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New findings since AR5 are described in detail below. There is, however, no clear and consistent signal of a climate change contribution. Losing 70–90% of today's coral reefs, however, will remove resources and increase poverty levels across the world's tropical coastlines, highlighting the key issue of equity for the millions of people that depend on these valuable ecosystems (Cross-Chapter Box 6; Spalding et al., 2014; Halpern et al., 2015)734. Projections of the future distribution of seagrasses suggest a poleward shift, which raises concerns that low-latitude seagrass communities may contract as a result of increasing stress levels (Valle et al., 2014)647. Working Group II of AR5 concluded that the detection of changes in groundwater systems, and attribution of those changes to climatic changes, are rare, owing to a lack of appropriate observation wells and an overall small number of studies (Jiménez Cisneros et al., 2014)420. Regionally differentiated multi-sector risks are already apparent at 1.5°C of warming, being more prevalent where vulnerable people live, predominantly in South Asia (mostly Pakistan, India and China), but these risks are projected to spread to sub-Saharan Africa, the Middle East and East Asia as temperature rises, with the world's poorest people disproportionately impacted at 2°C of warming (Byers et al., 2018)1129. In contrast to summer, little ice is projected to be lost during winter for either 1.5°C or 2°C of global warming (medium confidence) (Niederdrenk and Notz, 2018)1173. Small islands are projected to be at risk and very sensitive to coastal climate change and other stressors (high confidence) (Nurse et al., 2014; Benjamin and Thomas, 2016; Ourbak and Magnan, 2017; Brown et al., 2018a; Nicholls et al., 2018; Rasmussen et al., 2018;777 AR5 Sections 29.3 and 29.4), such as oceanic warming, SLR (resulting in salinization, flooding and erosion), cyclones and mass coral bleaching and mortality (Section 3.4.4, Boxes 3.4 and 3.5). (2014)1119 were recently reviewed, and most judgements were confirmed in the light of more recent literature (O'Neill et al., 2017)1120. At 2°C of global warming, it is likely that temperature increases of more than 2°C would occur over most land regions in terms of extreme temperatures (up to 4°C–6°C depending on region and considered extreme index) (Section 3.3.2, Table 3.2). An understanding of the sensitivities of tipping points in the physical climate system, as well as in ecosystems and human systems, is essential for understanding the risks associated with different degrees of global warming. The potential impacts of climate change on livestock (Section 3.4.6), in particular the direct impacts through increased heat stress, have been less well studied than impacts on crop yield, especially from the perspective of critical thresholds being exceeded. In a groundwater-dependent irrigated region in northwest Bangladesh, the average groundwater level during the major irrigation period (January–April) is projected to decrease in accordance with temperature rise (Salem et al., 2017)426. (2013)389 highlighted the importance of water use scenarios in water scarcity assessments, but neither quantitative nor qualitative information regarding water use is available. Numerous impacts have not been quantified at 1.5°C or 2°C but remain important. (2018)1133 identified several regions where economic damages are projected to be greater at 2°C compared to 1.5°C of warming, further estimating that projected damages at 1.5°C remain similar to today's levels of economic damage. O'Neill et al. Chen et al., 2014; Sun et al., 2015; He and Zhou, 2016)854 to America (Cho and McCarl, 2017)855 and Europe (Ramirez-Cabral et al., 2016)856, and they particularly affect the typical local crops cultivated in specific climate conditions (e.g., Mediterranean crops like olive and grapevine, Moriondo et al., 2013a, b)857. Spatially compound risks, often referred to as hotspots, involve multiple hazards from different sectors overlapping in location (Piontek et al., 2014)1101. The studies on migration that have most closely explored the probable impacts of 1.5°C and 2°C have mainly focused on the direct effects of temperature and precipitation anomalies on migration or the indirect effects of these climatic changes through changing agriculture yield and livelihood sources (Mueller et al., 2014; Piguet and Laczko, 2014; Mastrorillo et al., 2016; Sudmeier-Rieux et al., 2017)1079. Mean monthly dissolved oxygen concentrations and nutrient concentrations in the upper Qu'Appelle River (Canada) in 2050–2055 are projected to decrease less at about 1.5°C of warming (RCP2.6) compared to concentrations at about 2°C (RCP4.5) (Hosseini et al., 2017)434. It should be noted that at 1.5°C of warming, and if species' ability to disperse naturally to track their preferred climate geographically is inhibited by natural or anthropogenic obstacles, there would still remain 10% of the amphibians, 8% of the reptiles, 6% of the mammals, 5% of the birds, 10% of the insects and 8% of the plants which are projected to lose over half their range, while species on average lose 20–27% of their range (Warren et al., 2018a)480. Examples of such services include soil conservation (avoidance of desertification), flood control, water and air purification, pollination, nutrient cycling, sources of food, and recreation. Z. This indicates the potential for phenological mismatch and associated risks for ecosystem functionality in the future under global warming of 2.1°C–2.7°C above pre-industrial levels. Increases in the risks associated with runoff at the global scale (medium confidence), and in flood hazard in some regions (medium confidence), can be expected at global warming of 1.5°C, with an overall increase in the area affected by flood hazard at 2°C (medium confidence) (Section 3.3.5). There are potential benefits to small island developing states (SIDS) from avoided risks at 1.5°C versus 2°C, especially when coupled with adaptation efforts. Climate change (e.g., sea level rise, heat stress, storms) presents risk for coastal ecosystems such as seagrass (high confidence) and reef-building corals (very high confidence) (Figure 3.18, Supplementary Material 3.SM.3.2), with evidence of increasing concern since AR5 and the conclusion that tropical corals may be even more vulnerable to climate change than indicated in assessments made in 2014 (Hoegh-Guldberg et al., 2014; Gattuso et al., 2015)648. Assuming adaptation takes place reduces the projected magnitude of risks (Hales et al., 2014; Huynen and Martens, 2015; T. The magnitude of global sea level rise that could occur over the next two centuries under 1.5°C–2°C of global warming is estimated to be in the order of several tenths of a metre according to most studies (low confidence) (Schewe et al., 2011; Church et al., 2013; Levermann et al., 2014; Marzeion and Levermann, 2014; Fürst et al., 2015; Golledge et al., 2015)1147, although a smaller number of investigations (Joughin et al., 2014; Golledge et al., 2015; DeConto and Pollard, 2016)1148 project increases of 1–2 m. In summary, constraining global warming to 1.5°C rather than 2°C has strong benefits for terrestrial and wetland ecosystems and their services (high confidence). The risks (assuming current adaptation) related to water deficit in the Mediterranean are high for global warming of 2°C but could be substantially reduced if global warming were limited to 1.5°C (Section 3.3.4; Guiot and Cramer, 2016; Schleussner et al., 2016b; Donnelly et al., 2017)1192. In general, recognizing and restoring coastal ecosystems may be more cost-effective than installing human structures, in that creating and maintaining structures is typically expensive (Temmerman et al., 2013; Mycoo, 2017)696. Since AR5, evidence of present-day impacts in these systems has continued to grow (Sections 3.4.2, 3.4.4 and 3.4. 5), whilst new evidence has also accumulated for reduced risks at 1.5°C compared to 2°C of warming in Arctic ecosystems (Section 3.3.9), coral reefs (Section 3.4.4) and some other unique ecosystems (Section 3.4.3), as well as for biodiversity. Table 3.SM.11 in Supplementary Material 3.SM summarizes the cited publications. A major barrier to understanding the risks of climate change for tourism, from the destination community scale to the global scale, has been the lack of integrated sectoral assessments that analyse the full range of potential compounding impacts and their interactions with other major drivers of tourism (Rosselló-Nadal, 2014; Scott et al., 2016b)1047. Wang et al., 2016; Castillo et al., 2017; Lemasson et al., 2017; Ong et al., 2017; X. Similarly, a decrease in forage quality is expected for both natural grassland in France (Graux et al., 2013)913 and sown pastures in Australia (Perring et al., 2010)914. Marine organisms are already responding to these changes by shifting their biogeographical ranges to higher latitudes at rates that range from approximately 0 to 40 km yr–1 (Burrows et al., 2014; Chust, 2014; Bruge et al., 2016; Poloczanska et al., 2016)564, which has consequently affected the structure and function of the ocean, along with its biodiversity and foodwebs (high confidence). Other deltas are similarly vulnerable. Woody encroachment, including increased tree cover and biomass, has increased over the past century, owing to changes in land management, rising CO2 levels, and climate variability and change (often in combination) (Settele et al., 2014)541. While some ecosystems (e.g., mangroves) may be able to move shoreward as sea levels increase, coastal development (e.g., coastal building, seawalls and