosystems from the very interior of small islands to those of the ocean waters that surround them as well as damage to human settlements and economic activities within the whole Caribbean region. Although knowledge is limited regarding long term increases in tropical cyclone intensity, studies have shown that heavy rainfall and intense wind speed of individual tropical cyclones were increased by climate change. The combination of various climate events, such as tropical cyclones, extreme ocean waves, and El Niño phases, with sea-level rise causes increased coastal flooding, especially on low-lying atoll islands of the Indian and Pacific Oceans.

The expected increased risk of such impacts under further climate change is significant. For example, some low-lying islands and areas may be extensively flooded at every high tide or during storms. As a result, their freshwater supplies and soils would be repeatedly contaminated by saltwater, with adverse consequences for freshwater and terrestrial food supplies, biodiversity and ecosystems. It is unlikely that these locations would remain habitable unless such impacts are reduced through ambitious reduction of heat-trapping greenhouse gas emissions of climate change or adaptation solutions that are acceptable for the populations of these islands. Additionally, drought intensity may challenge freshwater security in some regions such as the Caribbean and the Pacific. Likewise, remote atoll islands where their inhabitants rely on reef-derived food and other resources and that are at high risk of widespread coral reef degradation may become uninhabitable. Strategies to reduce risk may include substituting the consumption of reef resources such as fish and shellfish by promoting permaculture and aquaculture and/or importing food to meet nutritional needs. However, adoption of these strategies will depend on the acceptance of their local populations.

The intensity and timing of such impacts will be more severe under high warming futures compared to low warming futures accompanied by ambitious adaptation. Tailored, desirable and locally owned adaptation responses that incorporate both short- and long-term time horizons would certainly help to reduce future risks to nature and human life in small islands. Among the short-term measures frequently employed to address sea level rise and flooding are seawalls. Long-term measures include ecosystem-based adaptation such as mangrove replanting, relocation of coastal villages to upland sites, revised building codes as part of a broader disaster risk reduction strategy, shifting to alternative livelihoods and changes in farming and fishing practices.

FAQ 15.2: How have some small-island communities already adapted to climate change?

Faced with rising sea levels and storm surges along their coastal areas which have significantly threatened people's safety, buildings, infrastructure and livelihoods, Small Island communities have already embarked on the use of different adaptation strategies. These include reactive adaptation, which deals with short-term measures, and anticipatory adaptation, which takes action in advance to lessen

climate change impacts in the long run. Reactive measures have proven not always to be effective. In contrast, anticipatory measures hold much promise for future adaptation.

The majority of people living on small islands occupy coasts, so the most widespread threats to people's livelihoods are those from sea-level rise, shoreline erosion, increased lowland flooding, and salinization of groundwater and soil. Humans can either adapt reactively or anticipate coming changes and prepare for them. Given the diversity of small islands across the world, and their capacities to adapt, there is no single solution that fits all contexts.

Coastal livelihoods in particular are already impacted by climate impacts. Coastal fishers have adapted to these changes in environmental conditions by diversifying livelihoods, expanding aquaculture production, considering weather insurance, building social networks to cope with reduced catches and availability during extreme storms, switching fishing grounds, and changing target species. Similarly, farmers have diversified livelihoods to more cash- and service-based activities such as tourism, changed plant species that thrive better in altered conditions, and shifted planting seasons according to changes in climate.

A typical reactive adaptation along small-island coasts involves the construction of hard impermeable structures such as seawalls to stop the encroachment of the sea. Yet such structures, especially along rural island coasts, often fail to prevent flooding during extreme sea levels or extreme-wave impacts, and can inadvertently damage nearshore ecosystems such as mangroves and beaches. In the Caribbean, Indian Ocean islands and some Pacific islands, there are numerous examples of coastal engineering structures that have been destroyed already or are in grave danger from the encroaching sea. In many instances, citizens and governments are unable to access external advice or funding, communities have built such structures without assistance or knowledge of expected future sea level rise.

In contrast, anticipatory adaptation, which anticipates expected future impacts and acts in advance, requires a longer-term view as well as some understanding of future climate-change impacts in particular contexts. Along small-island coasts, anticipatory adaptation typically involves recognising that sea level will continue rising and that problems currently experienced will be amplified in the future. The most common form of anticipatory adaptation in response to sea level rise and flooding is relocation, which is the movement of coastal communities away from vulnerable (coastal-fringe) locations to sites that are less vulnerable, typically upslope or inland. Coastal setback policies have been applied to hotels in some islands such as Barbados. In coastal locations where the risks of rising sea level, flooding and erosion are very high and cannot effectively be reduced, 'retreat' from the shoreline is the only way to eliminate or reduce such risks.

