Cross-Chapter Box 5: Low-lying Islands and Coasts

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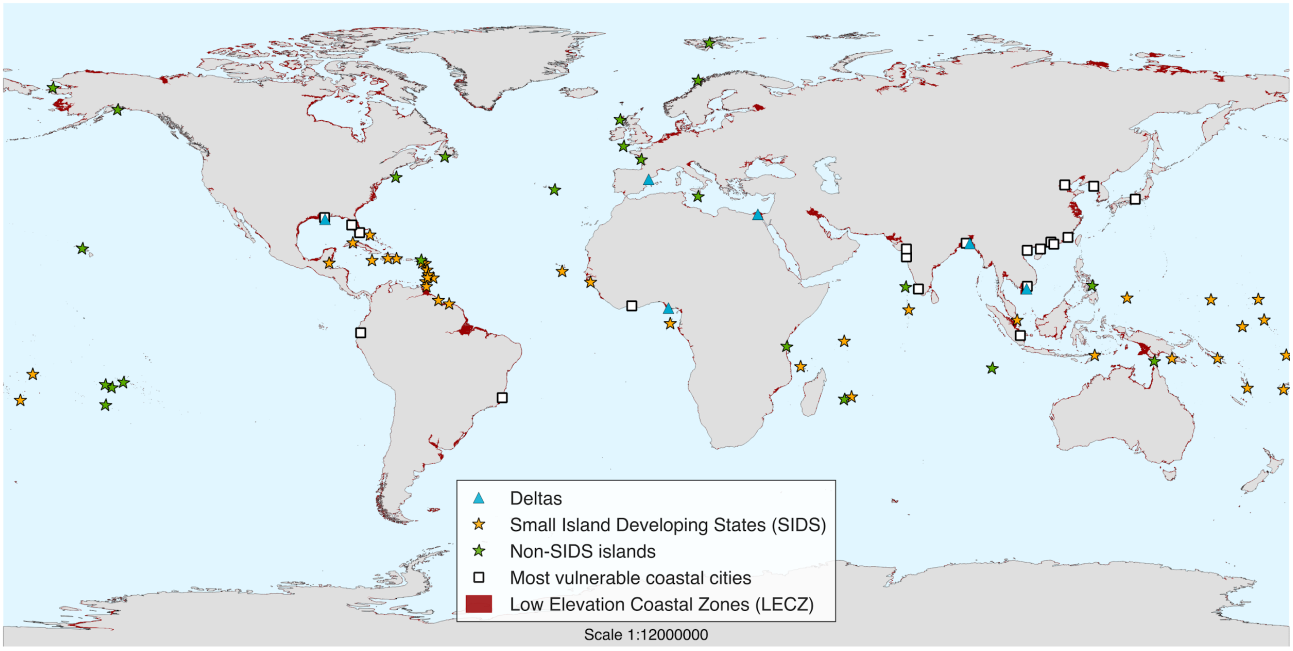
Cross-Chapter Box 5.1 Introduction

'Low-lying islands and coasts' (LLIC) are areas near mean sea level and up to 10 m elevation (McGranahan et al., 2007; Wong et al., 2014; Neumann et al., 2015). They encompass very diverse systems (Cross-Chapter Box 5, Figure 1): from continental coasts (including shelf areas) to small islands, from the tropics to polar regions, in the Global North and South, and with various demographic and socio-economic patterns (e.g., urban or rural). Due to their natural features (low elevations, sensitive ecosystems and environmental resources) and increasing anthropogenic pressure at the coast, LLIC are at the frontline of climate change impacts to the ocean and the cryosphere (Sections 1.3.2., 2.3., 6.x) and are characterized by particularly high levels of risk (i.e., the potential for harm, loss and damage; Cross-Chapter Box 1) (*robust evidence, high agreement*[1]). Ocean- and cryosphere-related changes include both extreme events (e.g., tropical/extra-tropical storms and associated surges, marine heat waves; Sections 6.3, 6.4, 6.5) and slow on-set changes (e.g., retreat of ice sheets and permafrost thaw (Section 3.4), sea level rise (Section 4.2), ocean warming and acidification (Section 5.2.1)). Associated impacts on coastal geomorphology, ecosystems and dependent human communities are considerable, already detectable and expected to increase (Gattuso et al., 2015; Nagelkerken and Connell, 2015) (*medium evidence, high agreement*). The magnitude of future impacts will thus depend both on the scale of global mitigation efforts, and on LLIC societies' efforts towards adaptation.



Cross-Chapter Box 5, Figure 1: Overview of the global distribution of low-lying islands and coasts (selected examples). The figure illustrates in a non-exhaustive way, the location of some of the major populated deltas; small islands (Small Island Developing States (SIDS) and selected low lying non-SIDS islands that are vulnerable to climate change impacts); most vulnerable coastal cities, as identified by Hallegatte et al. (2013); and Low Elevation Coastal Zones (LECZ), which are defined as 'contiguous area along the coast that is less than 10 metres above sea level' (McGranahan et al., 2007). Elevation data based on National Geophysical Data Center (1999).

Cross-Chapter Box 5.2 Climate and Anthropogenic Drivers of Risk

Cross-Chapter Box 5.2.1 Climate-, Ocean- and Cryosphere-Related Processes

LLIC are subject to the same climate drivers as other islands and coasts (Wong et al., 2014) (Sections 1.3.2., 2.3., 4.2, 5.2, 6.x), with ocean warming and acidification and sea level rise being of particular concern.

[1] In this Report, the following summary terms are used to describe the available evidence: limited, medium, or robust; and for the degree of agreement: low, medium, or high. A level of confidence is expressed using five qualifiers: very low, low, medium, high, and very high, and typeset in italics, e.g., *medium confidence*. For a given evidence and agreement statement, different confidence levels can be assigned, but increasing levels of evidence and degrees of agreement are correlated with increasing confidence (see Section 1.8.3 and Table 1.2 for more details).

Occurrence of ocean warming since the 1970s has increased in average temperature of the upper 75 m by around 0.11°C per decade over the last four decades (Cheng et al., 2013; Rhein et al., 2013). As a result from the uptake of atmospheric CO_2 by the ocean, water pH decreased by 0.1 pH units since the beginning of the Industrial Era, representing a 30% increase of ocean acidity in 250 years. Global mean sea level rise ranges from 0.40 to 0.89 m as median values among the Representative Concentration Pathways 2.6 and 8.5 scenarios, implying a large uncertainty due to limited knowledge on the contribution of the Antarctic ice sheet to sea level rise. Locally, differences in the trends are typically on the order of 20% on top of the global values. Moreover, projections of extreme sea level show that events which are currently rare will become normal by the end of the century (Section 4.2).

Combined with storm surges and waves, sea level rise will generate temporary or permanent marine flooding, coastal erosion and salinization (soils, groundwater, surface waters) (Section 4.3.3). Changes in the ocean and the cryosphere physics and chemistry will translate into major impacts on marine and coastal organisms and ecosystems (Sections 1.3.1, 1.3.2, 4.3.3, 5.2, 5.3) (*robust evidence, high agreement*), e.g., the alteration by ocean acidification of the basic conditions of many organisms that will be less able to build their skeletons and shells. Ocean acidification will indeed have major impact on microbes, phytoplankton and zooplankton, benthic communities (e.g., corals, mangroves, oysters, seagrasses), pelagic communities (tuna, mammals, etc.), with subsequent implications on species' abundance and geographical distribution, and then on ecosystem services to human societies (e.g., coastal protection, food security). Those impacts are extensively discussed in this report (e.g., Sections 4.3.3.2, 5.2.2, 5.2.3, 5.3).

Cross-Chapter Box 5.2.2 Anthropogenic Drivers

Over the last decade, there has been a growing number of local scale LLIC studies with a social science perspective, e.g., in the Arctic (e.g., Ford et al., 2012; Ford et al., 2014), on temperate (e.g., Muir et al., 2014; Petzold, 2017) and tropical (e.g., Ratter et al., 2016; Duvat et al., 2017; Weir and Pittock, 2017) small islands, and coastal cities (e.g., Rosenzweig and Solecki, 2014; Paterson et al., 2017; Texier-Teixeira and Edelblutte, 2017). Conclusions demonstrate that human societies contribute to generate their own local exposure and vulnerability to climate-related hazards (Section 4.3.2.2), through both individual (e.g., coastal constructions, sand mining, poverty, inadequate resource extraction) and combinations of anthropogenic drivers such as coastal urbanization, coastal squeeze, intensified and conflicting resource use, trends in socioeconomic inequalities (*robust evidence*, *high agreement*).

Individual drivers are better captured, with emerging issues such as the loss of Indigenous and Local Knowledge (ILK; Cross-Chapter Box 3). ILK critically influences how people recognize and respond to environmental risk (e.g., Leonard et al., 2013), with recent examples developed in small islands in South-East Asia and the Pacific (Hiwasaki et al., 2014; McMillen et al., 2014; Campbell, 2015; Lazrus, 2015; Morrison, 2017; Nunn et al., 2017). Scholars suggest that the loss of ILK also plays a role in Global North contexts, either in response to extreme events (e.g., Katrina in 2005 in the USA; Kates et al., 2006) or in the face of slow onset changes such as sea level rise (Wong et al., 2014). Scholars notably point out that modern, externally-driven socioeconomic dynamics (e.g., the introduction of imported food) diminish the cultural importance of ILK-based practices locally, together with introducing dependency on monetization and external markets (Hay, 2013; Campbell, 2015), unsustainable livelihood practices and poor consideration of natural hazards (Ignatowski and Rosales, 2013; Miller Hesed and Paolisso, 2015; Ford et al., 2016; Janif et al., 2016). Such dynamics can be considered as harmful and increase long-term vulnerability to ocean- and cryosphere-related changes, as the loss of cultural relationships with in situ environmental features and dynamics limits communities' ability to anticipate and cope with environmental disruptions.

Population growth is also a major concern, especially in coastal cities and megacities. Studies assessing scenarios of future urban population growth in the low elevation coastal zone (LECZ) often use the year 2000 as a baseline. In that year already, the LECZ was estimated to host 625 million people—despite considerable uncertainties in the assessment of urban population figures (Lichter et al., 2011)—, i.e., over 10% of the global population (Neumann et al., 2015). Out of these, roughly a quarter was living in high-density urban areas and the vast majority (517 million) in Global South contexts. Modelling suggests that the amount of population in the LECZ in a high-growth scenario is going to increase up to almost 950 million by 2030 (Neumann et al., 2015). Other modelling running through 2100 and using assumptions of the global Shared Socioeconomic Pathways (SSP) storylines suggests that the population living in the LECZ might increase to as much as 1.14 billion people in an SSP3 world over that time frame (Jones and O'Neill, 2016). Asia features the highest figure of LECZ population in this scenario (765 million), whilst Africa has the highest growth rate (almost 300%) (Jones and O'Neill, 2016).