agriculture) often interrupt these transitions (Saunders et al., 2014)812. Overall, modelling studies (Huntingford et al., 2013; Nobre et al., 2016)1250 and observational constraints (Cox et al., 2013)1251 suggest that pronounced rainforest dieback may only be triggered at 3°C–4°C (medium confidence), although pronounced biomass losses may occur at 1.5°C– 2°C of global warming. The acceleration of these changes, coupled with non-climate stresses (e.g., pollution, overfishing and unsustainable coastal development), are driving many small-scale fisheries well below the sustainable harvesting levels required to maintain these resources as a source of food (McClanahan et al., 2009, 2015; Cheung et al., 2010; Pendleton et al., 2016)927. Let us know! Here you can also share your thoughts and ideas about updates to LiveJournal Your request has been filed. Although physical changes in streamflow and continental runoff that are consistent with climate change have been identified (Section 3.3.5), water scarcity in the past is still less well understood because the scarcity assessment needs to take into account various factors, such as the operations of water supply infrastructure and human water use behaviour (Mehran et al., 2017)376, as well as green water, water quality and environmental flow requirements (J. Anticipating these challenges to food and livelihoods for coastal communities will become increasingly important, as will adaptation options, such as the diversification of livelihoods and the development of new sustainable industries, to reduce the dependency of coastal communities on threatened ecosystems such as coral reefs (Cinner et al., 2012, 2016; Pendleton et al., 2016)735. For heat-related morbidity and mortality (related to RFCs 2, 3 and 4), detection and attribution studies show heat-related mortality in some locations increasing with climate change (high confidence) (Section 3.4.7; Ebi et al., 2017)1116. Strategies for adapting to reduced coastal protection involve (a) avoidance of vulnerable areas and hazards, (b) managed retreat from threatened locations, and/or (c) accommodation of impacts and loss of services (Bell, 2012; André et al., 2016; Cooper et al., 2016; Mills et al., 2016; Raabe and Stumpf, 2016; Fu and Song, 2017)692. Armed-conflict risks and climate-related disasters are both relatively common in ethnically fractionalized countries, indicating that there is no clear signal that environmental disasters directly trigger armed conflicts (Schleussner et al., 2016a)1100. Settele et al. As CO2 concentrations continue to increase along with other GHGs, pH will decrease while sea temperature will increase, reaching 1.7°C and a decrease of 0.2 pH units (by 2100 under RCP4.5) relative to the pre-industrial period. Key evidence assessed in earlier parts of this chapter is summarized to indicate the transition points between the levels of risk. One exception is the projection that an eventual 1 m SLR could partially or fully inundate 29% of 900 coastal resorts in 19 Caribbean countries, with a substantially higher proportion (49–60%) vulnerable to associated coastal erosion (Scott and Verkoeyen, 2017)1046. Moreover, an analysis is provided of how integrated risks across physical, natural and human systems may accumulate to lead to the exceedance of thresholds for particular systems. More than 815 million people were undernourished in 2016, and 11% of the world's population has experienced recent decreases in food security, with higher percentages in Africa (20%), southern Asia (14.4%) and the Caribbean (17.7%) (FAO et al., 2017)941. Across all these systems, the efficiency of adaptation strategies is uncertain because it is strongly linked with future economic and trade environments and their response to changing food availability (medium confidence) (Lobell et al., 2011; von Lampe et al., 2014; d'Amour et al., 2016960; Wei et al., 2017)961. Despite these uncertainties, recent studies confirm that observed climate change has already affected crop suitability in many areas, resulting in changes in the production levels of the main agricultural crops. An ensemble of seven Dynamic Vegetation Models driven by projected climates from 19 alternative general circulation models (GCMs) (Warszawski et al., 2013)451 shows 13% (range 8–20%) of biomes transforming at 2°C of global warming, but only 4% (range 2–7%) doing so at 1°C, suggesting that about 6.5% may be transformed at 1.5°C; these estimates indicate a doubling of the areal extent of biome shifts between 1.5°C and 2°C of warming (medium confidence) (Figure 3.16a). Further compilations of quantified levels of risk taken from the literature may be found Tables 3.SM1-5 in the Supplementary Material. These changes are strongly affecting people in the Arctic who have close relationships with sea ice and associated ecosystems, and these people are facing major adaptation challenges as a result of sea level rise, coastal erosion, the accelerated thawing of permafrost, changing ecosystems and resources, and many other issues (Ford, 2012; Ford et al., 2015)623. It is also important to appreciate these changes in the context of large-scale ocean processes such as the ocean carbon pump. For marine fisheries, limiting warming to 1.5°C decreases the risk of species extinction and declines in maximum catch potential, particularly for small islands in tropical oceans (Cheung et al., 2016a)842. This indicates a transition in risk in this system from high to very high (high confidence) at 1.5°C of warming and contributes to a lowering of the transition from high to very high (Figure 3.21) in this RFC1 compared to in AR5. However, some of these adaptive strategies can have negative impacts that deepen the divide between land-wealthy and land-poor farmers (Chapman et al., 2016)983. In the 21st century, land area exposed to sea level rise (assuming there is no adaptation or protection at all) is projected to be at least an order of magnitude larger than the cumulative land loss due to submergence (which takes into account defences) (Brown et al., 2016, 2018a)745 regardless of the SLR scenario applied. Even with warming up until today (GMST for decade 2006–2015: 0.87°C; Chapter 1), a substantial proportion of coral reefs have experienced large-scale mortalities that have lead to much reduced coral populations (Hoegh-Guldberg et al., 2014)705. The transition from moderate to high risk relocates very slightly from 1.6°C to 1.5°C (high confidence). Hence, limiting global warming to 1.5°C compared with 2°C would be expected to reduce both range losses and associated extinction risks in terrestrial species (high confidence). Warming is projected to result in increased numbers of days of ice-free navigation and a longer shipping season in cold regions, thus affecting shipping and reducing transportation costs (Arent et al., 2014)1068. Climate change influences food and nutritional security through its effects on food availability, quality, access and distribution (Paterson and Lima, 2010; Thornton et al., 2014; FAO, 2016)940. (2013)383 determined that an additional 8% of the world population in 2000 would be exposed to new or aggravated water scarcity at 2°C of global warming. Sea level rise also amplifies the impacts of storms and wave action (Section 3.3.9), with robust evidence that storm surges and damage are already penetrating farther inland than a few decades ago, changing conditions for coastal ecosystems and human communities. Tens of thousands of people on small islands are exposed to SLR (Rasmussen et al., 2018)782. Nevertheless, this difference between 1.5°C and 2°C of warming might be limited for plants that are able to expand their range. These studies did not find evidence of bifurcation or indicate that sea ice returns within a few years of its loss, leading Collins et al. In the AR5 analysis, a transition from white to yellow indicated that the onset of moderate risk was located below present-day global temperatures (medium confidence); a transition from yellow to red indicated that the onset of high risk was located at 1.6°C, and a transition from red to purple indicated that the onset of very high risk was located at about 2.6°C. Weakening of the Atlantic Meridional Overturning Circulation (AMOC), for example, is projected to be highly disruptive to natural and human systems as the delivery of heat to higher latitudes via this current system is reduced (Collins et al., 2013)592. In addition, some micronutrients such as iron and zinc will accumulate less and be less available in food (Myers et al., 2014)949. Limited analyses of projected risks associated with 1.5°C versus 2°C are available (Section 3.4.4.12). However, the carbon released to the atmosphere from thawing permafrost is projected to be restricted to 0.09–0.19 Gt C yr–1 at 2°C of global warming and to 0.08–0.16 Gt C yr–1 at 1.5°C (E.J. Burke et al., 2018)1235, which does not indicate a tipping point (medium confidence). At 2°C of warming, more than 90% of global coastlines are projected to experience SLR greater than 0.2 m, suggesting regional differences in the risks of coastal flooding. The High Arctic region, with tundra-dominated landscapes, has warmed more than the global average over the last century (Section 3.3; Settele et al., 2014)520. Role of the Southern Ocean in the global carbon cycle: The critical role of the Southern Ocean as a net sink of carbon might decline under global warming, and assessing this effect under 1.5°C compared to 2°C of global warming is a priority. Tundra-dominated landscapes have warmed more than the global average over the last century (Settele et al., 2014)1230, with associated increases in fires and permafrost degradation (Bring et