Such anticipatory adaptation strategies as relocation are most commonly driven and funded by governments and non-government organisations, often within a specially designed policy framework. The Government of Fiji, for example, has introduced a relocation framework that specifically develops guidance on relocation processes, with several villages already having relocated. The Bahamas relocated a community on Family Island from the shoreline to an inland location and the community of Boca de Cachón in the Dominican Republic was relocated to higher ground. The Government of Kiribati has gone a step further in its anticipatory adaptation and purchased land in Fiji in order to ensure food security, economic development and possibly a place for migration in the eventuality of sea level rise rendering its islands uninhabitable. The Navunievu community (Bua, Fiji) has mandated that every young adult building their family home in the village should do so upslope rather than on the regularly flooded coastal flat where the existing village is located. Over the next few decades, this will result in the gradual upslope migration of the community, an example of autonomous adaptation. Such creative community-grounded solutions hold great promise for future adaptation on small islands.

Anticipatory adaptation has been aligned with disaster risk reduction in some small islands. For example, Jamaica adopted such an approach in relocating three communities. Recognising that a proactive approach is needed, Jamaica developed a Resettlement Policy Framework aligned with the National Development Plan and based on vulnerability assessments of communities at risk of climate change and disaster risk. A resettlement action plan was developed for the Harbour Heights community using community engagement to design successful planned relocation. In some islands revised building codes are implemented as an anticipatory adaptation measure. As part of the build-back-better strategy hurricane resistant roofs are being built to cope with strong winds associated with tropical cyclones.

Ecosystem-based adaptation can be a low-cost anticipatory adaptation measure that is often used in small islands. It is referred to as a 'no-regret' or 'low-regret' strategy because it is low-costing, brings co-benefits and requires less maintenance in contrast to hard engineering structures. Ecosystem-based adaptation is used at different scales and in different sectors such as to protect fisheries, farming and tourism assets, and integrates various stakeholders from national to local governments and non-governmental agencies. Many islands have implemented ecosystem-based adaptation such as watershed management, mangrove replanting and other nature-based solutions to strengthen coastal foreshore areas that are subjected to coastal erosion and flooding caused by sea level rise and changing rainfall patterns. For example, mangroves have been planted on several cays in Belize and pandanus trees have been planted near the coastlines of the Marshall Islands. Agroforestry is another example of ecosystem-based adaptation. Planting trees and shrubs in combination with crops has been used to increase resilience of crops to droughts or excessive rainfall run-off. Case studies show that people living on islands benefit even further from using ecosystem-based adaptation. Their health improves as well as their food and water supply, while risks of disasters caused by extreme events are reduced.