In parallel, the scientific literature pays growing attention to multi-parameter, dynamic and context-specific analyses (Section 4.3.2.2). For example, major changes in coastal settlement patterns have been fuelled over the last decades by socioeconomic processes such as population growth, rural exodus and marginalization, coastal tourism development, changes in construction and access to critical infrastructure, and human-induced subsidence. This notably resulted in the densification of urban coastal development worldwide (e.g., McCubbin et al., 2015; Yan et al., 2015; Yin et al., 2015; Liu et al., 2016; Fawcett et al., 2017; Hay, 2017), with a growing number of people living in LECZ (see above) and of assets located in risk-prone coastal areas (Kumar and Taylor, 2015) (*robust evidence, high agreement*). In rural LLIC such as outer atolls, e.g., population densification induces growing pressure on freshwater lenses, which usually results in increasing communities' exposure to brackish, polluted groundwater, and then in water security and health problems (Storey and Hunter, 2010; Lazrus, 2015; Duvat et al., 2017). In the Arctic, 'indigenous peoples (…) have been pushed into marginalized territories that are more sensitive to climate impacts [(…) and thus undermining] aspects of social-cultural resilience' (Ford et al., 2016: 350).

In addition, cross-scale drivers are better understood. One key illustration is the sediment starvation due to damming and deforestation on downstream coastal areas (Kondolf et al., 2014), or locally due to the loss of vegetated coastal ecosystems (e.g., mangroves and salt-marshes).

Recent literature irrevocably confirms that anthropogenic drivers played a major role in the increase of exposure and vulnerability worldwide (Cardona et al., 2012) and that they will continue to do so in the absence of adequate adaptation measures (*robust evidence, high agreement*).

Cross-Chapter Box 5.3 Major Observed and Projected Impacts

Context-specificities are critical in shaping the influence of both natural and anthropogenic drivers on the ground (*robust evidence, high agreement*). Accordingly, different locations will face different risk situations, even within a same areal category (e.g., small islands or deltas). The following section only provides selected examples.

Cross-Chapter Box 5.3.1 Major Impacts on Economic Sectors

Climate change economic impacts on LLIC will be particularly significant due to the expected increase in the number of LECZ inhabitants until 2050 (Jones and O'Neill, 2016; Merkens et al., 2016), their high dependency on ocean and marine ecosystems, and natural and human systems' high exposure to climate-, ocean- and cryosphere-related changes (United Nations, 2017). The average annual losses as a percentage of the Growth Domestic Product (GDP) are much higher in Small Island Developing States (SIDS), e.g., compared with the global average (UN-OHRLLS, 2015). However, the degree of climate change impact is not only dependent on the size of the territory but also the physical location and exposure. Read (2018) shows for example that small- and lower-medium-sized countries appear to perform as well as, if not better than, larger countries that potentially incur less disproportionate sunk and fixed costs in the provision of social goods.

Climate change impacts will challenge various aspects such as wealth and poverty, employment, livelihood and well-being, hunger and food security, as critical sectors are under threat (Sections 4.4.4, 5.3.1). Estimated annual losses from marine flooding amount to 0.3–9.3% of global GDP (Hinkel et al., 2014). While some authors encourage investment in hard coastal protection (Muis et al., 2017), others remind that coastal protection will also have economic costs (DiSegni and Shechter, 2013).

Climate change will affect LLIC coastal agriculture (e.g., rice crops; Smajgl et al., 2015; Genua-Olmedo et al., 2016), fisheries and aquaculture (Sections 4.3.3.3.2, 4.3.3.3.5). The fact that >90% of the world's rural poor are located in the LLIC of 15 developing countries (Barbier, 2015) and that these regions highly depend on fish for their dietary consumption (Blanchard et al., 2012), raises a serious concern about future food security (FAO et al., 2017). Lam et al., (2016) found that the negative impacts of climate change on fisheries will be more important in SIDS and African and Asian countries. The impacts of ocean warming and acidification on coral reefs will have consequences on various species (Sections 4.3.3.2.2, 5.2.2.3.3) that are directly consumed by human beings and that are critical to the broader food web-chain (Section 5.3). The potential for brackish water aquaculture development is also threatened by sea level rise especially.

Coastal tourism plays a major role for LLIC communities (employment and income), and it could be affected in various ways by ocean- and cryosphere-related changes (Section 4.3.3.3.4). Coastal infrastructures and facilities (e.g., harbours, resorts) can be destroyed by storm waves (e.g., in Ghana; Sagoe-Addy and Appeaning Addo, 2013), as well as attractive ecosystems could be degraded. For example, coral reefs support tourism activities such as diving and snorkelling (Spalding et al., 2017), and their degradation can have economic impacts. Future attractiveness will also depend on sea surface temperature (including induced effects such as invasive species, e.g., jellyfishes, and disease spreading) (Burge et al., 2014; Weatherdon et al., 2016) and the changes in climatic conditions in tourists' areas of origin (Bujosa and Rosselló, 2013; Amelung and Nicholls, 2014). Non-climatic components such as accommodation and travel prices, and tourists' and tourism developers' perceptions of ocean-related changes will also play a role (e.g., Shakeela et al., 2013; Davidson and Sahli, 2015). However, forecasting effects on global-to-local tourism flows remains challenging (Rosselló-Nadal, 2014; Wong et al., 2014).

In terms of human health, water-borne diseases are expected to increase especially due to sea level rise and ocean warming (Kim et al., 2014; Weatherdon et al., 2016), which will impact public health and health care expenses in many coastal regions (Sections 1.4.3., 5.3.2.1).

Human migration and displacement is another sensitive topic (Adger et al., 2014; Hajra et al., 2017) (Sections 3.3.5, 3.5.5, 4.4.3). Although it remains scientifically challenging to estimate future displacement associated with ocean-related changes, it is estimated that sea level rise in a 2°C warmer world could submerge land currently home to 280 million people globally by the end of this century (Strauss et al., 2015). Changes in the basic conditions of LLIC habitability—e.g., shoreline retreat, soils and groundwater salinization, depletion in fish resources, increase in health diseases—will impact people's mobility and may result in displacement and migration in safer locations (Connell, 2016; Janif et al., 2016). Significantly higher risks of human displacement are found in lower-income countries and LLIC (e.g., in Vietnam, Bangladesh, Egypt, Malaysia, Thailand, Myanmar, the Philippines, Indonesia, China and Iraq), and especially among people lacking the resources for planned migration (Milan and Ruano, 2014; Logan et al., 2016). Noteworthy is that countries in the Global North are also concerned, e.g., after hurricanes in the Gulf Coasts, USA (Logan et al., 2016), and that human relocation will have an economic impact on both the destination and host areas, e.g., in tourism-dependent coastal cities and harbours.

Eventually, property values and development of coastal cities at large will be affected by ocean- and cryosphere-related changes. For example, real estate values and insurance costs will be impacted by flooding risks (McNamara and Keeler, 2013; Putra et al., 2015), and properties will probably lose value, due to coastal landscape degradation. The economic consequences will also appear on the rental incomes, business activities and local unemployment.

Cross-Chapter Box 5.3.2 Major Impacts on Arctic Communities

Ongoing climate change shows negative impacts on Arctic LLIC, not only on the economy and life-stay of the communities but also on the local cultural identity, self-sufficiency and a loss of ILK and skills (Lacher, 2015) (Sections 3.4.3., 3.5, 4.3.2.2). Changes in fish and seabird populations amplified by climate change have an impact on ecosystems and livelihoods in Arctic island communities that are dependent on their local natural capital, such as the Lofoten, Norway (Dannevig and Hovelsrud, 2016; Kaltenborn et al., 2017).

There are currently 178 Alaskan communities facing coastal erosion issues, with 26 in a very critical situation such as Newtok, Shishmaref, Kivilina, and north-western coastal communities on the Chukchi Sea for those situated on permafrost. For coastal communities situated on permafrost and discontinuous permafrost, increased coastal erosion hazards will be affected by sea level rise, but in contrast to LLIC elsewhere in the world, additional factors unique to the polar regions heighten the risk in a future warmer world. Sea ice extent has decreased both in summer and winter in the Arctic (Section 3.1.1), reducing the physical protection provided by sea ice to the land (Overeem et al., 2011). Autumn storms have greater open water fetch due to lower sea ice extent and can produce strong wind-generated waves in the open water that causes erosion on land (Lantuit et al., 2011). At the same time, permafrost temperatures have increased (Romanovsky et al., 2010), which weakens the mechanical stability of frozen ground. Together these mechanisms of increased wave energy, decreased stability of permafrost ground in combination with increased sea level, are increasing erosion of coastal settlements (Section 3.4.3). This phenomenon is somewhat unique to Alaska, although there are other LLIC communities that are facing both permafrost thawing and subsidence (e.g., Selawik, Alaska) and river bank erosion (AMAP, 2017).

The communities of Arctic Alaska are populated primarily with Iñupiat, indigenous people who historically were seasonally nomadic, traveling the land and sea to harvest foods. Permanent settlements in coastal areas were established in the late 1800s to early 1900s, with populations becoming more stable after government policies required children to attend school. Infrastructure was constructed in near-shore areas with the assumption of stable coastlines. The degree of hazard varies by village, but in several cases, infrastructure has been lost and subsistence use areas are being modified (Bronen, 2011; Marino, 2012; Gorokhovich et al., 2013).

Cross-Chapter Box 5.3.3 Major Impacts on Small Islands

The combination of ocean- and cryosphere-related slow on-set changes and extreme events underscore LLIC vulnerabilities around the globe. Recent examples are the significant storm surge flooding in New York City, USA, due to 2012 Superstorm Sandy (Rosenzweig and Solecki, 2014), the combination of flooding and heavy precipitation from 2017 Hurricane Harvey in Houston, USA (Emanuel, 2017), and the combination of intense winds and storm surge during the 2013 Typhoon Haiyan in the Philippines (Takayabu et al., 2015). Recent events occurring in the Pacific and Caribbean illustrate the potential impact of ocean- and cryosphere-related changes on small islands. Tropical Cyclone (TC) Pam devastated Vanuatu in 2015 with 449.4 million USD in losses for an economy with a GDP of 758 million USD (Government of Vanuatu, 2015). In 2017, TC Winston losses in Fiji totalled more than 1.4 billion for an economy of with a GDP of 3.4 billion, and loss of 43 people. In 2017, Hurricanes Maria and Irma swept through the 15 Caribbean countries and rebuilding in 3 countries alone, Dominica, Barbuda and the British Virgin Islands will cost an estimated 5 billion USD (UNDP, 2017). Anthropogenic contributions may have increased losses by at least 20% through increased storm surge, inundation and wind speed (Takayabu et al., 2015; Lloyd and Oreskes, 2018) (*limited evidence*, *medium agreement*). The combined impacts of climate change on small island communities have created economic and adaptation burdens that may last several years or more while simultaneously compromising human, water and food security (Nurse et al., 2014).

Another growing concern regarding LLIC refers to the risk that especially some island nations may disappear due to climate change (Gerrard and Wannier, 2013; Yamamoto and Esteban, 2014; Donner, 2015). The narrative of 'drowning and eroding small islands' (Birk and Rasmussen, 2014; Cheriton et al., 2016; Stojanov et al., 2017) is however challenged by very recent scholarship documenting positive shoreline and surface area changes over the recent decades to century for atoll reef islands in the Pacific and Indian oceans (McLean and Kench, 2015; Kench et al., 2018; Duvat, submitted). For example, total land area increased in eight of nine atolls of Tuvalu in the recent decades, despite relatively high sea level rise [~15 cm in 1971–2014] (Kench et al., 2018). This shows that when shoreline processes have not been dramatically disturbed by human interventions (e.g., hard coastal defences; Albert et al., 2016), atoll reef islands can adjust and sometimes increase due to dynamic ecological processes. This suggests that LLIC in general are not 'static landforms', which has important implications in terms of adaptation options and planning.