al., 2016; DeBeer et al., 2016; Jiang et al., 2016; Yang et al., 2016)1231. At the global scale, these peatlands are undergoing rapid major transformations through drainage and burning in preparation for oil palm and other crops or through unintentional burning (Magrin et al., 2014)554. As assessed in Sections 3.3.1 and 3.3.2, impacts of 0.5°C of global warming can be identified for temperature extremes at global scales, based on observations and the analysis of climate models. Worldwide, the largest increases in the number of hot days are projected to occur in the tropics (Figure 3.7). However, the variation between socio-economic levels is larger than the variation between warming levels (Arnell and Lloyd-Hughes, 2014)386. These benefits include avoidance or reduction of changes such as biome transformations, species range losses, increased extinction risks (all high confidence) and changes in phenology (high confidence), together with projected increases in extreme weather events which are not yet factored into these analyses (Section 3.3). At the same time, coastal communities will need to pre-empt changes to other services provided by coral reefs such as coastal protection (Kennedy et al., 2013; Hoegh-Guldberg et al., 2014; Pörtner et al., 2014; Gattuso et al., 2015)736. These large-scale impacts, plus the observation of back-to-back bleaching events on the Great Barrier Reef (predicted two decades ago, Hoegh-Guldberg, 1999)649 and arriving sooner than predicted (Hughes et al., 2017b, 2018)650, suggest that the research community may have underestimated climate risks for coral reefs (Figure 3.18). There was low confidence due to limited evidence, however, that anthropogenic climate change has affected the frequency and magnitude of floods. Mangroves similarly play an important role in coastal protection, as well as providing resources for coastal communities, but they are already under moderate risk of not keeping up with sea level rise due to climate change and to contributing factors, such as reduced sediment supply or obstacles to shoreward shifts (Saunders et al., 2014; Lovelock et al., 2015)689. Hence, a transition from high to very high risk is expected between 1.5°C and 2°C of warming. Working Group II of AR5 (Settele et al., 2014)490 concluded that there is high confidence that net terrestrial ecosystem productivity at the global scale has increased relative to the pre-industrial era and that rising CO2 concentrations are contributing to this trend through stimulation of photosynthesis. (2013)1145 assessed this threshold to be at 2°C of warming or higher levels relative to pre-industrial temperature. Taken together, a transition from moderate to high risk is now located between 1.5°C and 2°C above pre-industrial levels, based on the assessment of risks to food security, water resources, drought, heat exposure and coastal submergence (high confidence; Figure 3.21). These invertebrate organisms underpin important fisheries and aquaculture industries, from polar to tropical regions, and are important food sources for a range of organisms including humans. In addition, deoxygenation interacts with ocean acidification to present substantial separate and combined challenges for fisheries and aquaculture (medium confidence) (Hamukuaya et al., 1998; Bakun et al., 2015; Rodrigues et al., 2015; Feely et al., 2016; S. Countries with at least 50 million people exposed to SLR (assuming no adaptation or protection at all) based on a 1,280 Pg C emissions scenario (approximately a 1.5°C temperature rise above today's level) include China, Bangladesh, Egypt, India, Indonesia, Japan, Philippines, United States and Vietnam (Clark et al., 2016)754. This is particularly relevant for groups in the least developed countries (von Uexkull et al., 2016)1093, in sub-Saharan Africa (Serdeczny et al., 2016; Almer et al., 2017)1094 and in the Middle East (Waha et al., 2017)1095. Tourism is one of the largest industries globally (Rosselló-Nadal, 2014; Markham et al., 2016; Spalding et al., 2017)690. Climate change, however, will regionally exacerbate or offset the effects of population pressure (Jiménez Cisneros et al., 2014)381. These projections assume that no upgrade to current protection levels occurs (Nicholls et al., 2018)749. Road, air, rail, shipping and pipeline transportation can be impacted directly or indirectly by weather and climate, including increases in precipitation and temperature; extreme weather events (flooding and storms); SLR; and incidence of freeze–thaw cycles (Arent et al., 2014)1067. The predictions of back-to-back bleaching events (Hoegh-Guldberg, 1999)721 have become the reality in the summers of 2016–2017 (e.g., Hughes et al., 2017b)722, as have projections of declining coral abundance (high confidence). Vector populations are projected to shift with climate change, with expansions and reductions depending on the degree of local warming, the ecology of the mosquito vector, and other factors (Ren et al., 2016)1011. In this regard, initiatives such as 'climate-smart' food production and distribution systems may assist via technologies and adaptation strategies for food systems (Lipper et al., 2014; Martinez-Baron et al., 2018; Whitfield et al., 2018)964, as well as helping meet mitigation goals (Harvey et al., 2014)965. While attribution can be difficult because of the complexity of the processes involved, both related and unrelated to climate change, some impacts associated to deoxygenation (low-medium confidence) include the expansion of oxygen minimum zones (OMZ) (Turner et al., 2008; Carstensen et al., 2014; Acharya and Panigrahi, 2016; Lachkar et al., 2018)615, physiological impacts (Pörtner et al., 2014)616, and mortality and/or displacement of oxygen dependent organisms such as fish (Hamukuaya et al., 1998; Thronson and Quigg, 2008; Jacinto, 2011)617 and invertebrates (Hobbs and Mcdonald, 2010; Bednaršek et al., 2016; Seibel, 2016; Altieri et al., 2017)618. At least 136 megacities (port cities with a population greater than 1 million in 2005) are at risk from flooding due to SLR (with magnitudes of rise possible under 1.5°C or 2°C in the 21st century, as indicated in Section 3.3.9) unless further adaptation is undertaken (Hanson et al., 2011; Hallegatte et al., 2013)760. Changes to the frequency of extreme El Niño and La Niña events may also increase the frequency of droughts and floods in South Pacific islands (Box 4.2, Section 3.5.2; Cai et al., 2012)833. Latitudinal and elevational shifts of biomes (major ecosystem types) in boreal, temperate and tropical regions have been detected (Settele et al., 2014)448 and new studies confirm these changes (e.g., shrub encroachment on tundra; Larsen et al., 2014)449. In this regard, the assessed confidence in assigning the transitions between risk levels are as follows: L=Low, M=Medium, H=High, and VH=Very high levels of confidence. (2015)788 found that future climate scenarios for the USA (A1B 1.6°C and B1 2°C in the 2040s) had a greater effect on salinity intrusion than future land-use/land-cover change in the Snohomish River estuary in Washington state (USA). Ocean warming and acidification are already affecting the life history stages of bivalve molluscs (e.g., Asplund et al., 2014; Mackenzie et al., 2014; Waldbusser et al., 2014; Zittier et al., 2015; Shi et al., 2016; Velez et al., 2016; Q. Burke et al., 2018)1163. These findings are consistent with estimates made from an earlier study suggesting that range losses at 1.5°C were significantly lower for plants than those at 2°C of warming (Smith et al., 2018)479. Since AR5, new literature has indicated that impacts on marine fish stocks and fisheries are lower under 1.5°C–2°C of global warming relative to pre-industrial levels compared to under higher warming scenarios (Section 3.4.6), especially in tropical and polar systems. At 1.5°C in 2100, 31–69 million people (2010 population values) worldwide are projected to be exposed to flooding, assuming no adaptation or protection at all, compared with 32–79 million people (2010 population values) at 2°C in 2100 (Supplementary Material 3.SM, Table 3.SM.4; Rasmussen et al., 2018748). Raising existing dikes helps protect against SLR, substantially reducing risks, although other forms of adaptation exist. In conclusion, ecosystem respiration is expected to increase with increasing temperature, thus reducing soil carbon storage. A link between very high levels of range loss and greatly increased extinction risk may be inferred (Urban, 2015)489. A few studies since AR5 have focused on the impacts on cropping systems for scenarios where the global mean temperature increase is within 1.5°C. Quantifying the observed impacts of climate change on food security and food production systems requires assumptions about the many non-climate variables that interact with climate change variables. Ocean warming and acidification can also slow growth and calcification, making corals less competitive compared to other benthic organisms such as macroalgae or seaweeds (Dove et al., 2013; Reyes-Nivia et al., 2013, 2014)715. Less of the permafrost in the Arctic is projected to thaw under 1.5°C of warming (17–44%) compared with under 2°C (28–53%) (Section 3.3.5.2; Chadburn et al., 2017)1124, which is expected to reduce risks to both social and ecological systems in the Arctic. Global fisheries and aquaculture contribute a total of 88.6 and 59.8 million tonnes of fish and other products annually (FAO, 2016)918, and play important roles in the food security of a large number of countries (McClanahan et al., 2015; Pauly and Charles, 2015)919 as well as being essential for meeting the protein demand of a growing global population (Cinner et al., 