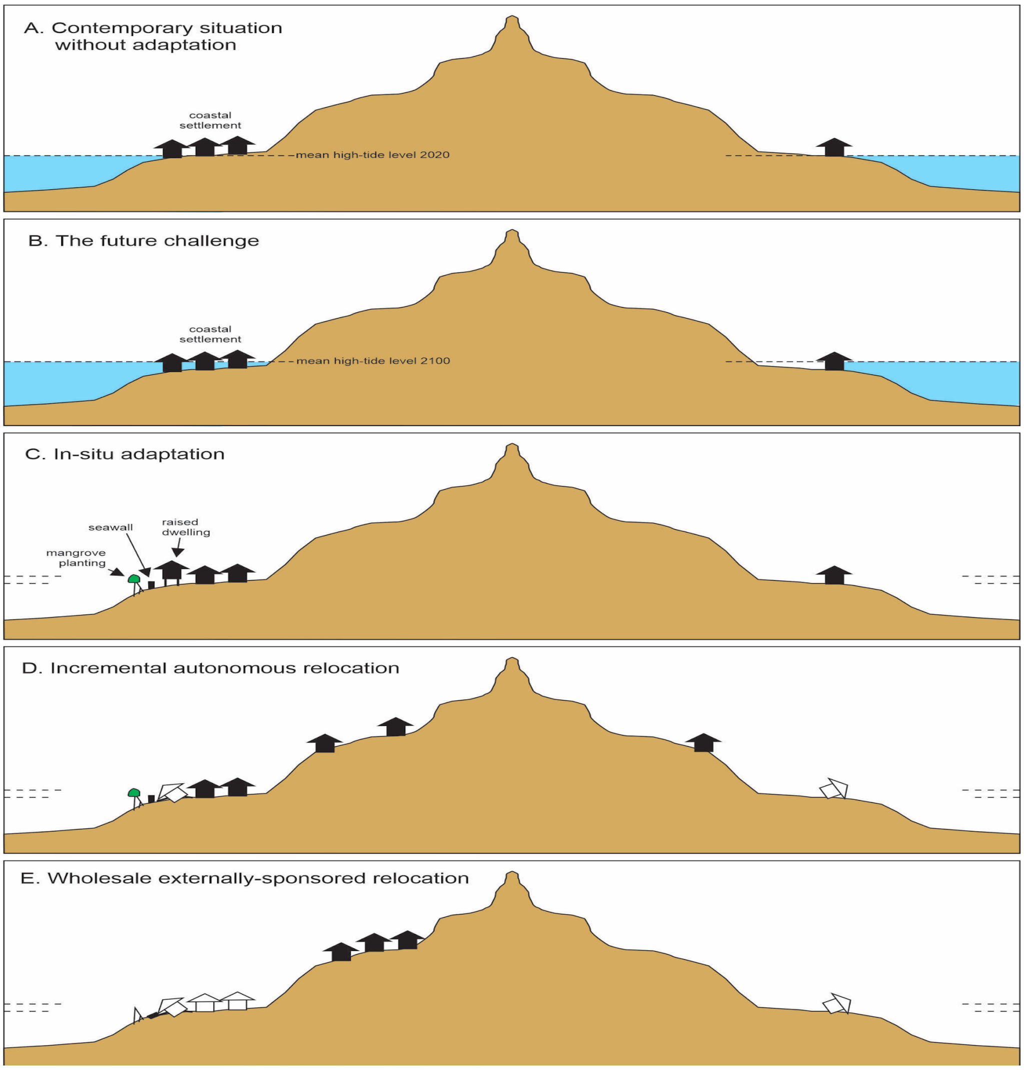

Figure FAQ15.2: Adaptation options for rural coastal communities in small islands
A – In many places today, coastal communities which have been established for hundreds of years are being more regularly inundated than ever before as a result of rising sea level. B – By the end of this century, sea level in such places may have risen one meter or more, making many such settlements (largely) uninhabitable, underscoring the need for effective (anticipatory) adaptation. C – One option is in-situ adaptation, popular because it is cheaper and less disruptive than other options; it is typically characterised by mangrove replanting, seawall construction and raising of dwellings. D – A second option is for communities to incrementally relocate upslope by building all new houses further inland. E – A third option is complete relocation of a vulnerable coastal community with external support upslope and inland.

FAQ 15.3: How will climate related changes affect the contributions of agriculture and fisheries to food security in small islands?

Agriculture and fisheries are heavily influenced by climate, which means a change in air temperature, ocean temperature and/or rainfall can have considerable impacts on the production and availability of crops and seafood and therefore the health and welfare of island inhabitants. Projected impacts of climate change on agriculture and fisheries in some cases will enhance productivity, but in many cases could undermine food production, greatly exacerbating food insecurity challenges for human populations in small islands.

Small islands mostly depend on rain-fed agriculture, which are likely to be affected in various ways from climate change, including loss of agricultural land through floods and droughts, and contamination of freshwater and soil through salt-water intrusion, warming temperatures leading to stresses of crops, and extreme events such as cyclones. In some islands, crops that have been traditionally part of people's diet can no longer be cultivated due to such changes. For example, severe rainfall during planting seasons could damage seedlings, reduce growth and provide conditions that promote plant pests and diseases.

Changes in the frequency and severity of tropical cyclones or droughts will pose challenges for many islands. For example, more pronounced dry seasons, warmer temperatures, greater evaporation could cause plant stress reducing productivity and harvests. The projected impacts of climate change on drought may hinder insects and animals from pollinating crops, trees and other vegetative food sources on tropical islands. For instance, many agroforestry crops are completely dependent on insect pollination, and it is, therefore, important to monitor and recognize climate change is affecting the number and productivity of these insects. Coastal agroforest systems in small islands are important to national food security but rely on biodiversity (e.g., insects for pollination services) that is rapidly declining. Such biodiversity loss from traditional agroecosystems has been identified as one of the most serious threats to food and livelihoods security in islands. Ecosystem-based adaptation practices such as agroforestry and diversification of crop varieties are possible solutions.