Cross-Chapter Box 5.3.4 Major Impacts on Coastal Cities and Megacities

Coastal cities—especially megacities with over 10 million inhabitants—are particular hotspots of risks related to the impacts of climate change on the ocean and cryosphere (Pelling and Blackburn, 2013). Over half of today's global population lives in cities—over 12% in megacities—, many of which located in LECZ, such as New York City, Tokyo, Jakarta, Mumbai, Shanghai, Lagos or Cairo (UN-DESA, 2015). In some of the world's largest coastal cities, present flood losses reach up to 1% of the cities' GDP (Hallegatte et al., 2013). Future flood losses in the largest 136 coastal cities are projected to rise up to 1 trillion USD per year in 2050 (up from 6 billion at present) when considering the compounding effects of future growth in the cities' population and assets, sea level rise and continued subsidence, along with the assumption of no significant adaptation measures (Hallegatte et al., 2013). As a result, considerable flood protection measures will probably be implemented. These can be expected to mitigate the average annual losses but potentially increase the risk of loss from extreme events exceeding the new protection levels.

Despite the importance of megacities and large port cities, small and mid-sized cities are often characterized by particularly high vulnerabilities. They often grow extremely fast and lack in political attention and human as well as financial capacities for risk reduction, when compared to larger cities (Birkmann et al., 2016).

Cross-Chapter Box 5.3.5 Major Impacts on Populated Deltas

Marine flooding is already affecting deltas around the world, and ~260,000 km^2 have been temporarily submerged over the 1990s/2000s (Syvitski et al., 2009; Wong et al., 2014). In addition, the intrusion of saline and/or brackish water due to sea level rise and storm surges, affects the quality of surface water resources (Section 4.3.3.1.3). Positive correlation between rising sea levels and increasing residual salinity has been reported in the Delaware Estuary, USA (Ross et al., 2015), in the Ebro Delta, Italy (Genua-Olmedo et al., 2016) and in the Mekong Delta, Vietnam (Gugliotta et al., 2017). In Bangladesh, e.g., some freshwater fish species are expected to lose their habitat with increasing salinity, with profound consequences on fish-dependent communities (Dasgupta et al., 2017). Limitations in drinking water supply due to salinization is also a growing concern (Wilbers et al., 2014), as well as other environmental impacts, such as the influence of salinity levels on the abundance and toxicity of *Vibrio cholerae* in the Ganges Delta (Batabyal et al., 2014). Future local agriculture is also at serious threat. Taking the case of rice cultivation, recent works emphasize the prevailing role of combined surface elevation and soil salinity, e.g., in the Mekong delta (Smajgl et al., 2015) and in the Ebro delta (Genua-Olmedo et al., 2016), estimating for this latter a decrease in the normalized rice production index from 61.2% in 2010 to 33.8% by 2100 in a 1.8 m sea level rise scenario. In coastal Bangladesh, salinity is projected to have an unambiguously negative influence on all dry-season crops over the next 15 to 45 years (especially in the South-West; Kabir et al., 2018), as well as oilseed, sugarcane and jute cultivation was reported to be already discontinued due to challenges to cope with current salinity levels (Khanom, 2016).

Cross-Chapter Box 5.3.6 Risk and Cascades

Because ocean- and cryosphere-related changes meet with highly exposed and often vulnerable elements (infrastructure, human settlements and natural systems) (Sections 1.4, 4.3.2, 5.3.2, 6.8), and in the absence of adequate adaptation efforts, the level of risk in LLIC is expected to increase in the future (*high confidence*). Due to the above-mentioned observed and expected impacts, climate change has the potential to significantly increase the level of loss and damage experienced by local to global coastal livelihoods (e.g., fishing, logistics or tourism), as well as to slow down and reverse overall development achievements, particularly on poverty reduction (Hallegatte et al., 2016). Global time series analysis of risk and vulnerability trends shows that many Pacific island states have fallen behind the global average in terms of progress made in the reduction of social vulnerability towards natural hazards over the past years (Feldmeyer et al., 2017). Major coastal cities are also particularly at risk due to high densities of people and assets in highly hazard-prone locations (Hallegatte et al., 2013; Hinkel et al., 2014) (*robust evidence, high agreement*). Noteworthy is that urbanization however can also hold substantial opportunities for risk reduction as cities continue to be engines of economic growth, centres of innovation and political attention and hotbeds of private sector investments (Garschagen and Romero-Lankao, 2013). This will depend on the level of transformations in cities' risk management regimes in order to harness these potentials and shift course towards climate resilient development (Solecki et al., 2017).

Ocean- and cryosphere-related changes in LLIC further have the potential to accumulate in compound events and cause cascade effects in hazards and impacts. This is the case when coastal flooding and riverine inundation occur together (Section 4.3.4.1). On longer timescales, another example is sea level rise in the Arctic that has the potential to accelerate permafrost thawing and coastal erosion (Sections 4.3.4.1, 6.8, Box 6.1). In addition, climate change impacts to LLIC bear the potential for risk cascades far beyond the extent of the original impact (*medium evidence, high agreement*), through economic, environmental and social processes. This means that transboundary risks have to be considered (Atteridge and Remling, 2018). In that perspective, coastal megacities can be considered as critical vehicles as well for transboundary risks, as they are major contributors to national economies and present nodal points of global trade and transportation networks as well as global supply chains. The 2011 floods in Bangkok, for example, lead to direct losses of 46.5 billion USD (World Bank, 2012; Haraguchi and Lall, 2015) and massive ripple-on effects in supply chains across the globe (Abe and Ye, 2013).

Cross-Chapter Box 5.4 Responses

LLIC-relevant adaptation initiatives refer to four main categories (Sections 1.5.2, 4.4.2, 5.4, 6.9). *(i)* Protection deals with hard and soft defences against increased marine flooding and land loss due to coastal erosion. *(ii)* Advance-the-line consists in creating new land by building seaward and upwards (e.g., large-scale land reclamation). *(iii)* Accommodation refers to transformations in the way societies occupy space and use natural resources. Accommodation goes from technical measures (e.g., standards to raise building floors, alert systems) to the diversification of livelihoods (e.g., shift in harvesting activities in the Arctic, cultivation of saline-tolerant crops, landscape restoration for tourism purposes) and institutional innovations (e.g., community participation in local government decision-making, evacuation plans). *(iv)* Coastal retreat of people, infrastructures and activities comes when accelerated rates of environmental change such as permafrost thaw, loss of coastal sea ice, storm event, sea level rise, are observed and force local communities to move to expected safer places.

Cross-Chapter Box 5.4.1 Adaptation Strategies in Practice

Adaptation-labelled measures are growingly implemented worldwide (*robust evidence*, *medium agreement*). They cover a wide range of options (Sections 2.4.3.3., 3.5.5, 4.4.2, 4.4.3, 5.4.2), including the installation of major infrastructures to face sea level rise, the armouring of coasts (e.g., seawalls, groynes, revetments, rip-raps), soft engineering (e.g., beach nourishment), ecosystem-based measures (e.g., vegetation planting, coral farming, artificial reef), community-based approaches (e.g., social networks, access to knowledge, economic diversification) and institutional arrangements (e.g., integrated coastal management plans). The diversified examples below, however, demonstrate that the effectiveness of each solution to enhance adaptation is highly variable depending on local context-specificities.

Protection with hard coastal defence measures are a common way of adapting, as they can stop higher peak tides and storm surges from overtopping. They demonstrate some success in terms of risk reduction in the case of coastal megacities, where assets at the coast cannot be removed and natural environments are already severely damaged (Hallegatte et al., 2013; Hinkel et al., 2014). In other contexts, however, and especially rural ones with partly natural coasts, hard coastal structures can lead to detrimental effects because seawalls, e.g., both exacerbate some underlying processes of coastal erosion (i.e., reflecting wave energy; Donner and Webber, 2014) and prevent the beaches from getting back to natural dynamics (see Cross-Chapter Box 4.5.3, below). In turn, this hampers beach-dune systems to buffer waves (David et al., 2016). Another issue refers to the design and placement of coastal structures, with artisanal ones often having counterproductive effects. During the tropical cyclone Oli in 2010 on Tubuai Island, French Polynesia, the waves pulled out many blocks from the non-consolidated coastal structures, which then played as cannonballs and increased the damages on assets (Etienne, 2012).

During the last decade, new concepts in coastal engineering have emerged. Several technical measures with an ecosystem-based design have been developed and, in some places, already implemented. Coconut fibre blankets (Schlurmann et al., 2014), plantations of seagrass (Paul et al., 2012; Paul and Gillis, 2015), artificial reefs made from bio-rock materials (Goreau and Prong, 2017) and bamboo breakwater (Schmitt et al., 2013; David et al., 2016), e.g., are considered as being low-regret measures that stabilize the coastal vegetation and protect against coastal erosion and extreme events. These measures reveal their full potential as stand-alone coastal protection or when used in combination with each other (David et al., 2016) (*medium evidence, high agreement*). Synthesizing 69 studies on wave damping performance of different soft-protection systems, i.e., mangroves, salt marshes, coral reefs and seagrass meadows, Narayan et al. (2016) show significant potential effectiveness from 35 to 71% depending on the ecosystems (70% for coral reefs, 62–79% for salt marshes, 31% for mangroves and 36% for seagrass meadows). In addition, the costs for afforestation and restoration of salt marshes or mangroves are 2 to 5-times lower than cost to build an artificial submerged reef breakwater (Narayan et al., 2016). It is however critical for nature-based measures' sustainability and its contribution to increase the system's long-term resilience, that local communities are fully part of their deployment. On the other extreme, Yamamoto and Esteban (2014) describe some of the engineering options for constructing new, artificial islands, including prospects for floating islands which are anchored to the seabed or to submerged islands.