2012, 2016; FAO, 2016; Pendleton et al., 2016)920. Sea ice is a persistent feature of the planet's polar regions (Polyak et al., 2010)621 and is central to marine ecosystems, people (e.g., food, culture and livelihoods) and industries (e.g., fishing, tourism, oil and gas, and shipping). There is medium confidence that vulnerabilities to water and food security in the African Sahel will be higher at 2°C compared to 1.5°C of global warming (Cheung et al., 2016a; Betts et al., 2018)1200, and at 2°C these vulnerabilities are expected to be worse (high evidence) (Sultan and Gaetani, 2016; Lehner et al., 2017; Betts et al., 2018; Byers et al., 2018; Rosenzweig et al., 2018)1201. The comprehensive assessment undertaken by AR5 evaluated the evidence of changes to natural systems, and the impact on human communities and industry. Mass coral bleaching and mortality are projected to increase because of interactions between rising ocean temperatures, ocean acidification, and destructive waves from intensifying storms (Section 3.4.4 and 5.2.3, Box 3.4). Findings are summarized in Table 3.6. Ice-free Arctic Ocean summers are very likely at levels of global warming higher than 2°C (Notz and Stroeve, 2016; Rosenblum and Eisenman, 2016; Screen and Williamson, 2017; Niederdrenk and Notz, 2018)1169. A discussion of potential adaptation options is also provided, the details of which will be further explored in later chapters of this special report. Impacts on energy systems can affect gross domestic product (GDP). Schleussner et al. Figure 3.21 modifies Figure 19.4 from AR5 WGII, and the following text in this subsection provides justification for the modifications. Clearly, these options need to be carefully assessed in terms of feasibility, cost and scalability, as well as in the light of the coastal ecosystems involved (Bayraktarov et al., 2016)666. The impacts of climate change on sea ice are part of the focus of the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC), due to be released in 2019, and hence are not covered comprehensively here. Yohe (2017)1269 calculated transient temperature trajectories from a linear relationship with contemporaneous cumulative emissions under a median no-policy baseline trajectory that brings global emissions to roughly 93 GtCO2 yr–1 by the end of the century (Fawcett et al., 2015)1270, with 1.75°C per 1000 GtCO2 as the median estimate. (2015)496 showed that fires reduce the carbon sink of global terrestrial ecosystems by 0.57 PgC yr–1 in ecosystems with large carbon stores, such as peatlands and tropical forests. (2018)418 studied the increase of potential economic loss under SSP3 and projected that the smaller loss at 1.5°C compared to 2°C (0.9%) is marginal, regardless of whether the vulnerability is fixed at the current level or not. Intra-annual variability is expected to increase in northern Europe and decrease in southern Europe. This approach, for example, does not incorporate the effects of extreme weather events and the role of interactions between species. The overall impacts of the various types of radiative forcing under different emissions scenarios are more subtle, with a weakening of the monsoon north of about 25°N in East Asia but a strengthening south of this latitude projected by Jiang and Tian (2013)1240 under high and modest emissions scenarios. For tourism (related to RFCs 3 and 4), changing weather patterns, extreme weather and climate events, and sea level rise are affecting many – but not all – global tourism investments, as well as environmental and cultural destination assets (Section 3.4.4.12), with 'last chance to see' tourism markets developing based on observed impacts on environmental and cultural heritage (Section 3.4.9.1), indicating a transition from undetectable to moderate risk between 0°C and 1.5°C of warming (high confidence). Source: Byers et al. Projected risks of impacts from reductions in carbon uptake, coastal protection and services contributing to coral reef recreation suggest a transition from moderate to high risks at 1.5°C and higher (low confidence). In the last three years alone (2016–2018), large coral reef systems such as the Great Barrier Reef (Australia) have lost as much as 50% of their shallow water corals (Hughes et al., 2017b)706. Heavy precipitation: AR5 assessed trends in heavy precipitation for land regions where observational coverage was sufficient for assessment. Assuming a constant population in the models used in his study, Gerten et al. It is easier to achieve many of the sustainable development goals (SDGs) at 1.5°C, suggesting that a transition to higher risk will not begin yet at this level. In some regions, groundwater is often intensively used to supplement the excess demand, often leading to groundwater depletion. That is, although restraining the global temperature increase to 2°C is projected to reduce crop losses under climate change relative to higher levels of warming, the associated mitigation costs may increase the risk of hunger in low-income countries (low confidence) (Hasegawa et al., 2016)1155. Mediterranean water stress is projected to increase from 9% at 1.5°C to 17% at 2°C compared to values in 1986–2005 period. The Mekong is a major food bowl (Smajgl et al., 2015)971 but is also a climate change hotspot (de Sherbinin, 2014; Lebel et al., 2014)972. These risks are associated with biome shifts and species range losses (Sections 3.4.3 and 3.5.2.4); however, because many systems and species are projected to be unable to adapt to levels of warming below 2°C, the transition to high risk (red areas in Figure 3.20) is located below 2°C (high confidence). Warren et al. Human influences on food security include demography, patterns of food waste, diet shifts, incomes and prices, storage, health status, trade patterns, conflict, and access to land and governmental or other assistance (Chapters 4 and 5). AR5 located the transition from undetectable to moderate risk below recent temperatures, owing to the detection and attribution of regionally differentiated changes in crop yields (medium to high confidence; Figure 3.20), and new literature has continued to confirm this finding. Climate change adds further pressure on water resources and exaggerates human water demands by increasing temperatures over agricultural lands (Wada et al., 2017)423. It was also observed that many species and ecosystems have a limited ability to adapt to the very large risks associated with warming of 2.6°C or more, particularly Arctic sea ice and coral reef systems (high confidence). Each element, or burning ember, presented here (Figures 3.18, 3.20) maps to one or more RFCs (Figure 3.21). Long-term risks of coastal flooding and impacts on populations, infrastructure and assets are projected to increase with higher levels of warming (high confidence). Under global warming of more than 2°C, regional losses are projected to be about 20% if they co-occur with reductions in rainfall (Lana et al., 2017)1260. Few studies, have explored projected impacts on water quality under 1.5°C versus 2°C of warming, however, the differences are unclear (low confidence) (Bonte and Zwolsman, 2010431; Hosseini et al., 2017)432. This assessment considered the heatwave-related loss of 50% of shallow water corals across hundreds of kilometres of the world's largest continuous coral reef system, the Great Barrier Reef, as well as losses at other sites globally. This change stimulated marsh carbon storage and aided climate change mitigation. The major increase in the size and loss of coral reefs over the past three years, plus sequential mass coral bleaching and mortality events on the Great Barrier Reef, (Hoegh-Guldberg, 1999; Hughes et al., 2017b, 2018)1110, have reinforced the scale of climate-change related risks to coral reefs. Climate variability has been found to explain more than 60% of the of maize, rice, wheat and soybean yield variations in the main global breadbaskets areas (Ray et al., 2015)862, with the percentage varying according to crop type and scale (Moore and Lobell, 2015; Kent et al., 2017)863. Thus, there is high confidence that SLR will have significant impacts worldwide in this century and beyond. This WGII AR5 analysis already implied that there would be a significant reduction in risks to unique and threatened systems if warming were limited to 1.5°C compared with 2°C. There is thus low confidence in the level at which global warming could lead to very high risks associated with extreme weather events in the context of this report. SLR is only one factor affecting deltas, and assessment of numerous geophysical and anthropogenic drivers of geomorphic change is important (Tessler et al., 2018)793. Moreover, over much of the Arctic, a further increase of 0.5°C in the global surface temperature, from 1.5°C to 2°C, may lead to further temperature increases of 2°C–2.5°C (Figure 3.3). For several SIDS, approximately 25% of the overall freshwater stress projected under 2°C at 2030 could be avoided by limiting global warming to 1.5°C (Karnauskas et al., 2018)827. A 1°C increase in average temperature in the International Migration Database of the Organisation for Economic Co-operation and Development (OECD) was associated with a 1.9% increase in bilateral migration flows from 142 sending countries and 19 receiving countries, and an additional millimetre of average annual precipitation was associated with an increase in migration by 0.5% (Backhaus et al., 2015)1081. (2016a)936, simulating the loss in fishery productivity at 1.5°C, 2°C and 3.5°C above the pre-industrial period, found that the potential global catch for marine fisheries will likely decrease by more than three million metric tonnes for each degree of