The continuous reduction of soil fertility and increasing incidences of pests, diseases, and invasive species also contribute to growing vulnerability of the agricultural systems of small islands. The perishability and safety of fresh (harvested) foods decrease in warmer temperatures. Higher temperatures could increase the presence of food or water borne diseases and the challenge of managing food safety. Changes in weather patterns can also disrupt food transportation and distribution systems on islands where indigenous communities are often located in remote areas.

Impacts of climate change on fisheries in small islands result from ocean temperature change, sea-level rise, extreme weather patterns such as cyclones, reducing ocean oxygen concentrations and ocean acidification. These combined pressures are leading to the widespread loss of marine habitats such as coral reefs and consequently of important reef fish species that are crucial both to the food security (a high proportion of dietary protein is derived from seafood) and incomes of island communities. Shifting ocean currents and warming waters are also changing the distribution of pelagic fish stocks, especially of open-water tuna stocks, with further consequences for both local food security and national economies, where they are often highly dependent on income from fishing licenses (e.g., 98% of Gross Domestic Product in Tokelau, 80% of national income in Kiribati).

Climate change is projected to have profound effects on the future status and distribution of coastal and oceanic habitats, and consequently of the fish and invertebrates they support. High water temperature causes changes in physiology and growth rate of fish species as well as the timing of spawning and migration patterns, with consequences for fisheries catch potential. Some small island countries and territories are projected to experience more than 50% declines in fishery catches by 2100. Other small islands such as Easter Island (Chile), Pitcairn Islands (UK), Bermuda, and Cabo Verde may actually witness increases in catch potential under certain climate scenarios. Food shortages are often apparent in small islands, following the passage of catastrophic tropical cyclones. Access to resurgent pelagic fisheries can help to alleviate immediate food insecurity pressures in some circumstances, whereas aquaculture (fish farming) is being viewed as a longer term means of diversifying incomes and enhancing resilience in many Caribbean and Pacific islands.

Large Tables

Table 15.1: Climate Refugia Burning Embers. Percentage of selected islands classified as refugia for biodiversity at increasing levels of warming. There is a burgeoning literature on the extinction-mitigation potential of highly heterogeneous landscapes within islands and associated local climate micro-refugia (e.g., Médail, 2017; Le Roux et al., 2019). This table demonstrates the difficulty of protecting lands which might be 'more resilient' to climate change under increasing levels of warming and current land use practices (Price et al. submitted Mapping the Planet for conservation) – by illustrating how much potential refugia space may already have been lost due to habitat conversion.

For each island or island chain, there are two columns-sets, the first column-set is the percentage of the island, or island chain, that is a refugia based on *climate alone*, assuming all areas are equally suitable. The second column-set illustrates the percent of natural land projected to be a climate refugia based on the ESA CCI 2015 satellite derived land-cover data (treating bare rock/sand, ice and water as no data, and agricultural urban land cover as being unsuitable). This second column-set provides a measure of *how much of potential refugia 'space' might have already been lost owing to habitat conversion*.

Colour coding: > 50% of the land as refugia – white; 30%-50% of the land yellow; 17%-30% of the land red and <17% dark red. These thresholds were chosen based on the current CBD 2020 (Aichi) targets of 17%, proposed or inspirational targets of 30% of land protected, and suggested goals of setting aside "half-for-nature".

Results were derived from the current and future projected distributions of ~130,000 terrestrial fungi, plants, invertebrates and vertebrates (Warren et al. 2018a).;with refugia classified as areas remaining climatically suitable for >75% of the species modelled (Warren et al. (2018b Implications)and Price et al. (submitted Biodiversity Losses)). Projections are based on the mean impacts from 21 CMIP5 climate model patterns with no dispersal. The modelled spatial resolution was 20km - which was subsequently elevationally downscaled to 1km following the methods in Price et al.(Submitted increasing risks). Warming levels were originally derived from the RCP 2.6, 4.5, 6 and 8 scenarios and subsequently interpolated on a cell-by-cell level to the temperatures listed. Details of the modelling undertaken can be found in Warren et al. (2018a).