Relocation of communities and economic activities in response to the effects of climate change is increasingly being considered as an adaptation option (IPCC, 2014; Shayegh et al., 2016; Hauer, 2017; Morrison, 2017). Coastal retreat is experienced in various LLIC around the world, e.g., in Alaska and the US (Bronen and Chapin III, 2013; Bronen, 2015; Ford et al., 2015; Logan et al., 2016; Hino et al., 2017), Guatemala (Milan and Ruano, 2014), the Caribbean (Rivera-Collazo et al., 2015) and Vietnam (Collins et al., 2017). There are experiences of planned relocation in Pacific Islands, such as the resettlement of Gilbertese people from Kiribati to the Solomon Islands during the 1950s and 1960s, as a result of long periods of droughts and subsequent environmental degradation (Birk and Rasmussen, 2014; Tabe, 2016; Weber, 2016). It has also been reported that due to sea level rise entire communities in the Carteret Islands, Papua New Guinea, have been forced to relocate to the main island of Bougainville in Papua New Guinea in response to coastal erosion and salt-water inundation (Birk, 2012; Campbell, 2012; Strauss, 2012; Connell, 2016). In Taro Island, Solomon Islands, the relocation of the islanders and the Taro Township as a result of increasing sea level rise and coastal erosion, is already underway (Haines and McGuire, 2014; Haines, 2016). Still, in the Solomon Islands, the inhabitants of Ontong Java and Sikaina have requested the government to assist with the relocation to the mainland of Malaita or elsewhere due to recent prolonged droughts and salt-water intrusion on the atolls (Monson and Foukona, 2014). People who are moving, however, are rarely exclusively moving due to climate change. Migration pressures as a result of habitual disasters and increasing hazards interact with other migration pressures on the ground (Marino and Lazrus, 2015; Stojanov et al., 2017; Perumal, 2018). There is, however, too little empirical evidence that masses of people will suddenly migrate due to climate change (Hartmann, 2010; Bettini, 2017), and Kelman (2015) suggests that the idea of ‘climate refugees’ is a political construct. In Alaska, several cases have been reported of communities that responded with self-initiated relocation efforts, with Newtok being the most proactive. As well, assessment methods have been proposed and Alaska state funding has been allocated to assist in relocating Newtok community (Bronen, 2015). Relocation also concerns economic activities, as illustrated with shellfish aquaculture relocation in the West coast of the US due to ocean acidification-driven crises (Cooley et al., 2016).

In general, adaptation is growingly recognized as being a social challenge, and not merely a question of technological solutions (Jones and Clark, 2014; McCubbin et al., 2015). Enhancing adaptation indeed implies various socio-political and economic framings, coping capacities and cross-scale social impacts (including economic ones). As a result, community-based approaches and new institutional arrangements gain more and more attention. Sustainable spatial planning could be used to reduce vulnerability to climate change and ensure sustainable coastal adaptation if it is based on a large-scale flood risk assessment, place-specific strategies and only if it is planned and implemented well in advance. Such approaches can involve working with local planning groups (Barron et al., 2012), participative approaches enhancing risk ownership by communities (McEwen et al., 2017), establishing collaborative community networks (Hernández-González et al., 2016) and integrate island communities’ ILK (see McMillen et al., 2014), foster awareness at the local level, integrate local-scale expertise and observations of change with regard to weather, life-history cycles, and ecological processes, implement adaptive action and create acceptance for adaptation policies throughout citizens. Participatory scenario building processes, collaborative landscape planning and co-design of Ecosystem-Based Land Management for LLIC resilience are also already applied and promising approaches to actively engage stakeholders and local citizens in the exploration of future scenarios for resilience. Experiences are reported for German North Sea coast (Karrasch et al., 2017), Tenerife island (Hernández-González et al., 2016) and the Pacific region (Burnside-Lawry et al., 2017). Some scholars also suggest that small islands may benefit from higher adaptive capacities than other LLIC due to high degrees of social capital, i.e., social networks, collective action, reciprocity, and relations of trust (Petzold and Ratter, 2015; Barnett and Waters, 2016; Petzold, 2016).

Cross-Chapter Box 5.4.2 Towards a ‘Pathway’ Approach

Although adaptation-labelled measures currently developed on the ground are mainly reactive and short-term (*robust evidence*, *high agreement*), long-term approaches are emerging (Noble et al., 2014; Wong et al., 2014). In addition, scholars point out the context-specific nature of the measures, each one demonstrating trade-offs (Sections 4.4, 5.4.2, 5.4.3, 5.4.4) and entailing a winner/loser dilemma (e.g., Cormier-Salem and

Panfili, 2016). This suggests the response area to be primarily based on combinations of measures (Section 1.5).

This is in line with the emerging ‘adaptation pathway' approach that describes long-term adaptation strategies based upon decision cycles that, over time, explore and sequence a set of possible actions (including cost-benefits) based on alternative external, uncertain developments (Haasnoot et al., 2013; Barnett et al., 2014; Wise et al., 2014). Practical experiences are burgeoning in LLIC, e.g., in the Netherlands (Haasnoot et al., 2013), Indonesia (Butler et al., 2014), New York City (Rosenzweig and Solecki, 2014), Singapore (Buurman and Babovic, 2017). They notably suggest that as their constituting individual measures, adaptation pathways are context-specific by nature and necessarily reflect ‘competing prioritized values and objectives, and different visions of development that can change over time' (O'Brien et al., 2012: 440). They also highlight the importance of thinking adaptation and resilience in a very dynamic way, in order to reflect the evolving nature of vulnerability (Denton et al., 2014; Dilling et al., 2015; Duvat et al., 2017; Fawcett et al., 2017), improve the projection of climate change impacts (Cardona et al., 2012), and better anticipate the risks of maladaptation (Juhola et al., 2016; Magnan et al., 2016) and climate change uncertainty (O'Brien et al., 2012; Brown et al., 2014; Noble et al., 2014). That is, adaptation pathways are practical tools for identifying opportunities, low- or no-regret strategies and actions, path-dependencies and lock-ins, actions sequencing, areas of flexibility, and possible abrupt changes in a changing environment (Haasnoot et al., 2013; Werners et al., 2015; Hermans et al., 2017).

Interestingly, empirically-based works often consider extreme events and gradual sea level rise together, hence calling for linking adaptation to climate change and disaster risk reduction policies. For example, Hurricane Sandy in 2012 played as a ‘tipping point' that led to the strengthening and the expansion of an existing adaptation pathway strategy and a policy shift ‘from a generalized heuristic to a specific trajectory with milestones' (Rosenzweig and Solecki, 2014: 406). Adaptation pathways also usually bring together multiple sectors, institutions and stakeholders, and finally lay the foundations for the elaboration of Climate Resilient Development Pathways (CRDP), broadly defined as sustainable development pathways simultaneously promoting climate resilience.

Cross-Chapter Box 5.4.3 The Risk of Maladaptation to Climate Change

As suggested above, adaptation-labelled measures that have negative consequences refer to ‘actions or inaction that may lead to increased risk of adverse climate-related outcomes, increased vulnerability to climate change, or diminished welfare' (Noble et al., 2014: 857). In the Comoros and Tuvalu, e.g., seawalls are being built as measures of climate change adaptation with the support of international donors. These options however do not solve the severe erosion problem the islands are facing, and that is rather due to sand mining practices than to sea level rise (Marino and Lazrus, 2015; Betzold and Mohamed, 2016; Ratter et al., 2016). This example refers to the point made above (see Cross-Chapter Box 5.2) that societies' vulnerability is not only driven by climate, ocean and cryosphere changes, but also by anthropogenic dynamics such as coastal urbanization, population growth, modernization of the economy and lifestyles, and the loss of ILK (*robust evidence, high agreement*). Anthropogenic drivers are key contributors to vulnerability from temperate coasts (e.g., in France; Genovese and Przyluski, 2013), to tropical islands (Duvat et al., 2017; Hay, 2017) and Polar regions (Ford et al., 2015). To limit the contribution of these anthropogenic drivers to future impacts at the coast, e.g., by promoting regulations to avoid new buildings in flood-prone areas, is fully part of the adaptation challenge (*medium evidence, medium agreement*) (Magnan and Duvat, submitted). This suggests minimizing the risk of maladaptation to climate change to be a first, key step to the long-term adaptation process (Barnett and O'Neill, 2013; Juhola et al., 2016; Magnan et al., 2016).

Cross-Chapter Box 5.5 Conclusion on Overarching Issues

LLIC are hot spots of climate change impacts, whether they are from the Global North or South, urban or rural, continental or island, at any latitude (*robust evidence*, *high agreement*). LLIC are particularly vulnerable not only because of the ocean-related multiple threats—that are also partly inherent to changes in the worldwide cryosphere system—, but also because of anthropogenic drivers. In this way, LLIC provide relevant illustrations of some of the Reasons for Concern (RFC) developed by the IPCC since the Third Assessment Report (McCarthy et al., 2001) and describing potentially dangerous anthropogenic interference with the climate system. Especially, LLIC illustrate the risks to unique and threatened systems (RFC1), and risks associated with extreme weather events (RFC2) and the uneven distribution of impacts (RFC3). Recent scientific advances emphasize contrasting end-century futures for such RFC from ocean acidification and sea level rise under various global warming scenarios (IPCC, 2014; O'Neill et al., 2017). Regarding sea level rise, e.g., it is estimated that the potential for coastal protection and ecosystem-based adaptation will reach significant limits in the case of a 1m-rise by 2100 (O'Neill et al., 2017). This raises all the more concerns that such a rise is now revisited upwards due to new knowledge on Antarctica's possible contribution (Section 4.2.3), and that current RFC do not fully integrate the possibility of abrupt changes (Sections 6.2, 6.7), the crossing of environmental and/or anthropogenic tipping points (Section 6.2) or changes in extreme sea levels (Sections 4.2.2.5, 4.2.3.3). There are also still gaps in including the potential benefits from adaptation in terms of risk reduction and sustainable development.

Furthermore, the RFC and associated 'burning embers' were developed at a global scale (see Oppenheimer et al., 2014; Gattuso et al., 2015; Magnan et al., 2016; O'Neill et al., 2017). As a result, in its current form, the framework is not suited to describe the geographical variability of risk from one LLIC to another, except with respect to RFC3. For example, Malé (Maldives), South Tarawa (Kiribati) and Rangiroa (French Polynesia) present relatively contrasting situations, although they belong to the same 'urban atoll reef islands' category. The same for New York City (USA), Shanghai (China) and Mumbai (India), the three of them being representative of 'coastal megacities'. Stocktaking on such variability of impacts, risks and vulnerability profiles has two main implications.

First, it questions the future habitability of LLIC, a topic that gained critical policy and media attention over the last decades, especially through the iconic situations of atoll reef islands threatened by sea level rise and Arctic coasts affected by permafrost thaw. Recent scientific evidence, however, challenges the 'sinking islands' concern in atoll contexts (*robust evidence*, *medium agreement*). Out of ~700 studied islands to date, ~73% were stable in area over the last forty to seventy years, and ~15% and ~11% increased and decreased in size, respectively (Mann and Westphal, 2014; McLean and Kench, 2015; Kench et al., 2018; Duvat, submitted). While this does not mean that such trends will necessarily continue in the future, due to different sea level rise patterns and combined effects of ocean warming and acidification on coral reefs systems (Sections 1.4.2.4., 5.2.2), but it shows that diversified profiles must be considered in the way climate-related issues are framed locally. Combining natural drivers with human dimensions such as population dynamics and economic diversification, and building on previous prospective works, Manley et al. (2016) highlight that *(i)* earliest and *(ii)* latest dates when Pacific atolls are expected to become potentially uninhabitable (see also Storlazzi et al., 2015). Despite huge uncertainty, such projections vary *(i)* from 2050 (e.g., North Cook Islands, Western and Eastern Caroline Islands) to 2080 (e.g., Marshall Islands, Tokelau), and *(ii)* from 2100 (e.g., Line Islands in Kiribati, Cook-Austral chain) to 2160 (e.g., Southern Tuamotu archipelago). This very illustrative case of atolls shows the importance of island and coastal dynamics (see above) and suggests that there is a need for better understanding the place-specific variability in impacts, risks and vulnerabilities, and the implications for the future habitability of LLIC (Hay et al., 2018). Moreover, future habitability will not only be challenged by trends in sea level, but also by recurring extreme events that will compromise the background conditions for human life (*medium evidence*, *high agreement*) through saltwater intrusion and/or storm surges. Noteworthy is that issues related to changing precipitation patterns and water stress, as well as resettlements/relocation of villages, are concerns not only for LLIC but also for high mountain regions (Section 2.6.2.3), suggesting possible experience sharing.