warming. These results are largely consistent with those of other studies (Faye et al., 2018; Ruane et al., 2018)884. For instance, in the Delaware River estuary on the east coast of the USA, upward trends of salinity (measured since the 1900s), accounting for the effects of streamflow and seasonal variations, have been detected and SLR is a potential cause (Ross et al., 2015)787. Additionally, impacts increased in the second half of the 21st century. There is, however, a single study that questions the validity of the 1.5°C threshold in terms of maintaining summer Arctic Ocean sea ice (Niederdrenk and Notz, 2018)1172. At minimum and maximum increases in global mean temperature of 1.35°C and 2°C, the overall stream flow in Florida, USA is projected to increase by an average of 21%, with pronounced seasonal variations, resulting in increases in power generation in winter (+72%) and autumn (+15%) and decreases in summer (–14%; Chilkoti et al., 2017)1058. (2016)762 projected that more than 90% of global coastlines could experience SLR greater than 0.2 m with 2°C of warming by 2040 (RCP8.5). (2017)526 predicted a 72% reduction in cryogenic land surface processes in northern Europe for RCP2.6 in 2040–2069 (corresponding to a global warming of approximately 1.6°C), with only slightly larger losses for RCP4.5 (2°C of global warming). Fisheries, for example, may expand temporarily at high latitudes in the Northern Hemisphere as the extent of summer sea ice recedes and NPP increases (medium confidence) (Cheung et al., 2010; Lam et al., 2016; Weatherdon et al., 2016)569. Populations at highest risk include older adults, children, women, those with chronic diseases, and people taking certain medications (very high confidence). These impacts can have significant socio-economic and ecological implications, such as on health, agriculture and water resources, which in turn have impacts on livelihoods (Sovacool, 2012; Mycoo, 2014, 2017; Nurse et al., 2014)778. Projected risks also depend on assumptions with respect to population growth, the rate and pattern of urbanization, and investments in infrastructure. For example, Johnson and Poiani (2016)557 found that the wetland function of the Prairie Pothole region in North America is projected to decline at temperatures beyond a local warming of 2°C–3°C above present-day values (1°C local warming, corresponding to 0.6°C of global warming). Changes in precipitation patterns, freshwater availability and drought sensitivity differ among small island regions (medium to high confidence). Under constant socio-economic conditions, the population exposed to drought at 2°C of warming is projected to be larger than at 1.5°C (low to medium confidence) (Smirnov et al., 2016; Sun et al., 2017; Arnell et al., 2018; Liu et al., 2018)410. Further, differing responses could alter community structure in temperate forests (Roberts et al., 2015)467. Previous sections of this report have described changes in the ocean, including rapid increases in ocean temperature down to a depth of at least 700 m (Section 3.3.7). Sea level rise poses a long-term threat (Section 3.3.9), and adaptation will remain essential at the centennial scale under 1.5°C and 2°C of warming (high confidence). Niang et al. The projected changes are larger with greater warming and under higher greenhouse gas emissions pathways. Growth-rate projections based on temperature impacts alone indicate robust negative impacts on gross domestic product (GDP) per capita growth for SIDS (Sections 3.4.7.1, 3.4.9.1 and 3.5.4.9; Pretis et al., 2018)839. Very high risk is assessed as lying above 5°C because the growing literature on process-based projections of the West Antarctic ice sheet predominantly supports the AR5 assessment of an MISI contribution of several additional tenths of a metre by 2100. See Cross-Chapter Box 5 in Chapter 2 for the definition of the social cost of carbon and for a discussion of the economics of 1.5°C-consistent pathways and the social cost of carbon, including the impacts of inequality on the social cost of carbon. These authors found that photovoltaic and wind power might be reduced by up to 10%, and hydropower and thermoelectric generation might decrease by up to 20%, with impacts being limited at 1.5°C of warming but increasing as temperature increases (Tobin et al., 2018)1066. Fire: Increasing evidence that anthropogenic climate change has already caused significant increases in fire area globally (Section 3.4.3) is in line with projected fire risks. There are limited observations and analyses of how cities will cope with higher and/or multi-centennial SLR, with the exception of Amsterdam, New York and London (Nicholls et al., 2018)758. WGII AR5 concluded that increases in heavy rainfall and temperature are projected to change soil erosion and sediment yield, although the extent of these changes is highly uncertain and depends on rainfall seasonality, land cover, and soil management practices (Jiménez Cisneros et al., 2014)443. (2014, AR5 WGII Chapter 19)1118 provided a framework that aggregates projected risks from global mean temperature change into five categories identified as 'Reasons for Concern'. (2017)484 summarized at the global level the consequences of climate-change-induced species redistribution for economic development, livelihoods, food security, human health and culture. In agreement with the assessment in WGII AR5 Section 5.4.3.1 (Wong et al., 2014)746, climate change mitigation may reduce or delay coastal exposure and impacts (very high confidence). There is additional evidence for the attribution of increased forest fire frequency in North America to anthropogenic climate change during 1984–2015, via the mechanism of increasing fuel aridity almost doubling the western USA forest fire area compared to what would have been expected in the absence of climate change (Abatzoglou and Williams, 2016)530. If global CO2 concentrations and temperatures stabilize, or peak and decline, then both land and ocean carbon sinks – which are primarily driven by the continued increase in atmospheric CO2 – will also decline and may even become carbon sources (Jones et al., 2016)518. Firmly attributing recent changes in the strength and direction of ocean currents to climate change, however, is complicated by long-term patterns and variability (e.g., Pacific decadal oscillation, PDO; Signorini et al., 2015)582 and a lack of records that match the long-term nature of these changes in many cases (Lluch-Cota et al., 2014)583. Moreover, in the Congo basin (Dargie et al., 2017)552 and in the Amazonian basin (Draper et al., 2014)553, the peatlands store the equivalent carbon as that of a tropical forest. Since AR5, the number of studies related to fluvial flooding and meteorological drought based on long-term observed data has been gradually increasing. However, these projections do not integrate adaptation to projected warming, for instance cooling that could be achieved with more reflective roofs and urban surfaces in general (Akbari et al., 2009; Oleson et al., 2010)1257. (2018)414 also suggested that more urban populations would be exposed to severe droughts at 1.5°C in central Europe, southern larger storm surges, infrastructure damage, erosion and habitat loss (Church et al., 2013; Stocker et al., 2013; Blankespoor et al., 2014)632. The literature on compound as well as interacting and cascading risks at warming of 1.5°C and 2°C is limited. Rosenzweig et al. Evidence of a slowdown of AMOC has increased since AR5 (Smeed et al., 2014; Rahmstorf et al., 2015a, b, Kelly et al., 2016)593, yet a strong causal connection to climate change is missing (low confidence) (Section 3.3.7).

of-century (see Figure 2A in M. There are consistent and statistically significant increases in projected risks of increased meteorological drought in southern Africa at 2°C versus 1.5°C of warming (medium confidence). Burke et al., 2018)1135. Combinations of drivers causing adverse impacts are important. For these systems, climate is one of many drivers that result in adverse outcomes. Changes in ocean chemistry (e.g., oxygen content and ocean acidification), especially those associated with the deep sea, are associated concerns (Section 3.3.10). Nobre et al. (2016b)1199 found consistently reduced impacts on crop yield for West Africa under 2°C compared to 1.5°C of global warming. Biological components of carbon uptake by the ocean are also changing, with observations of changing net primary productivity (NPP) in equatorial and coastal upwelling systems (medium confidence) (Lluch-Cota et al., 2014; Sydeman et al., 2014; Bakun et al., 2015)683, as well as subtropical gyre systems (low confidence) (Signorini et al., 2015)684. In the western Sahel and southern Africa, moving from 1.5°C to 2°C of warming has been projected to result in a further reduction of the suitability of maize, sorghum and cocoa cropping areas and yield losses, especially for C3 crops, with rainfall change only partially compensating these impacts (Läderach et al., 2013; World Bank, 2013; Sultan and Gaetani, 2016)885. These analyses suggest that the point at which global aggregates of economic impacts become negative is below 2°C (medium confidence), and that there is a possibility that it is below 1.5°C of warming. By the mid-to late 21st century, climate change is projected to be a poverty multiplier that makes poor people poorer and increases poverty head count, and the association between temperature and economic productivity is not linear (high confidence). Changes in ocean circulation can have profound impacts on marine ecosystems by connecting regions and facilitating the entry and establishment of species in areas where they were