Island(s)	Climate °C								Climate + Land Use °C							
	0.5	*1*	*1.5*	*2*	*2.5*	*3*	*3.5*	*4*	*0.5*	*1*	*1.5*	*2*	*2.5*	*3*	*3.5*	***4***
Aegean Islands	98	89	85	68	39	19	12	6	66	62	60	50	32	16	11	6
American Samoa	100	100	100	100	83	52	39	25	39	39	39	39	34	24	18	11
Andaman Nicobar	100	95	90	46	7	2	1	0	92	88	84	45	7	2	1	0
Balearic Islands	99	97	95	82	26	6	4	2	29	28	28	25	13	6	3	2
Bangka	100	100	97	3	1	0	0	0	20	20	19	1	0	0	0	0
Barbados	94	67	53	25	5	0	0	0	10	7	6	3	1	0	0	0
Borneo	98	92	89	60	25	14	10	6	67	62	60	43	24	13	10	6
Bougainville	92	81	77	62	39	28	24	19	87	77	74	58	37	27	23	18
British Indian Ocean Territory	100	100	94	0	0	0	0	0	47	47	47	0	0	0	0	0
Corsica	72	61	57	43	29	18	15	10	64	53	50	38	26	16	13	8
Crete	91	83	80	68	52	35	27	20	51	47	46	42	35	26	22	17
Cuba	97	94	92	69	14	4	3	1	48	46	45	36	10	4	3	1
Cyprus	53	51	49	44	32	20	14	8	48	46	44	37	24	14	9	6

Dominica	79	66	63	51	41	28	20	14	79	66	63	51	41	28	20	14
French Polynesia	100	100	100	100	100	81	68	54	38	38	38	38	38	32	28	23
Galapagos	91	82	79	67	50	27	18	13	93	88	86	74	54	33	21	14
Grenada	73	49	43	29	18	10	6	3	71	48	43	29	18	10	6	3
Guadeloupe	91	71	64	27	19	13	9	6	57	46	42	26	19	13	9	6
Guernsey	100	52	41	0	0	0	0	0	13	7	5	0	0	0	0	0
Hispaniola	77	60	54	35	22	15	12	9	55	43	40	28	19	13	11	8
Indonesia	95	87	81	54	28	17	14	11	60	55	51	36	23	15	12	10
Jamaica	77	65	61	47	31	17	10	5	64	54	51	40	27	15	9	4
Java	91	74	65	37	24	17	13	10	27	24	22	18	14	11	9	7
Kiribati	100	55	38	14	0	0	0	0	15	12	12	5	0	0	0	0
Madagascar	98	90	87	70	47	28	22	13	84	77	73	58	37	21	16	10
Maldives	100	38	1	0	0	0	0	0	16	0	0	0	0	0	0	0
Marajo	100	58	33	0	0	0	0	0	91	55	33	0	0	0	0	0
Marshall Islands	100	99	99	55	22	0	0	0	46	46	46	15	10	0	0	0
Mauritius	100	100	100	100	100	100	92	74	27	27	27	27	27	27	25	23
Micronesia	100	100	100	78	59	31	16	6	86	86	86	72	56	29	15	6
Montserrat	61	43	39	27	20	9	9	4	56	38	35	23	17	9	7	4
Nauru	100	100	97	0	0	0	0	0	11	11	11	0	0	0	0	0
New Caledonia	100	100	99	97	89	62	45	31	76	75	75	74	69	53	41	28
New Guinea	95	84	73	47	32	25	22	19	86	76	67	43	30	23	21	18
Northern Mariana Islands	100	100	99	95	58	29	19	11	49	49	49	46	35	22	16	9
Orinoco Delta	100	31	9	0	0	0	0	0	93	29	9	0	0	0	0	0
Palau	100	79	73	21	0	0	0	0	74	59	55	17	0	0	0	0
Palawan	86	70	64	36	21	12	9	6	55	47	44	31	20	12	9	6
Philippines	90	74	66	41	27	16	12	8	34	30	28	21	15	10	8	6
Prince Edward	100	100	100	100	100	97	9	0	35	35	35	35	35	33	2	0
Puerto Rico	84	66	59	41	25	15	11	7	63	52	49	36	24	14	11	7