Second, future habitability will not only depend on the extent and rates of changes in environmental conditions, but also on the future effectiveness of coastal nations' and communities' responses (*medium evidence*, *high agreement*). Responses' effectiveness will partly depend on each measure's context-specific appropriateness. While nature-based solutions to reduce wave-induced impacts may be relevant in still relatively natural coastal systems, they could be of limited effectiveness for Arctic retreating coasts or coastal megacities. The effectiveness of adaptation measures also varies in time, partly because of changing environmental conditions. This, in turn, suggests variable limits to adaptation across time and geographies. Hence, the recent emergence of a critical question in the scientific, policy and practice arenas: what are the options for adapting, and how to sequence them over time? This questioning paves the way for the elaboration of LLIC-specific 'Climate Resilient Development Pathways' based on the critical conclusions raised in this Cross-Chapter Box, i.e., LLIC are highly dynamic environments confronted to a range of climate-driven pressures (slow and fast on-set events) and diverse anthropogenic drivers and demonstrating a wide geographical variability in terms of risk and vulnerability profiles.

References

Abe, M. and L. Ye, 2013: Building Resilient Supply Chains against Natural Disasters: The Cases of Japan and Thailand. *Global Business Review*, **14** (4), 567-586, doi:10.1177/0972150913501606.

Adger, W. N. et al., 2014: Human security. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change [Field, C. B., V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea and L. L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 755-791.

Albert, S. et al., 2016: Interactions between sea-level rise and wave exposure on reef island dynamics in the Solomon Islands. *Environmental Research Letters*, **11** (5), 054011.

AMAP, 2017: *Adaptation Actions for a Changing Arctic: Perspectives from the Bering-Chukchi-Beaufort Region*. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway [Available at: https://www.amap.no/documents/download/2993].

Amelung, B. and S. Nicholls, 2014: Implications of climate change for tourism in Australia. *Tourism Management*, **41**, 228-244, doi:10.1016/j.tourman.2013.10.002.

Atteridge, A. and E. Remling, 2018: Is adaptation reducing vulnerability or redistributing it? *Wiley Interdisciplinary Reviews: Climate Change*, **9** (1), 1-16, doi:10.1002/wcc.500.

Barbier, E. B., 2015: Climate change impacts on rural poverty in low-elevation coastal zones. *Estuarine, Coastal and Shelf Science*, **165**, A1-A13, doi:10.1016/j.ecss.2015.05.035.

Barnett, J. et al., 2014: A local coastal adaptation pathway. *Nature Climate Change*, **4**, 1103-1108, doi:10.1038/nclimate2383.

Barnett, J. and S. O'Neill, 2013: Minimising the risk of maladaptation: a framework for analysis. In: Climate Adaptation Futures [Palutikof, J., S. Boulter, A. Ash, M. Stafford-Smith, M. Parry, M. Waschka and D. Guitart (eds.)]. Wiley-Blackwell, Chichester, 87-94.

Barnett, J. and E. Waters, 2016: Rethinking the Vulnerability of Small Island States: Climate Change and Development in the Pacific Islands. In: The Palgrave Handbook of International Development [Grugel, J. and D. Hammett (eds.)]. Palgrave Macmillan UK, London, 731-748.

Barron, S. et al., 2012: A Climate Change Adaptation Planning Process for Low-Lying, Communities Vulnerable to Sea Level Rise. *Sustainability*, **4** (9), 2176-2208, doi:10.3390/su4092176.

Batabyal, P. et al., 2014: Influence of hydrologic and anthropogenic factors on the abundance variability of enteropathogens in the Ganges estuary, a cholera endemic region. *Science of The Total Environment*, **472**, 154-61, doi:10.1016/j.scitotenv.2013.10.093.

Bettini, G., 2017: Where Next? Climate Change, Migration, and the (Bio)politics of Adaptation. *Global Policy*, **8** (S1), 33-39, doi:10.1111/1758-5899.12404.

Betzold, C. and I. Mohamed, 2016: Seawalls as a response to coastal erosion and flooding: a case study from Grande Comore, Comoros (West Indian Ocean). *Regional Environmental Change*, 1-11, doi:10.1007/s10113-016-1044-x.

Birk, T., 2012: Relocation of reef and atoll island communities as an adaptation to climate change: learning from experiences in Solomon Islands. In: Climate change and human mobility [Hastrup, K. and K. F. Olwig (eds.)]. Cambridge University Press, Cambridge, 81-109.

Birk, T. and K. Rasmussen, 2014: Migration from atolls as climate change adaptation: Current practices, barriers and options in Solomon Islands. *Natural Resources Forum*, **38** (1), 1-13, doi:10.1111/1477-8947.12038.

Birkmann, J. et al., 2016: Boost resilience of small and mid-sized cities. *Nature*, **537** (7622), 605-8, doi:10.1038/537605a.

Blanchard, J. L. et al., 2012: Potential consequences of climate change for primary production and fish production in large marine ecosystems. *Philosophical Transactions of the Royal Society B: Biological Sciences*, **367** (1605), 2979-89, doi:10.1098/rstb.2012.0231.

Bronen, R., 2011: Climate-induced community relocations: Creating an adaptive governance framework based in human rights doctrine. *New York University Review of Law and Social Change*, **35** (2), 356-406.

Bronen, R., 2015: Climate-induced community relocations: using integrated social-ecological assessments to foster adaptation and resilience. *Ecology and Society*, **20** (3), doi:10.5751/ES-07801-200336.

Bronen, R. and F. S. Chapin III, 2013: Adaptive governance and institutional strategies for climate-induced community relocations in Alaska. *Proceedings of the National Academy of Sciences*, **110** (23), 9320-5, doi:10.1073/pnas.1210508110.

Brown, S. et al., 2014: Shifting perspectives on coastal impacts and adaptation. *Nature Climate Change*, **4**, 752, doi:10.1038/nclimate2344.

Bujosa, A. and J. Rosselló, 2013: Climate change and summer mass tourism: the case of Spanish domestic tourism. *Climatic Change*, **117** (1), 363-375, doi:10.1007/s10584-012-0554-x.

Burge, C. A. et al., 2014: Climate change influences on marine infectious diseases: implications for management and society. *Annual Review of Marine Science*, **6**, 249-77, doi:10.1146/annurev-marine-010213-135029.

Burnside-Lawry, J. et al., 2017: Communication, Collaboration and Advocacy: A Study of Participatory Action Research to Address Climate Change in the Pacific. *The International Journal of Climate Change: Impacts and Responses*, **9** (4), 11-33, doi:10.18848/1835-7156/CGP/v09i04/11-33.

Butler, J. R. A. et al., 2014: Framing the application of adaptation pathways for rural livelihoods and global change in eastern Indonesian islands. *Global Environmental Change*, **28**, 368-382, doi:10.1016/j.gloenvcha.2013.12.004.

Buurman, J. and V. Babovic, 2017: Adaptation Pathways and Real Options Analysis: An approach to deep uncertainty in climate change adaptation policies. *Policy and Society*, **35** (2), 137-150, doi:10.1016/j.polsoc.2016.05.002.

Campbell, J., 2012: Climate-induced community relocation in the Pacific: The meaning and importance of land. In: Climate Change and Displacement: Multidisciplinary Perspectives [McAdam, J. (ed.)]. Hart Publishing, Oxford, 57-79.

Campbell, J., 2015: Development, global change and traditional food security in Pacific Island countries. *Regional Environmental Change*, **15** (7), 1313-1324.

Cardona, O. D. et al., 2012: Determinants of Risk: Exposure and Vulnerablity. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC) [Field, C. B., V. R. Barros, T. F. Stocker, D. Qin, D. J. Dokken, K. L. Ebi, M. D. Mastrandrea, K. J. Mach, G. K. Plattner, S. K. Allen, M. Tignor and P. M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 65-108.

Cheng, W., J. C. H. Chiang and D. Zhang, 2013: Atlantic Meridional Overturning Circulation (AMOC) in CMIP5 Models: RCP and Historical Simulations. *Journal of Climate*, **26** (18), 7187-7197, doi:10.1175/jcli-d-12-00496.1.

Cheriton, O. M., C. D. Storlazzi and K. J. Rosenberger, 2016: Observations of wave transformation over a fringing coral reef and the importance of low-frequency waves and offshore water levels to runup, overwash, and coastal flooding. *Journal of Geophysical Research: Oceans*, **121** (5), 3121-3140, doi:10.1002/2015jc011231.

Collins, N., S. Jones, T. H. Nguyen and P. Stanton, 2017: The contribution of human capital to a holistic response to climate change: learning from and for the Mekong Delta, Vietnam. *Asia Pacific Business Review*, **23** (2), 230-242, doi:10.1080/13602381.2017.1299449.

Connell, J., 2016: Last days in the Carteret Islands? Climate change, livelihoods and migration on coral atolls. *Asia Pacific Viewpoint*, **57** (1), 3-15.

Cooley, S. R., C. R. Ono, S. Melcer and J. Roberson, 2016: Community-Level Actions that Can Address Ocean Acidification. *Frontiers in Marine Science*, **2** (128), 1-12, doi:10.3389/fmars.2015.00128.

Cormier-Salem, M. C. and J. Panfili, 2016: Mangrove reforestation: greening or grabbing coastal zones and deltas? Case studies in Senegal. *African Journal of Aquatic Science*, **41** (1), 89-98, doi:10.2989/16085914.2016.1146122.

Dannevig, H. and G. K. Hovelsrud, 2016: Understanding the need for adaptation in a natural resource dependent community in Northern Norway: issue salience, knowledge and values. *Climatic Change*, **135** (2), 261-275, doi:10.1007/s10584-015-1557-1.

Dasgupta, S., I. Sobhan and D. Wheeler, 2017: The impact of climate change and aquatic salinization on mangrove species in the Bangladesh Sundarbans. *AMBIO*, **46** (6), 680-694, doi:10.1007/s13280-017-0911-0.

David, C. G., N. Schulz and T. Schlurmann, 2016: Assessing the Application Potential of Selected Ecosystem-Based, Low-Regret Coastal Protection Measures. In: Ecosystem-Based Disaster Risk Reduction and Adaptation in Practice [Renaud, F. G., K. Sudmeier-Rieux, M. Estrella and U. Nehren (eds.)]. Springer International Publishing, Cham, **42**, 457-482.

Davidson, L. and M. Sahli, 2015: Foreign direct investment in tourism, poverty alleviation, and sustainable development: a review of the Gambian hotel sector. *Journal of Sustainable Tourism*, **23** (2), 167-187, doi:10.1080/09669582.2014.957210.

Denton, F. et al., 2014: Climate-resilient pathways: adaptation, mitigation, and sustainable development. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change [Field, C. B., V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea and L. L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1101-1131.