unknown before (e.g., 'tropicalization' of temperate ecosystems; Wernberg et al., 2012; Vergés et al., 2014, 2016; Zarco-Perello et al., 2017)587, as well as the arrival of novel disease agents (low-medium confidence) (Burge et al., 2014; Maynard et al., 2015; Weatherdon et al., 2016)588. Infrastructure and geological constraints reduce shoreline movement, causing coastal squeeze. With 2.5°C of warming, adaptation limits are expected to be exceeded in sensitive areas, and hence a transition to very high risk is projected. (2017, 2018)882 did not find a clear distinction between yield declines or increases in some breadbasket regions between the two temperature levels, they generally did find projections of decreasing yields in breadbasket regions when the effects of CO_2 fertilization were excluded. Factors affecting the projections of food security include variability in regional climate projections, climate change mitigation (where land use is involved; see Section 3.6 and Cross-Chapter Box 7 in this chapter) and biological responses (medium confidence) (Section 3.4.6.1; McGrath and Lobell, 2013; Elliott et al., 2014; Pörtner et al., 2014; Durand et al., 2018)952, extreme events such as droughts and floods (high confidence) (Sections 3.4.6.1, 3.4.6.2; Rosenzweig et al., 2014; Wei et al., 2017)953, financial volatility (Kannan et al., 2000; Ghosh, 2010; Naylor and Falcon, 2010; HLPE, 2011)954, and the distributions of pests and disease (Jiao et al., 2014; van Bruggen et al., 2015)955. Under the SSP2 population scenario, Arnell et al. Responses to sea level rise challenges for ocean and coastal systems include reducing the impact of other stresses, such as those arising from tourism, fishing, coastal development, reduced sediment supply and unsustainable aquaculture/agriculture, in order to build ecological resilience (Hossain et al., 2015; Sutton-Grier and Moore, 2016; Asiedu et al., 2017a)636. As well, climate change can drive undernutrition-related childhood mortality, and increase disability-adjusted life years lost, with the largest risks in Asia and Africa (Supplementary Material 3.SM, Table 3.SM.12; Ishida et al., 2014; Hasegawa et al., 2016; Springmann et al., 2016)967). However, short-term benefits could arise for high-latitude fisheries production as waters warm, sea ice contracts and primary productivity increases under climate change (high confidence) (Section 3.4.6.3; Cheung et al., 2010; Hollowed and Sundby, 2014; Lam et al., 2016; Sundby et al., 2016; Weatherdon et al., 2016)951. There is limited published literature examining modelled land carbon changes specifically under 1.5°C of warming, but existing CMIP5 models and published data are used in this report to draw some conclusions. Changes in the frequency of extreme events, such as an increase in the frequency of intense storms, have the potential (along with other factors, such as disease, food web changes, invasive organisms and heat stress-related mortality; Burge et al., 2014; Maynard et al., 2015; Weatherdon et al., 2016; Clements et al., 2017)580 to overwhelm the capacity for natural and human systems to recover following disturbances. To avoid legacy effects of the choice of scenario, this report focuses on the response of gross primary productivity (GPP) – the rate of photosynthetic carbon uptake – by the models, rather than by changes in their carbon store. While the number of published studies of climate change impacts on soil erosion have increased globally since 2000 (Li and Fang, 2016)444, few articles have addressed impacts at 1.5°C and 2°C of global warming. In AR5, the transition from undetectable to moderate impacts was considered to occur between 1.6°C and 2.6°C of global warming reflecting impacts on the economy and on biodiversity globally, whereas high risks were associated with 3.6°C of warming to reflect the high risks to biodiversity and accelerated effects on the global economy. AR5 assessed that large uncertainty remains regarding the land carbon cycle behaviour of the future (Ciais et al., 2013)500, with most, but not all, CMIP5 models simulating continued terrestrial carbon uptake under all four RCP scenarios (Jones et al., 2013)501. Burke et al., 2018)1159, it is more likely than not that there will be large differences in economic growth under 1.5°C and 2°C of global warming for developing versus developed countries (M. In some cases, 'optimistic' assumptions in models include rapid thermal adaptation by corals of 0.2°C–1°C per decade (Donner et al., 2005)725 or 0.4°C per decade (Schleussner et al., 2016b)726, as well as very rapid recovery rates from impacts (e.g., five years in the case of Schleussner et al., 2016b)727. Marine organisms ('ecosystem engineers'), such as seagrass, kelp, oysters, salt marsh species, mangroves and corals, build physical structures or frameworks (i.e., sea grass meadows, kelp forests, oyster reefs, salt marshes, mangrove forests and coral reefs) which form the habitat for a large number of species (Gutiérrez et al., 2012)640. (2018)1064 assessed wind power generation over Europe for 1.5°C of warming and found the potential for wind energy to be greater than previously assumed in northern Europe. Sea ice in Antarctica is undergoing changes that exceed those seen in the Arctic (Maksym et al., 2011; Reid et al., 2015)629, with increases in sea ice coverage in the western Ross Sea being accompanied by strong decreases in the Bellingshausen and Amundsen Seas (Hobbs et al., 2016)630. A 1°C increase in temperature or more extreme rainfall increases the frequency of intergroup conflicts by 14% (Hsiang et al., 2013)1097. Projected impacts on forests as climate change occurs include increases in the intensity of storms, wildfires and pest outbreaks (Settele et al., 2014)527, potentially leading to forest dieback (medium confidence). However, hazards by droughts at 1.5°C could be reduced compared to the hazards at 2°C in some regions, in particular in the Mediterranean region and southern Africa (Section 3.3.4). Within these broad options, there are some strategies that involve direct human intervention, such as coastal hardening and the construction of seawalls and artificial reefs (Rinkevich, 2014, 2015; André et al., 2016; Cooper et al., 2016; Narayan et al., 2016)693, while others exploit opportunities for increasing coastal protection by involving naturally occurring oyster banks, coral reefs, mangroves, seagrass and other ecosystems (UNEP-WCMC, 2006; Scyphers et al., 2011; Zhang et al., 2012; Ferrario et al., 2014; Cooper et al., 2016)694. (2016)876 highlighted that cropland stability declines rapidly between 1°C and 3°C of warming, whilst Bassu et al. In particular, AR5 attributed observed impacts in natural ecosystems to anthropogenic climate change, including changes in phenology, geographic and altitudinal range shifts in flora and fauna, regime shifts and increased tree mortality, all of which can reduce ecosystem functioning and services thereby impacting people. As sea ice retreats, mixing of the water column increases, and phototrophs have increased access to seasonally high levels of solar radiation (medium confidence) (Dalpadado et al., 2014; W.N. Meier et al., 2014)625. Temperature has a positive and statistically significant effect on outmigration for agriculture-dependent communities (medium confidence). Ahlström et al. The Caribbean region will experience 0.5°C–1.5°C of warming compared to a 1971–2000 baseline, with the strongest warming occurring over larger land masses (Taylor et al., 2018)823. The differences in projected changes to levels of runoff under 1.5°C and 2°C of global warming, particularly those that are regional, are described in Section 3.3.5. Constraining warming to 1.5°C instead of 2°C might mitigate the risks for water availability, although socio-economic drivers could affect water availability more than the risks posed by variation in warming levels, while the risks are not homogeneous among regions (medium confidence) (Gerten et al., 2013; Hanasaki et al., 2013; Arnell and Lloyd-Hughes, 2014; Schewe et al., 2014; Karnauskas et al., 2018)382. Additionally, damage was also reduced under mitigation scenarios compared with non-mitigation scenarios. Rasmussen et al. The format for Figures 3.18 and 3.20 match that of Figure 19.4 of WGII AR5 Chapter 19 (Oppenheimer et al., 2014)1105 indicating the levels of additional risk as colours: undetectable (white) to moderate (detected and attributed; yellow), from moderate to high (severe and widespread; red), and from high to very high (purple), the last of which indicates significant irreversibility or persistence of climate-related hazards combined with a much reduced capacity to adapt. While the impacts of species shifting their ranges are mostly negative for human communities and industry, there are instances of short-term gains. However, these are distinct from impacts associated with higher increases in temperature (e.g., 4ºC or more, as discussed in Brown et al., 2018a)740 over centennial scales. Ocean acidification also leads to enhanced activity by decalcifying organisms such as excavating sponges (Kline et al., 2012; Dove et al., 2013; Fang et al., 2013, 2014; Reyes-Nivia et al., 2013, 2014)720. Large rice and maize yield losses are to be expected in China, owing to climate extremes (medium confidence) (Wei et al., 2017; Zhang et al., 2017)888. Impacts on adult bivalves include decreased growth, increased respiration and reduced calcification, whereas larval stages tend to show greater developmental abnormalities and increased mortality after exposure to these conditions (medium to high confidence) (Q. Avoided damages from achieving a 1.5°C temperature limit along the