Saint Lucia	77	50	45	29	14	6	3	1	72	50	45	29	14	6	3	1
Saint Vincent & the Grenadines	73	57	50	37	27	18	13	8	63	50	44	34	23	15	10	5
Samoa	100	100	100	99	89	67	56	46	34	34	34	34	31	24	22	20
Sardinia	95	87	83	65	34	16	10	5	41	38	37	31	22	12	8	4
Seychelles	100	100	98	83	57	25	16	9	25	25	25	22	18	8	6	5
Sicily	93	84	80	60	35	18	11	7	16	15	15	13	10	7	6	4
Singapore	100	100	100	98	9	0	0	0	14	14	14	13	3	0	0	0
Solomon Islands	93	79	74	48	28	15	10	6	92	78	73	48	28	15	10	6
Sri Lanka	98	94	89	64	23	11	7	5	47	46	44	36	16	7	5	4
Sulawesi	86	75	71	58	44	33	28	23	60	54	52	46	38	30	26	21
Sumatra	96	90	87	65	24	16	13	11	40	37	36	30	18	13	11	9
Sumba	98	90	86	70	49	23	11	4	36	33	31	26	18	9	4	2
Timor	92	84	80	66	48	30	22	15	11	10	9	8	7	5	4	3
Trinidad and Tobago	88	24	16	6	3	1	0	0	64	20	14	6	3	1	0	0
Tuvalu	100	100	100	34	0	0	0	0	3	3	3	0	0	0	0	0
Wallis and Futuna	100	100	100	65	32	11	3	0	35	35	35	33	21	7	1	0

Table 15.3: Summary of inter- and intra-regional transboundary risks and impacts on small islands

Transboundary Risks/Issues	Small Island examples	Reference
Large Ocean Waves from Distant Sources	Unusually large deep ocean swells generated from sources in the mid and high latitudes by extratropical cyclones (ETCs) cause considerable damage on the coasts of small islands thousands of kilometres away in the tropics. Impacts include inundation of settlements, infrastructure, and tourism facilities as well as severe erosion of beaches. Examples of extratropical swell waves causing flooding and inundation have been reported for small islands throughout the Pacific (French Polynesia, Fiji, Micronesia, the Marshall Islands, Kiribati, Papua New Guinea and the Solomon Islands). Modelling of future wave climates has been performed for 25 tropical Pacific islands, and results suggests that December–February extreme wave heights will decrease for most islands by 2100 under both an RCP4.5 and RCP 8.5 scenario, although the frequency of the large winter wave events may increase around the Hawaiian Islands. In the Caribbean, northerly swells affecting the islands have been widely recognised as a significant coastal hazard. They cause considerable seasonal damage to beaches, marine ecosystems, and coastal infrastructure throughout the region.	Wandres et al., 2020; Hoeke et al., 2013 Shope et al., 2016; Canavesio, 2019 IPCC, 2014; Jury, 2018
Transcontinental dust clouds and their impacts	The transport of airborne Saharan dust across the Atlantic and into the Caribbean has engaged the attention of researchers for some time. In the West African Sahel, where drought has been persistent since the mid-1960s, analysis of wind, precipitation and visibility data has shown that there have been remarkable changes in dust emissions since the late 1940s. Variability in Sahel dust emissions may be related not only to droughts, but also to changes in the North Atlantic Oscillation (NAO), North Atlantic sea surface temperatures and the Atlantic. Multidecadal Oscillation. The frequency of dust storms has been on the rise during the last decade. Forecasts suggest that their incidence will increase further as a response to the effects of climate change and anthropogenic activities. Transboundary movement of Saharan dust into the island regions of the Caribbean and Mediterranean has been associated with various human health problems including asthma cases in the Caribbean, cardiovascular morbidity in Cyprus, and pulmonary disease in the Cape Verde islands.	IPCC, 2014; Prospero and Lamb, 2003; Schweitzer et al., 2018; Goudie, 2014; Goudie, 2019 Akpinar-Elci et al., 2015; Sakhamuri and Cummings, 2019; Middleton et al., 2008; Martins et al., 2009