Dilling, L. et al., 2015: The dynamics of vulnerability: why adapting to climate variability will not always prepare us for climate change. *Wiley Interdisciplinary Reviews: Climate Change*, **6** (4), 413-425, doi:10.1002/wcc.341.

DiSegni, D. M. and M. Shechter, 2013: Socioeconomic Aspects: Human Migrations, Tourism and Fisheries. In: The Mediterranean Sea. Its history and present challenges [Goffredo, S. and Z. Dubinski (eds.)]. Springer Netherlands, Dordrecht, 571-575.

Donner, S. D., 2015: The legacy of migration in response to climate stress: learning from the Gilbertese resettlement in the Solomon Islands. *Natural Resources Forum*, **39** (3-4), 191-201, doi:10.1111/1477-8947.12082.

Donner, S. D. and S. Webber, 2014: Obstacles to climate change adaptation decisions: a case study of sea-level rise and coastal protection measures in Kiribati. *Sustainability Science*, **9** (3), 331-345, doi:10.1007/s11625-014-0242-z.

Duvat, V. et al., 2017: Trajectories of exposure and vulnerability of small islands to climate change. *Wiley Interdisciplinary Reviews: Climate Change*, **8** (6), e478, doi:10.1002/wcc.478.

Duvat, V. K. E., submitted: A global review of atoll reef island change over the past century. *Wiley Interdisciplinary Reviews: Climate Change*.

Emanuel, K., 2017: Assessing the present and future probability of Hurricane Harvey's rainfall. *Proceedings of the National Academy of Sciences*, **114** (48), 12681-12684, doi:10.1073/pnas.1716222114.
Etienne, S., 2012: Marine inundation hazards in French Polynesia: geomorphic impacts of Tropical Cyclone Oli in February 2010. *Geological Society, London, Special Publications*, **361** (1), 21-39, doi:10.1144/sp361.4.
FAO et al., 2017: *The State of Food Security and Nutrition in the World 2017. Building resilience for peace and food security*. FAO, Rome [Available at: http://www.fao.org/3/a-I7695e.pdf].
Fawcett, D., T. Pearce, J. D. Ford and L. Archer, 2017: Operationalizing longitudinal approaches to climate change vulnerability assessment. *Global Environmental Change*, **45**, 79-88, doi:10.1016/j.gloenvcha.2017.05.002.
Feldmeyer, D., J. Birkmann and T. Welle, 2017: Vulnerability to natural hazards and climate change is reducing at the global scale, however, regional differences are significant – Analysis and interpretation of the vulnerability component of the WorldRiskIndex between 2012 and 2017. *Journal of Extreme Events*, **accepted**.
Ford, J. D. et al., 2012: Mapping Human Dimensions of Climate Change Research in the Canadian Arctic. *AMBIO*, **41** (8), 808-822, doi:10.1007/s13280-012-0336-8.
Ford, J. D. et al., 2016: Including indigenous knowledge and experience in IPCC assessment reports. *Nature Climate Change*, **6** (4), 349-353, doi:10.1038/Nclimate2954.
Ford, J. D., G. McDowell and J. Jones, 2014: The state of climate change adaptation in the Arctic. *Environmental Research Letters*, **9** (10), 104005.
Ford, J. D., G. McDowell and T. Pearce, 2015: The adaptation challenge in the Arctic. *Nature Climate Change*, **5** (12), 1046-1053.
Garschagen, M. and P. Romero-Lankao, 2013: Exploring the relationships between urbanization trends and climate change vulnerability. *Climatic Change*, **133** (1), 37-52, doi:10.1007/s10584-013-0812-6.
Gattuso, J.-P. et al., 2015: Contrasting futures for ocean and society from different anthropogenic CO2 emissions scenarios. *Science*, **349** (6243), doi:10.1126/science.aac4722.
Genovese, E. and V. Przyluski, 2013: Storm surge disaster risk management: the Xynthia case study in France. *Journal of Risk Research*, **16** (7), 825-841, doi:10.1080/13669877.2012.737826.
Genua-Olmedo, A., C. Alcaraz, N. Caiola and C. Ibáñez, 2016: Sea level rise impacts on rice production: The Ebro Delta as an example. *Science of The Total Environment*, **571**, 1200-1210, doi:10.1016/j.scitotenv.2016.07.136.
Gerrard, M. B. and G. E. Wannier, Eds., 2013: Threatened Island Nations: Legal Implications of Rising Seas and a Changing Climate. Cambridge University Press, Cambridge,
Goreau, T. and P. Prong, 2017: Biorock Electric Reefs Grow Back Severely Eroded Beaches in Months. *Journal of Marine Science and Engineering*, **5** (4), 48.
Gorokhovich, Y., A. Leiserowitz and D. Dugan, 2013: Integrating Coastal Vulnerability and Community-Based Subsistence Resource Mapping in Northwest Alaska. *Journal of Coastal Research*, 158-169, doi:10.2112/JCOASTRES-D-13-00001.1.
Government of Vanuatu, 2015: *Vanuatu. Post-Disaster Needs Assessment. Tropical Cyclone Pam, March 2015*. Government of Vanuatu, Port Vila [Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/vanuatu_pdna_cyclone_pam_2015.pdf].
Gugliotta, M. et al., 2017: Process regime, salinity, morphological, and sedimentary trends along the fluvial to marine transition zone of the mixed-energy Mekong River delta, Vietnam. *Continental Shelf Research*, **147**, 7-26, doi:10.1016/j.csr.2017.03.001.
Haasnoot, M., J. H. Kwakkel, W. E. Walker and J. ter Maat, 2013: Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Global Environmental Change*, **23** (2), 485-498, doi:10.1016/j.gloenvcha.2012.12.006.
Haines, P., 2016: *Choiseul Bay Township Adaptation and Relocation Program, Choiseul Province, Solomon Islands. Case Study for CoastAdapt*. National Climate Change Adaptation Research Facility, Gold Coast [Available at: https://coastadapt.com.au/sites/default/files/case_studies/CSS3_Relocation_in_the_Solomon_Islands.pdf].
Haines, P. and S. McGuire, 2014: Rising tides, razing capitals: A Solomon Islands approach to adaptation [online]. In: *Practical Responses to Climate Change Conference 2014*, Barton, Engineers Australia, 152-162.
Hajra, R. et al., 2017: Unravelling the association between the impact of natural hazards and household poverty: evidence from the Indian Sundarban delta. *Sustainability Science*, **12** (3), 453-464, doi:10.1007/s11625-016-0420-2.
Hallegatte, S. et al., 2016: *Shock Waves: Managing the Impacts of Climate Change on Poverty*. Climate Change and Development Series, World Bank, Washington D.C. [Available at: https://openknowledge.worldbank.org/bitstream/handle/10986/22787/9781464806735.pdf?sequence=13&isAllowed=y].
Hallegatte, S., C. Green, R. J. Nicholls and J. Corfee-Morlot, 2013: Future flood losses in major coastal cities. *Nature Climate Change*, **3** (9), 802-806, doi:10.1038/nclimate1979.
Haraguchi, M. and U. Lall, 2015: Flood risks and impacts: A case study of Thailand’s floods in 2011 and research questions for supply chain decision making. *International Journal of Disaster Risk Reduction*, **14** (3), 256-272, doi:10.1016/j.ijdrr.2014.09.005.
Hartmann, B., 2010: Rethinking climate refugees and climate conflict: Rhetoric, reality and the politics of policy discourse. *Journal of International Development*, **22** (2), 233-246, doi:10.1002/jid.1676.

Hauer, M. E., 2017: Migration induced by sea-level rise could reshape the US population landscape. *Nature Climate Change*, **7** (5), 321-325, doi:10.1038/nclimate3271.

Hay, J. E., 2013: Small island developing states: coastal systems, global change and sustainability. *Sustainability Science*, **8** (3), 309-326, doi:10.1007/s11625-013-0214-8.

Hay, J. E., 2017: *Nadi Flood Control Project. Climate Risk and Vulnerability Assessment (CRVA). Final Report*. Prepared for the Asian Development Bank.

Hay, J. E. et al., 2018: *Climate Change and Disaster Risk Reduction: Research Synthesis Report*. Submitted to the New Zealand Ministry of Foreign Affairs and Trade, Wellington, New Zealand [Available at: https://www.mfat.govt.nz/assets/Aid-Prog-docs/Research/Climate-Change-and-DRR-Synthesis-Report-Final-v6.4.pdf].

Hermans, L. M., M. Haasnoot, J. ter Maat and J. H. Kwakkel, 2017: Designing monitoring arrangements for collaborative learning about adaptation pathways. *Environmental Science & Policy*, **69**, 29-38, doi:10.1016/j.envsci.2016.12.005.

Hernández-González, Y. et al., 2016: *Perspectives on contentions about climate change adaptation in the Canary Islands: A case study for Tenerife*. European Union, Union, P. O. o. t. E., Luxembourg [Available at: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC104349/lbna28340enn.pdf].

Hinkel, J. et al., 2014: Coastal flood damage and adaptation costs under 21st century sea-level rise. *Proceedings of the National Academy of Sciences*, **111** (9), 3292-3297, doi:10.1073/pnas.1222469111.

Hino, M., C. B. Field and K. J. Mach, 2017: Managed retreat as a response to natural hazard risk. *Nature Climate Change*, **7**, 364-370, doi:10.1038/nclimate3252.

Hiwasaki, L., E. Luna, Syamsidik and J. A. Marçal, 2014: Local and indigenous knowledge on climate-related hazards of coastal and small island communities in Southeast Asia. *Climatic Change*, **128** (1-2), 35-56, doi:10.1007/s10584-014-1288-8.

Ignatowski, J. A. and J. Rosales, 2013: Identifying the exposure of two subsistence villages in Alaska to climate change using traditional ecological knowledge. *Climatic Change*, **121** (2), 285-299, doi:10.1007/s10584-013-0883-4.

IPCC, 2014: *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R. K. Pachauri and L. A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Janif, S. Z. et al., 2016: Value of traditional oral narratives in building climate-change resilience: insights from rural communities in Fiji. *Ecology and Society*, **21** (2), doi:10.5751/ES-08100-210207.

Jones, B. and B. C. O'Neill, 2016: Spatially explicit global population scenarios consistent with the Shared Socioeconomic Pathways. *Environmental Research Letters*, **11** (8), doi:10.1088/1748-9326/11/8/084003.

Jones, N. and J. R. A. Clark, 2014: Social capital and the public acceptability of climate change adaptation policies: a case study in Romney Marsh, UK. *Climatic Change*, **123** (2), 133-145, doi:10.1007/s10584-013-1049-0.

Juhola, S., E. Glaas, B.-O. Linnér and T.-S. Neset, 2016: Redefining maladaptation. *Environmental Science & Policy*, **55**, 135-140, doi:10.1016/j.envsci.2015.09.014.

Kabir, M. J., D. S. Gaydon, R. Cramb and C. H. Roth, 2018: Bio-economic evaluation of cropping systems for saline coastal Bangladesh: I. Biophysical simulation in historical and future environments. *Agricultural Systems*, **162**, 107-122, doi:10.1016/j.agsy.2018.01.027.