median-median case are nearly 4% (range 2–7%) by 2100. Wu et al., 2013)978; and disaster risk (D. This study revealed that there would be substantial divergence in water withdrawal for thermal power plant cooling under conditions in which the distribution of future cooling technology for energy generation is fixed, whereas adopting alternative cooling technologies and water resources would make the divergence considerably smaller. As the focus of the present assessment is on the consequences of global warming of 1.5°C–2°C above the pre-industrial period, no assessment for global warming of 3°C or more is included in the figure (i.e., analysis is discontinued at 2.5°C). These organisms in turn provide food, livelihoods, cultural significance, and services such as coastal protection to human communities (Bell et al., 2011, 2018; Cinner et al., 2012; Arkema et al., 2013; Nurse et al., 2014; Wong et al., 2014; Barbier, 2015; Bell and Taylor, 2015; Hoegh-Guldberg et al., 2015; Mycoo, 2017; Pecl et al., 2017)641. Best Customer Support Service Get 24/7 customer support help when you place a homework help service order with us. Compared to the 1971–2000 baseline, up to 50% of the year is projected to be under warm spell conditions in the Caribbean at 1.5°C, with a further increase of up to 70 days at 2°C (Taylor et al., 2018)825. One strategy is to maintain larger population levels of fished species in order to provide more resilient stocks in the face of challenges that are increasingly driven by climate change (Green et al., 2014; Bell and Taylor, 2015)678. Under 3°C of global warming, significant reductions in the areas suitable for livestock production could occur (low confidence), owing to strong increases in regional temperatures in the tropics and subtropics (high confidence). (2015)639 by assessing new literature from 2015–2017 and adjusting the levels of risk from climate change in the light of literature since 2014. Evidence for the impact of climate change on energy systems since AR5 is limited. There are not enough studies to assess differences in tropical cyclone statistics for 1.5°C versus 2°C (Section 3.3.6). Yohe (2017)1164 found a mean difference of 0.35% GDP (range 0.2–0.65%), while Hsiang et al. (2017)1268 shows that the USA stand to lose -0.1 to 1.7% of the Gross Domestic Product (GDP) at 1.5°C warming. Risks are already significant at current greenhouse gas concentrations and temperatures, and they vary significantly among depths, locations and ecosystems, with impacts being singular, interactive and/or cumulative (Boyd et al., 2015)562. Climate change is projected to lead to an increased demand for air conditioning in most tropical and subtropical regions (Arent et al., 2014; Hong and Kim, 2015)1049 (high confidence). Future warming and urban expansion could lead to more extreme heat stress (Argüeso et al., 2015; Suzuki-Parker et al., 2015)1021. Without considering adaptation options, such as cooling from more reflective roofs, and overall characteristics of urban agglomerations in terms of land use, zoning and building codes (UCCRN, 2018)1022, Karachi (Pakistan) and Kolkata (India) could experience conditions equivalent to the deadly 2015 heatwaves on an annual basis under 2°C of warming (Akbari et al., 2009; Oleson et al., 2010; Matthews et al., 2017)1023. (2012) and Romero-Lankao et al. When applied to 181 countries, a global vulnerability index including 27 indicators found that countries with the lowest risk are located in western and northern Europe, central Asia, Canada and New Zealand, while the highest sector risks are projected for Africa, the Middle East, South Asia and SIDS in the Caribbean, Indian and Pacific Oceans (Scott and Gössling, 2018)1048. Donk et al. Risks from deoxygenation are virtually certain to increase as warming continues, although our understanding of risks at 1.5°C versus 2°C is incomplete (medium confidence). Based on a 3% discount rate, this corresponds to 8.1–11.6 trillion USD and 38.5 trillion USD in avoided damages by mid-and end-of-century, respectively, agreeing closely with the estimate by Warren et al. Other factors include patterns of demographic change, socio-economic development, trade and tourism. As GMST increases by 1.5°C and more, the risk of impacts from ocean warming and acidification are expected to be moderate to high, except in the case of bivalves (mid-latitudes) where the risks of impacts are projected to be high to very high (Figure 3.18). Limiting warming to 1.5°C instead of 2°C would spare the inundation of lands currently home to 60,000 individuals in SIDS by 2150 (Rasmussen et al., 2018)846. For example, key insect crop pollinator families (Apidae, Syrphidae and Calliphoridae; i.e., bees, hoverflies and blowflies) are projected to retain significantly greater geographic ranges under 1.5°C of global warming compared with 2°C (Warren et al., 2018a)485. La Niña event (the opposite or balancing event to El Niño) frequency is projected to remain similar to that of the present day under 1.5°C–2°C of global warming. The ocean is also a net sink for CO_2 (another important service), absorbing approximately 30% of human emissions from the burning of fossil fuels and modification of land use (IPCC, 2013)680. The Arctic tundra biome is experiencing increasing fire disturbance and permafrost degradation (Bring et al., 2016; DeBeer et al., 2016; Jiang et al., 2016; Yang et al., 2016)521. Reduction in the availability of water resources at 2°C is projected to be greater than 1.5°C of global warming, although changes in socio-economics could have a greater influence (Section 3.4.2), with larger risks in the Mediterranean (Box 3.2); estimates of the magnitude of the risks remain similar to those cited in AR5. The large proportion of insects projected to lose over half their range at 2°C of warming (25%) compared to at 1.5°C (9%) also suggests a significant loss of functionality in these threatened systems at 2°C of warming, owing to the critical role of insects in nutrient cycling, pollination, detritivory and other important ecosystem processes (Section 3.4.3). (2017)887 indicated a significant reduction in rice yields for each degree Celsius increase, by about 10.3%, in the greater Mekong subregion (medium confidence; Cross-Chapter Box 6: Food Security in this chapter). At 1.5°C of warming an ice-free Arctic Ocean is considered unlikely, whilst by 2°C of warming it is considered likely and this unique ecosystem is projected to be unable to adapt. For instance, McGrath and Lobell (2013)869 indicated that production stimulation at increased atmospheric CO_2 concentrations was mostly driven by differences in climate and crop species, whilst yield variability due to elevated CO_2 was only about 50–70% of the variability due to climate. (2018)783 found that hard defence structures on the island of Ebeye in the Marshall Islands were effective in reducing damage due to SLR at 1.5°C and 2°C. Fisheries management at local to regional scales will be important in reducing stress on foodweb organisms, such as those discussed here, and in helping communities and industries adapt to changing foodweb structures and resources (see further discussion of fisheries per se below; Section 3.4.6.3). Greenland and West Antarctic ice sheets and marine ice sheet instability (MISI): Various feedbacks between the Greenland ice sheet and the wider climate system, most notably those related to the dependence of ice melt on albedo and surface elevation, make irreversible loss of the ice sheet a possibility. In boreal peatlands, for example, increased temperature may diminish carbon storage and compromise the stability of the peat (Dieleman et al., 2016)495. There are observations of ongoing and planned adaptation to SLR and extreme water levels in some cities (Araos et al., 2016; Nicholls et al., 2018)757, whilst other cities have yet to prepare for these impacts (high confidence) (see Section 3.4.8 and Cross-Chapter Box 9 in Chapter 4). This projection is supported by findings by Sakalli et al. Together, the impacts on protein availability may bring as many as 150 million people into protein deficiency by 2050 (Medek et al., 2017)950. At 2°C of global warming, lower economic growth is projected for many countries than at 1.5C of global warming, with low-income countries projected to experience the greatest losses (low to medium confidence) (M. The benefits of climate change mitigation reinforce findings of earlier IPCC reports (e.g., Wong et al., 2014)741. Wetland salinization, a widespread threat to the structure and ecological functioning of inland and coastal wetlands, is occurring at a high rate and large geographic scale (Section 3.3.6; Herbert et al., 2015)555. It remains unclear how wetlands will respond and under what conditions (including other climate parameters) to a global temperature rise of 1.5°C and 2°C. These impacts are exacerbated by increasingly intense storms (Section 3.3.6), which physically destroy coral communities and hence reefs (Cheal et al., 2017)718, and by ocean acidification (Sections 3.3.10 and 3.4.4.5), which can weaken coral skeletons, contribute to disease, and slow the recovery of coral communities after mortality events (low to medium confidence) (Gardner et al., 2005; Dove et al., 2013; Kennedy et al., 2013; Webster et al., 2013; Hoegh-Guldberg, 2014b; Anthony, 2016)719. With a 1.5°C stabilization scenario in 2100, 62.7 million people per year are at risk from flooding, with this value increasing to 137.6 million people per year in 2300 (50th percentile average across SSP1–5, no socio-economic change after 2100). Including disturbances in simulations may influence productivity changes in European forests in