Influx of Sargassum from distant sources	Since 2011, the Caribbean region has witnessed unprecedented influxes of the pelagic seaweed Sargassum. These extraordinary sargassum 'blooms' have resulted in mass stranding throughout the Lesser Antilles, with damage to coastal habitats, mortality of seagrass beds and associated corals, as well as consequences for fisheries and tourism. This recent phenomenon has been linked to climate change as well as the possible influence of nutrients from Amazon River floods and/or Sahara dust. Modelling studies have suggested that Sargassum observed in the Caribbean probably originate in the western Equatorial Atlantic (west of longitude 50°W).	Van Tussenbroek et al., 2017; Oviatt et al., 2019. Putman et al. 2018; Franks et al. 2016.
Large-scale changes in the distribution of fisheries resources	Ocean warming and other climatic phenomena (e.g., El Niño Southern Oscillation events and Indian Ocean Dipole) have been linked to observed oceanic shifts in tuna distribution with significant impacts on revenue for vulnerable small island states that depend on fisheries licences (e.g., 98% of national income in Tokelau, 80% of national income in Kiribati).	Bell et al., 2018; Oremus et al, 2020
Movement and impact of introduced and invasive species across boundaries	The spread of invasive alien species (IAS) is regarded as a significant transboundary threat to the health of biodiversity and ecosystems and has emerged as a major factor in species decline, extinction, and loss of biodiversity goods and services worldwide. The extent to which IAS (both animals and plants) successfully establish themselves at new locations in a changing climate will be dependent on many variables, but non-climate factors such as ease of access to migration pathways, suitability of the destination, ability to compete and adapt to new environments, and susceptibility to invasion of host ecosystems are deemed to be critical. Modelling studies have been used to project the future 'invisibility' of small island ecosystems subject to climate change and therefore to anticipate marine and terrestrial habitat degradation in the future. Evidence suggests that hurricanes may have hastened the spread of highly invasive Indo-Pacific lionfish (Pterois volitans) throughout the Caribbean in recent years. Similarly, two IAS, the Common Green Iguana (Iguana iguana) and Cuban Treefrog (Osteopilus septentrionalis) were reported in the Caribbean island of Dominica, following the passage of TC Maria in 2017. Observations 7 months after the hurricane, within close proximity to ports, suggest that these animals were commensals on ships or within relief containers, and did not arrive following a storm-mediated event on floating debris.	IPCC, 2014; Russell et al., 2017 Vorsino et al., 2014; Taylor and Lalit Kumar, 2016 Johnston et al., 2015 van den Burg et al., 2020

Spread of pests and pathogens within and between island regions	Increased climate instability has contributed to the emergence and spread of infections carried by mosquitoes like dengue, chikungunya and zika. The incidence and severity of mosquito borne diseases have increased significantly in Pacific, Indian Ocean and Caribbean islands during the past few 10 years, with calls for a better understanding of how climate change is shaping disease prevalence and transmission. Rising sea temperatures are likely to increase the frequency of disease outbreaks affecting reef-building corals through impacts on coral hosts and on pathogens. Of the range of bacterial, fungal and protozoan diseases known to affect stony corals, many have explicit links to temperature, including black band disease, yellow band disease and white syndromes. Global projections suggest that disease is as likely to cause coral mortality as bleaching in the coming decades at many localities, with effects occurring earlier at sites in the Caribbean. Analyses of model hindcasts suggest that decades-long climate-driven changes in sea surface temperature, increases in thermal minima, and the breach of thermal maxima have all played significant roles in the spread of white-band disease throughout the Caribbean. Global food security is also threatened by climate-related increases in crop pests and diseases. Black Sigatoka disease of bananas emerged from Asia in the late twentieth Century and has recently completed its invasion of Latin American and Caribbean banana-growing areas. Infection risk has increased by a median of 44.2% across the Caribbean since the 1960s, due to increasing canopy wetness and improving temperature conditions for the pathogen.	Filho et al., 2019, Cao-Lormeau and Musso, 2014; Caminade et al., 2017 Maynard et al., 2015; Randall and van Woesik, 2015. Bebber, 2019
Human migration and displacement	Currently there is limited empirical evidence that long-term climate change is driving transboundary human migration, however following Hurricane Maria, Puerto Rico witnessed "depopulation" of 14% in only 2 years as a result of emigration to the US mainland. Climate change affects population movement, thus tracking mobility patterns is necessary	Campbell, 2014a; Melendez and Hinojosa, 2017 UNESCAP, 2019
Transboundary risks to island food security. COVID-19 which caused disruptions to food supply and disaster risk management operations	While SIDS are a diverse group of nations, most share such characteristics as limited land availability, insularity, susceptibility to natural disasters that make them particularly vulnerable to global environmental and economic change processes leading to regional food insecurity. The Pacific Islands Forum (PIF) has established a transboundary Framework for Action on Food Security, that promotes cooperation, investments, research and development, capacity-building, and adaptation to mitigate climate change threats.	Connell et al., 2020 Islam and Kieu, 2020 Sheller, 2020