Kaltenborn, B. P. et al., 2017: Ecosystem Services and Cultural Values as Building Blocks for 'The Good life'. A Case Study in the Community of Røst, Lofoten Islands, Norway. *Ecological Economics*, **140**, 166-176, doi:10.1016/j.ecolecon.2017.05.003.

Karrasch, L., M. Maier, M. Kleyer and T. Klenke, 2017: Collaborative Landscape Planning: Co-Design of Ecosystem-Based Land Management Scenarios. *Sustainability*, **9** (9), doi:10.3390/su9091668.

Kates, R. W., C. E. Colten, S. Laska and S. P. Leatherman, 2006: Reconstruction of New Orleans after Hurricane Katrina: A research perspective. *Proceedings of the National Academy of Sciences*, **103** (40), 14653-14660, doi:10.1073/pnas.0605726103.

Kelman, I., 2015: Difficult decisions: Migration from Small Island Developing States under climate change. *Earth's Future*, **3** (4), 133-142, doi:10.1002/2014ef000278.

Kench, P. S., M. R. Ford and S. D. Owen, 2018: Patterns of island change and persistence offer alternate adaptation pathways for atoll nations. *Nature Communications*, **9** (1), 1-7, doi:10.1038/s41467-018-02954-1.

Khanom, T., 2016: Effect of salinity on food security in the context of interior coast of Bangladesh. *Ocean & Coastal Management*, **130**, 205-212, doi:10.1016/j.ocecoaman.2016.06.013.

Kim, I. N. et al., 2014: Chemical oceanography. Increasing anthropogenic nitrogen in the North Pacific Ocean. *Science*, **346** (6213), 1102-6, doi:10.1126/science.1258396.

Kondolf, G. M. et al., 2014: Sustainable sediment management in reservoirs and regulated rivers: Experiences from five continents. *Earth's Future*, **2** (5), 256-280, doi:10.1002/2013ef000184.

Kumar, L. and S. Taylor, 2015: Exposure of coastal built assets in the South Pacific to climate risks. *Nature Climate Change*, **5** (11), 992-996, doi:10.1038/nclimate2702.

Lacher, K., 2015: The island community of Chenega: Earthquake, tsunami, oil spill ... What's next? *Global Environment*, **8** (1), 38-60, doi:10.3197/ge.2015.080103.

Lam, V. W., W. W. Cheung, G. Reygondeau and U. R. Sumaila, 2016: Projected change in global fisheries revenues under climate change. *Scientific Reports*, **6**, 32607, doi:10.1038/srep32607.

Lantuit, H. et al., 2011: The Arctic Coastal Dynamics Database: A New Classification Scheme and Statistics on Arctic Permafrost Coastlines. *Estuaries and Coasts*, **35** (2), 383-400, doi:10.1007/s12237-010-9362-6.
Lazrus, H., 2015: Risk Perception and Climate Adaptation in Tuvalu: A Combined Cultural Theory and Traditional Knowledge Approach. *Human Organization*, **74** (1), 52-61, doi:10.17730/humo.74.1.q0667716284749m8.
Leonard, S., M. Parsons, K. Olawsky and F. Kofod, 2013: The role of culture and traditional knowledge in climate change adaptation: Insights from East Kimberley, Australia. *Global Environmental Change*, **23** (3), 623-632, doi:10.1016/j.gloenvcha.2013.02.012.
Lichter, M., A. T. Vafeidis, R. J. Nicholls and G. Kaiser, 2011: Exploring Data-Related Uncertainties in Analyses of Land Area and Population in the "Low-Elevation Coastal Zone" (LECZ). *Journal of Coastal Research*, **27** (4), 757-768, doi:10.2112/jcoastres-d-10-00072.1.
Liu, H., J. G. Behr and R. Diaz, 2016: Population vulnerability to storm surge flooding in coastal Virginia, USA. *Integrated environmental assessment and management*, **12** (3), 500-509, doi:10.1002/ieam.1705.
Lloyd, E. A. and N. Oreskes, 2018: Climate Change Attribution: When Is It Appropriate to Accept New Methods? *Earth's Future*, **6**, 1-15, doi:10.1002/2017ef000665.
Logan, J. R., S. Issar and Z. Xu, 2016: Trapped in Place? Segmented Resilience to Hurricanes in the Gulf Coast, 1970–2005. *Demography*, **53** (5), 1511-1534, doi:10.1007/s13524-016-0496-4.
Magnan, A. K. and V. K. E. Duvat, submitted: Inescapable solutions to coastal adaptation in Reunion Island. *Environmental Science & Policy*.
Magnan, A. K. et al., 2016: Addressing the risk of maladaptation to climate change. *Wiley Interdisciplinary Reviews: Climate Change*, **7** (5), 646-665, doi:10.1002/wcc.409.
Manley, M. et al., 2016: *Research and Analysis on Climate Change and Disaster Risk Reduction. Working Paper 1: Needs, Priorities and Opportunities Related to Climate Change Adaptation and Disaster Risk Reduction*. Report to the New Zealand Ministry of Foreign Affairs and Trade, Wellington.
Mann, T. and H. Westphal, 2014: Assessing Long-Term Changes in the Beach Width of Reef Islands Based on Temporally Fragmented Remote Sensing Data. *Remote Sensing*, **6** (8), 6961-6987, doi:10.3390/rs6086961.
Marino, E., 2012: The long history of environmental migration: Assessing vulnerability construction and obstacles to successful relocation in Shishmaref, Alaska. *Global Environmental Change*, **22** (2), 374-381, doi:10.1016/j.gloenvcha.2011.09.016.
Marino, E. and H. Lazrus, 2015: Migration or Forced Displacement?: The Complex Choices of Climate Change and Disaster Migrants in Shishmaref, Alaska and Nanumea, Tuvalu. *Human Organization*, **74** (4), 341-350, doi:10.17730/0018-7259-74.4.341.
McCarthy, J. J. et al., Eds., 2001: Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA,
McCubbin, S., B. Smit and T. Pearce, 2015: Where does climate fit? Vulnerability to climate change in the context of multiple stressors in Funafuti, Tuvalu. *Global Environmental Change*, **30**, 43-55, doi:10.1016/j.gloenvcha.2014.10.007.
McEwen, L. et al., 2017: Sustainable flood memories, lay knowledges and the development of community resilience to future flood risk. *Transactions of the Institute of British Geographers*, **42** (1), 14-28, doi:10.1111/tran.12149.
McGranahan, G., D. Balk and B. Anderson, 2007: The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. *Environment and Urbanization*, **19** (1), 17-37, doi:10.1177/0956247807076960.
McLean, R. and P. Kench, 2015: Destruction or persistence of coral atoll islands in the face of 20th and 21st century sea-level rise? *Wiley Interdisciplinary Reviews: Climate Change*, **6** (5), 445-463, doi:10.1002/wcc.350.
McMillen, H. L. et al., 2014: Small islands, valuable insights: systems of customary resource use and resilience to climate change in the Pacific. *Ecology and Society*, **19** (4), doi:10.5751/es-06937-190444.
McNamara, D. E. and A. Keeler, 2013: A coupled physical and economic model of the response of coastal real estate to climate risk. *Nature Climate Change*, **3** (6), 559-562, doi:10.1038/nclimate1826.
Merkens, J.-L., L. Reimann, J. Hinkel and A. T. Vafeidis, 2016: Gridded population projections for the coastal zone under the Shared Socioeconomic Pathways. *Global and Planetary Change*, **145**, 57-66, doi:10.1016/j.gloplacha.2016.08.009.
Milan, A. and S. Ruano, 2014: Rainfall variability, food insecurity and migration in Cabricán, Guatemala. *Climate and Development*, **6** (1), 61-68, doi:10.1080/17565529.2013.857589.
Miller Hesed, C. D. and M. Paolisso, 2015: Cultural knowledge and local vulnerability in African American communities. *Nature Climate Change*, **5**, 683-687, doi:10.1038/nclimate2668.
Monson, R. and J. D. Foukona, 2014: Climate-related Displacement and Options for Resettlement in Solomon Islands. In: Land Solutions for Climate Displacement [Leckie, S. (ed.)]. Routledge, Oxon and New York, 291-316.
Morrison, K., 2017: The Role of Traditional Knowledge to Frame Understanding of Migration as Adaptation to the 'Slow Disaster' of Sea Level Rise in the South Pacific. In: Identifying Emerging Issues in Disaster Risk Reduction, Migration, Climate Change and Sustainable Development [Sudmeier-Rieux, K., M. Fernández, I. Penna, M. Jaboyedoff and J. Gaillard (eds.)]. Springer International Publishing, Cham, 249-266.

Muir, D., J. A. G. Cooper and G. Pétursdóttir, 2014: Challenges and opportunities in climate change adaptation for communities in Europe's northern periphery. *Coastal Climate Change Adaptation In The Northern Periphery Of Europe*, **94** (0), 1-8, doi:10.1016/j.ocecoaman.2014.03.017.
Muis, S. et al., 2017: A comparison of two global datasets of extreme sea levels and resulting flood exposure. *Earth's Future*, **5** (4), 379-392, doi:10.1002/2016EF000430.
Nagelkerken, I. and S. D. Connell, 2015: Global alteration of ocean ecosystem functioning due to increasing human CO2 emissions. *Proceedings of the National Academy of Sciences*, **112** (43), 13272-7, doi:10.1073/pnas.1510856112.
Narayan, S. et al., 2016: The Effectiveness, Costs and Coastal Protection Benefits of Natural and Nature-Based Defences. *PLoS One*, **11** (5), e0154735, doi:10.1371/journal.pone.0154735.
National Geophysical Data Center, 1999: Global Land One-kilometer Base Elevation (GLOBE) v.1. D. and P.K. Dunbar. National Geophysical Data Center, NOAA, Hastings, doi:10.7289/V52R3PMS.
Neumann, B., A. T. Vafeidis, J. Zimmermann and R. J. Nicholls, 2015: Future coastal population growth and exposure to sea-level rise and coastal flooding--a global assessment. *PLoS One*, **10** (3), e0118571, doi:10.1371/journal.pone.0118571.
Noble, I. R. et al., 2014: Adaptation needs and options. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change [Field, C. B., V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea and L. L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 833-868.
Nunn, P. D., J. Runman, M. Falanruw and R. Kumar, 2017: Culturally grounded responses to coastal change on islands in the Federated States of Micronesia, northwest Pacific Ocean. *Regional Environmental Change*, **17** (4), 959-971, doi:10.1007/s10113-016-0950-2.
Nurse, L. A. et al., 2014: Small islands. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change [Barros, V. R., C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea and L. L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1613-1654.
O'Neill, B. C. et al., 2017: IPCC reasons for concern regarding climate change risks. *Nature Climate Change*, **7** (1), 28-37, doi:10.1038/nclimate3179.
O'Brien, K. et al., 2012: Toward a Sustainable and Resilient Future. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC) [Field, C. B., V. Barros, T. F. Stocker, D. Qin, D. J. Dokken, K. L. Ebi, M. D. Mastrandrea, K. J. Mach, G. K. Plattner, S. K. Allen, M. Tignor and P. M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 437-486.
Oppenheimer, M. et al., 2014: Emergent risks and key vulnerabilities. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change [Field, C. B., V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea and L. L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1039-1099.
Overeem, I. et al., 2011: Sea ice loss enhances wave action at the Arctic coast. *Geophysical Research Letters*, **38** (17), 1-6, doi:10.1029/2011gl048681.
Paterson, S. K. et al., 2017: Size does matter: City scale and the asymmetries of climate change adaptation in three coastal towns. *Geoforum*, **81**, 109-119, doi:10.1016/j.geoforum.2017.02.014.
Paul, M., T. J. Bouma and C. L. Amos, 2012: Wave attenuation by submerged vegetation: Combining the effect of organism traits and tidal current. *Marine Ecology Progress Series*, **444** (January), 31-41, doi:10.3354/meps09489.
Paul, M. and L. G. Gillis, 2015: Let it flow: how does an underlying current affect wave propagation over a natural seagrass meadow? *Marine Ecology Progress Series*, **523**, 57-70, doi:10.3354/meps11162.
Pelling, M. and S. Blackburn, 2013: *Megacities and the Coast: Risk, Resilience, and Transformation*. Earthscan, Abingdon.
Perumal, N., 2018: "The Place Where I Live Is Where I Belong": The Question of Climate-Related Migration in Vanuatu. *Island Studies Journal*, **in press**, doi:10.24043/isj.50.
Petzold, J., 2016: Limitations and opportunities of social capital for adaptation to climate change: A case study on the Isles of Scilly. *The Geographical Journal*, **182** (2), 123-134, doi:10.1111/geoj.12154.
Petzold, J., 2017: Social adaptability in ecotones: sea-level rise and climate change adaptation in Flushing and the Isles of Scilly, UK. *Island Studies Journal*, doi:10.24043/isj.17.
Petzold, J. and B. M. W. Ratter, 2015: Climate change adaptation under a social capital approach – An analytical framework for small islands. *Ocean & Coastal Management*, **112**, 36-43, doi:10.1016/j.ocecoaman.2015.05.003.
Putra, H. C., H. Zhang and C. Andrews, 2015: Modeling Real Estate Market Responses to Climate Change in the Coastal Zone. *Journal of Artificial Societies and Social Simulation*, **18** (2), doi:10.18564/jasss.2577.

Ratter, B. M. W., J. Petzold and K. M. Sinane, 2016: Considering the locals: coastal construction and destruction in times of climate change on Anjouan, Comoros. *Natural Resources Forum*, **40** (3), 112-126, doi:10.1111/1477-8947.12102.
Read, R., 2018: Small is beautiful: country size and national wellbeing in small economies. In: Handbook of Small States. Economic, Social and Environmental Issues [Briguglio, L. (ed.)]. Routledge, Abingdon, 386-402.
Rhein, M. et al., 2013: Observations: Ocean. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T. F., D. Qin, G. K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 255–316.
Rivera-Collazo, I. et al., 2015: Human adaptation strategies to abrupt climate change in Puerto Rico ca. 3.5 ka. *The Holocene*, **25** (4), 627-640, doi:10.1177/0959683614565951.
Romanovsky, V. E., S. L. Smith and H. H. Christiansen, 2010: Permafrost thermal state in the polar Northern Hemisphere during the international polar year 2007-2009: a synthesis. *Permafrost and Periglacial Processes*, **21** (2), 106-116, doi:10.1002/ppp.689.
Rosenzweig, C. and W. Solecki, 2014: Hurricane Sandy and adaptation pathways in New York: Lessons from a first-responder city. *Global Environmental Change*, **28**, 395-408, doi:10.1016/j.gloenvcha.2014.05.003.
Ross, A. C. et al., 2015: Sea-level rise and other influences on decadal-scale salinity variability in a coastal plain estuary. *Estuarine, Coastal and Shelf Science*, **157**, 79-92, doi:10.1016/j.ecss.2015.01.022.
Rosselló-Nadal, J., 2014: How to evaluate the effects of climate change on tourism. *Tourism Management*, **42**, 334-340, doi:10.1016/j.tourman.2013.11.006.
Sagoe-Addy, K. and K. Appeaning Addo, 2013: Effect of predicted sea level rise on tourism facilities along Ghana's Accra coast. *Journal of Coastal Conservation*, **17** (1), 155-166, doi:10.1007/s11852-012-0227-y.
Schlurmann, T., G. David and N. Schulz, 2014: Low-regret adaptation measures – The way forward in Coastal Engineering? In: Proceedings of the Taiwan-EU Symposium on Ocean Observation and its Application [Yu, P. S. (ed.)]. National Cheng Kung University, Tainan, Taiwan, 73-79.
Schmitt, K., T. Albers, T. T. Pham and S. C. Dinh, 2013: Site-specific and integrated adaptation to climate change in the coastal mangrove zone of Soc Trang Province, Viet Nam. *Journal of Coastal Conservation*, **17** (3), 545-558.
Shakeela, A., S. Becken and N. Johnston, 2013: *Gaps and Disincentives that Exist in the Policies, Laws and Regulations which Act as Barriers to Investing in Climate Change Adaptation in the Tourism Sector of the Maldives. Final Project Report*. UNDP, Maldives [Available at: http://www.tourism.gov.mv/downloads/tap/2014/FINALReport_REVISED_UNDPMaldives_161213.pdf].
Shayegh, S., J. Moreno-Cruz and K. Caldeira, 2016: Adapting to rates versus amounts of climate change: a case of adaptation to sea-level rise. *Environmental Research Letters*, **11** (10), doi:10.1088/1748-9326/11/10/104007.
Smajgl, A. et al., 2015: Responding to rising sea levels in the Mekong Delta. *Nature Climate Change*, **5** (2), 167-174, doi:10.1038/nclimate2469.
Solecki, W., M. Pelling and M. Garschagen, 2017: Transitions between risk management regimes in cities. *Ecology and Society*, **22** (2), doi:10.5751/ES-09102-220238.
Spalding, M. et al., 2017: Mapping the global value and distribution of coral reef tourism. *Marine Policy*, **82**, 104-113, doi:10.1016/j.marpol.2017.05.014.
Stojanov, R. et al., 2017: Local perceptions of climate change impacts and migration patterns in Malé, Maldives. *The Geographical Journal*, **183** (4), 370-385, doi:10.1111/geoj.12177.
Storey, D. and S. Hunter, 2010: Kiribati: an environmental 'perfect storm'. *Australian Geographer*, **41** (2), 167-181, doi:10.1080/00049181003742294.
Storlazzi, C. D., E. P. Elias and P. Berkowitz, 2015: Many Atolls May be Uninhabitable Within Decades Due to Climate Change. *Nature-Scientific Reports*, **5**, 14546, doi:10.1038/srep14546.
Strauss, B. H., S. Kulp and A. Levermann, 2015: *Mapping Choices: Carbon, Climate, and Rising Seas, Our Global Legacy. Climate Central Research Report*. Climate Central, Princeton [Available at: http://sealevel.climatecentral.org/uploads/research/Global-Mapping-Choices-Report.pdf].
Strauss, S., 2012: Are cultures endangered by climate change? Yes, but…. *Wiley Interdisciplinary Reviews: Climate Change*, **3** (4), 371-377, doi:10.1002/wcc.181.
Syvitski, J. P. M. et al., 2009: Sinking deltas due to human activities. *Nature Geoscience*, **2**, 681, doi:10.1038/ngeo629.
Tabe, T., 2016: Ngaira Kain Tari: We are people of the Sea. PhD Thesis. University of Bergen, Place.
Takayabu, I. et al., 2015: Climate change effects on the worst-case storm surge: a case study of Typhoon Haiyan. *Environmental Research Letters*, **10** (6), doi:10.1088/1748-9326/10/6/064011.
Texier-Teixeira, P. and E. Edelblutte, 2017: Jakarta: Mumbai—Two Megacities Facing Floods Engaged in a Marginalization Process of Slum Areas. In: Identifying Emerging Issues in Disaster Risk Reduction, Migration, Climate Change and Sustainable Development: Shaping Debates and Policies [Sudmeier-Rieux, K., M. Fernández, I. M. Penna, M. Jaboyedoff and J. C. Gaillard (eds.)]. Springer International Publishing, Cham, 81-99.
UN-DESA, 2015: *World Urbanization Prospects: The 2014 Revision*. United Nations, New York [Available at: https://esa.un.org/unpd/wup/Publications/Files/WUP2014-Report.pdf].
UN-OHRLLS, 2015: *Small Island Developing States in numbers. Climate change edition 2015*. United Nations, New York [Available at: https://unohrlls.org/custom-content/uploads/2015/12/SIDS-IN-NUMBERS-CLIMATE-CHANGE-EDITION_2015.pdf].

UNDP, 2017: *Regional Overview: Impact of Hurricanes Irma and Maria*. UN Development Programme, New York [Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/UNDP%20%20Regional%20Overview%20Impact%20of%20Hurricanes%20Irma%20and%20Maria.pdf].
United Nations, Eds., 2017: The First Global Integrated Marine Assessment. World Ocean Assessment I. Cambridge University Press, Cambridge,
Weatherdon, L. V. et al., 2016: Observed and Projected Impacts of Climate Change on Marine Fisheries, Aquaculture, Coastal Tourism, and Human Health: An Update. *Frontiers in Marine Science*, **3**, doi:10.3389/fmars.2016.00048.
Weber, E., 2016: Only a pawn in their games? environmental (?) migration in Kiribati – past, present and future. *Die Erde*, **147** (2), 153-164, doi:10.12854/erde-147-11.
Weir, T. and J. Pittock, 2017: Human dimensions of environmental change in small island developing states: some common themes. *Regional Environmental Change*, **17** (4), 949-958, doi:10.1007/s10113-017-1135-3.
Werners, S. E. et al., 2015: Turning points in climate change adaptation. *Ecology and Society*, **20** (4), doi:10.5751/ES-07403-200403.
Wilbers, G. J. et al., 2014: Spatial and temporal variability of surface water pollution in the Mekong Delta, Vietnam. *Science of The Total Environment*, **485-486**, 653-665, doi:10.1016/j.scitotenv.2014.03.049.
Wise, R. M. et al., 2014: Reconceptualising adaptation to climate change as part of pathways of change and response. *Global Environmental Change*, **28**, 325-336, doi:10.1016/j.gloenvcha.2013.12.002.
Wong, P. P. et al., 2014: Coastal systems and low-lying areas. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change [Field, C. B., V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea and L. L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 361-409.
World Bank, 2012: *Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning*. World Bank, Bangkok [Available at: https://openknowledge.worldbank.org/handle/10986/26862].
Yamamoto, L. and M. Esteban, 2014: *Atoll Island States and International Law. Climate Change Displacement and Sovereignty*. Springer, Berlin and Heidelberg.
Yan, B. et al., 2015: Socio-economic vulnerability of the megacity of Shanghai (China) to sea-level rise and associated storm surges. *Regional Environmental Change*, **16** (5), 1443-1456, doi:10.1007/s10113-015-0878-y.
Yin, J., M. Ye, Z. Yin and S. Xu, 2015: A review of advances in urban flood risk analysis over China. *Stochastic Environmental Research and Risk Assessment*, **29** (3), 1063-1070, doi:10.1007/s00477-014-0939-7.