Table 15.4: Enabling Conditions and Factors for Adaptation in Small Islands

Enabling conditions and factors for adaptation		
Enabler	Example	Reference
Knowledge (Indigenous, Local, External)		
IK & LK in developing adaptation strategies (soft protective structures; disaster preparedness)	Using IK & LK in identifying Indigenous vegetation (e.g., ecosystem-based adaptation) to reduce erosion (Samoa, Vanuatu)	Crichton and Esteban, 2018; Nalau et al., 2018; Duvat et al., 2020
	Pacific storm prediction, disaster preparedness	Kuruppu and Willie 2015/Chand et al 2014; Granderson 2017;
	Shared resource governance and understanding of linkages between sectors and ecosystems based on IL and LK (e.g., Lomanu Gau village initiative (Fiji)	Remling and Veitayaki, 2016
Increased access to climate information	Increased access to climate information increasing individuals will and capacity to support/take adaptive actions (Fiji)	Di Falco and Sharma, 2018
	Dissemination of adaptation skills and significance to youth (e.g., Ecocamps in Fiji)	McNaught et al., 2014
Increased access to climate information (continued)	Pacific women's improved participation in adaptation processes via training, access to information and decision-making Improved climate data quality, management and associated observation, modelling and information services Caribbean: Improved climate data quality, management and associated observation, modelling and information services Provision of user-tailored products and services through knowledge co-production processes	Mcleod et al., 2018 Martin et al., 2015; Hermes et al., 2019 Trotman et al., 2018 SPREP, 2016a
Economy and Finance		
Economic diversification and shifting to CRDPs	Tourism system transitions/cooperation from tourism sector	Loehr, 2020; Loehr et al., 2020; Sheller, 2020; Mahadew and Appadoo, 2019
Finance models for adaptation	Innovative financing models that enable adaptation (e.g., Seychelles) Parametric fisheries insurance products to increase fishery resilience funded by Caribbean Catastrophe Risk Insurance Facility (Grenada and Saint Lucia)	Rambarran, 2018 CCRIF SPC, 2019
Trans regional trade agreements/associated pressure	Revised socio-political arrangements for better fisheries management (Solomon Islands)	Keen et al., 2018
Economic viability via revenue from sale of new land	Maldives land raising on Hulhumale "Safe island development programme" after 2004 Indian Ocean Tsunami in the Maldives	Bisaro et al., 2019 Shaig, 2008
Government subsidies	Tuamotu's government subsidy of raised houses	Magnan et al., 2018

Co-investments and cooperation between agencies (donors, governments)	Tuvalu use of beach nourishment in collaboration with JICA	Onaka et al., 2017
Diversification of livelihoods as basis for economic activity	Coastal fishers' diversification of livelihoods into the tourism sector (Vanuatu and Madagascar) Fishermen varying fishing practices and locations depending on environmental conditions (e.g., Dominican Republic)	Blair and Momtaz, 2018 Karlsson and McLean, 2018
Governance		
Changed governance arrangements resulting in improved coordination	Improved governance arrangements: Cross-sectoral and cross-agency coordination (e. g. Vanuatu)	Webb et al., 2016; Nalau et al., 2016
Changed governance arrangements resulting in improved coordination (continued)	Agency explicitly tasked with coordinating sectors and services for climate resilience across government (Dominica)	Turner et al., 2020
	Efficient and coordinated distribution of climate adaptation support across national projects and departments (e.g., Samoa)	McGinn and Solofa, 2020
New strict/explicit building codes	Caribbean infrastructure (esp. housing and hotels) now must be built to withstand strong hurricanes	Mycoo, 2018a
Localising climate adaptation plans, frameworks and policies	Pacific Adaptive Capacity Framework Framework for the Disaster and Climate Resilient Development in the Pacific (FRDP) Island-centric adaptation policy and planning	Warrick et al., 2017 SPC, 2016 Schwebel, 2018
Social and cultural		
Social networks and capacity in disaster recovery	Support of social networks in hurricane recovery, access to livelihood opportunities (e.g., Dominica)	Turner et al., 2020
	Increased Indigenous resilience and adaptive capacity via social networks and capital (e.g., Samoa)	Petzold and Ratter, 2015; Parsons et al., 2018
	Informal credit for fishermen at food stores during and after disasters (e.g., Belize and Dominican Republic)	Karlsson and McLean, 2018
Social networks and traditional familiarity with barter/microfinance	Community-level fundraising (e.g., Samoa, Solomons, Jamaica)	Nunn and Kumar, 2019; Crichton and Estaban, 2018; Parsons et al., 2018; Birk and Rasmussen, 2014; Carby, 2017
Maintenance of home community	Circular migration between Tuvalu and overseas	Marino and Lazrus, 2015
Empowerment of the migrating individuals	Relocation of villages (Fiji)	Marino and Lazrus, 2015

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