response to climate change (Reyer et al., 2017b)529. This general pattern applies to low-latitude fin fish, which are expected to experience moderate to high risks of impact at 1.3°C of global warming (medium confidence), and very high risks at 1.8°C at low latitudes (medium confidence) (Figure 3.18). Climate change is already having large scale impacts on ecosystems, human health and agriculture, which is making it much more difficult to reach goals to eradicate poverty and hunger, and to protect health and life on land (Sections 5.1 and 5.2.1 in Chapter 5), suggesting a transition from undetectable to moderate risk for recent temperatures at 0.5°C of warming (medium confidence). (2016b)1215 project that constraining warming to 1.5°C rather than 2°C would avoid significant risks of tropical crop yield declines in West Africa, Southeast Asia, and Central and South America. This feedback loop between warming and the release of greenhouse gas from thawing tundra represents a potential tipping point. These calculations excluded the large health co-benefits that accrue when greenhouse gas emissions are reduced (Section 3.4.7.1; Shindell et al., 2018)1266. In three river basins in Southeast Asia (Sekong, Sesan and Srepok), about 2°C of warming (corresponding to a 1.05°C increase in the 2030s relative to the baseline period 1981–2008, RCP8.5), impacts posed by land-use change on water quality are projected to be greater than at 1.5°C (corresponding to a 0.89°C increase in the 2030s relative to the baseline period 1981–2008, RCP4.5) (Trang et al., 2017)435. Impacts on key natural and human systems Projected increases in aridity and decreases in freshwater availability at 1.5°C of warming, along with additional risks from SLR and increased wave-induced run-up, might leave several atoll islands uninhabitable (Storlazzi et al., 2015; Gosling and Arnell, 2016)837. Two studies focusing only on the USA found that economic damages are projected to be higher by 2100 if warming reaches 2°C than if it is constrained to 1.5°C. Zhao et al., 2017)886. Changes to ocean circulation can have even larger influence in terms of scale and impacts. The ocean provides important services, including the regulation of atmospheric composition via gas exchange across the boundary between ocean and atmosphere, and the storage of carbon in vegetation and soils associated with ecosystems such as mangroves, salt marshes and coastal peatlands. The Amazon tropical forest has been shown to be close to its climatic limits (Hutyra et al., 2005)533, but this threshold may move under elevated CO_2 (Good et al., 2011)534. Experimental manipulation of CO_2, temperature and consequently acidification indicate that these impacts will continue to increase in size and scale as CO_2 and SST continue to increase in tandem (Dove et al., 2013; Fang et al., 2013; Kroeker et al., 2013)599. (2018)1065 assessed impacts under 1.5°C and 2°C of warming on wind, solar photovoltaic and thermoelectric power generation across Europe. In the same study, Hanasaki et al. Yang et al. Warming of 2°C is expected to increase the risks of heatwaves in China's urban agglomerations (Yu et al., 2018)1024. The risks increase with greater warming. Iizumi et al. Given the potential value of such locations for promoting the survival of coral communities under climate change, efforts to prevent their loss resulting from other stresses are important (Bongaerts et al., 2010, 2017; Chollett et al., 2010, 2014; Chollett and Mumby, 2013; Fine et al., 2013; van Hooidonk et al., 2013; Cacciapaglia and van Woesik, 2015; Beyer et al., 2018)658. Heat-related extreme events (Matthews et al., 2017)1018, variability in precipitation (Yu et al., 2018)1019 and sea level rise can directly affect urban areas (Section 3.4.5, Bader et al., 2018; Dawson et al., 2018)1020. Under the same scenario, the global mean monthly number of people expected to be exposed to extreme drought at 1.5°C in 2021–2040 is projected to be 114.3 million, compared to 190.4 million at 2°C in 2041–2060 (Smirnov et al., 2016)411. In this regard, the interactions between climate change, sea level rise and coastal disasters are increasingly being informed by models (Bosello and De Cian, 2014)699 with a widening appreciation of the role of natural ecosystems as an alternative to hardened coastal structures (Cooper et al., 2016)700. Even achieving emissions reduction targets consistent with the ambitious goal of 1.5°C of global warming under the Paris Agreement will result in the further loss of 70–90% of reef-building corals compared to today, with 99% of corals being lost under warming of 2°C or more above the pre-industrial period (Frieler et al., 2013; Hoegh-Guldberg, 2014b; Hoegh-Guldberg et al., 2014; Schleussner et al., 2016b; Hughes et al., 2017a)724. It should be emphasized that risks to the elements assessed here are only a subset of the full range of risks that contribute to the RFCs. Figures 3.18 and 3.20 are not intended to replace the RFCs but rather to indicate how risks to particular elements of the Earth system accrue with global warming, through the visual burning embers format, with a focus on levels of warming of 1.5°C and 2°C. Burke et al., 2018; Pretis et al., 2018)1158. For example, Smith et al., (2018)487 estimated that 5.5–14% more of the globe's terrestrial land area could act as climatic refugia for plants under 1.5°C of warming compared to 2°C. If temperature were to decline subsequently the ice sheets might regrow, although the amount of cooling required is likely to be highly dependent on the duration and rate of the previous retreat. Given that bird and mammal species can disperse more easily than amphibians and reptiles, a small proportion can expand their range as climate changes, but even at 1.5°C of warming the total range loss integrated over all birds and mammals greatly exceeds the integrated range gain (Warren et al., 2018a)481. A large number of studies have consistently indicated that maize crop yield will be negatively affected under increased global warming, with negative impacts being higher at 2°C of warming than at 1.5°C (e.g., Niang et al., 2014; Schleussner et al., 2016b; J. Large-scale changes to foodweb structure are occurring in all oceans. Based on limited analyses, risks to the tourism sector are projected to be larger at 2°C than at 1.5°C, with impacts on climate-sensitive sun, beach and snow sports tourism markets being greatest. In all regional markets, the extent and timing of these impacts depend on the magnitude of climate change and the types of adaptive responses by the ski industry, skiers and destination communities. Under a 1.5°C stabilization scenario, there is a projected decrease in the frequency of weaker tropical storms and an increase in the number of intense cyclones (Section 3.3.6; Wehner et al., 2018a)836. More recently, climate change (i.e., heat stress; Hoegh-Guldberg, 1999; Baker et al., 2008; Spalding and Brown, 2015; Hughes et al., 2017b)713 has emerged as the greatest threat to coral reefs, with temperatures of just 1°C above the long-term summer maximum for an area (reference period 1985–1993) over 4–6 weeks being enough to cause mass coral bleaching (loss of the symbionts) and mortality (very high confidence) (WGII AR5, Box 18-2; Cramer et al., 2014)714. Protective features, such as seawalls or beach nourishment, are observed to locally reduce erosion and flood risk but can have other adverse implications (Sovacool, 2012; Mycoo, 2014, 2017; Nurse et al., 2014; AR5 Section 29.6.22)776. Whilst SLR is a major hazard for atolls, islands reaching higher elevations are also threatened given that there is often a lot of infrastructure located near the coast (high confidence) (Kumar and Taylor, 2015; Nicholls et al., 2018)781. Additionally, Tobin et al. Moreover, there is no strong direct relationship between the robustness of climate attribution and that of impact attribution (Hansen and Stone, 2016)1108. Mean sea level is increasing (Section 3.3.9), with substantial impacts already being felt by coastal ecosystems and communities (Wong et al., 2014)631 (high confidence). The probability of an ice-free Arctic in September at 1.5°C of global warming is low and substantially lower than for the case of 2°C of global warming (high confidence) (Section 3.3.8; Screen and of coastal protection by supporting and restoring ecosystems that protect coastal regions, (iii) ensuring fair and equitable access to the economic opportunities associated with recreational activities, and (iv) seeking and protecting supplies of water for tourism, industry and agriculture alongside community needs. Over the next few decades, and for 1961–1990. These changes have been accompanied by other changes such as ocean acidification, intensifying storms and deoxygenation (Levin and Le Bris, 2015)561. Taken together, the evidence suggests that the transition from high to very high risk in unique and threatened systems occurs at a lower level of warming, between 1.5°C and 2°C (high confidence), than in AR5, where this transition was located at 2.6°C. (2018)779 found that the impacts of SLR and wave-induced flooding (within a temperature horizon equivalent of 1.5°C), could affect freshwater availability on Roi-Namur, Marshall Islands, but is also dependent on other extreme weather events. Benefits obtained from projected reduction in extremes depend to a large extent on whether the lower range of increases in extremes at 1.5°C is sufficient for critical thresholds to be exceeded, within the context of wide-ranging aspects such as crop yields, human health and the sustainability of ecosystems. Coastal protection is a service provided by natural barriers such as mangroves, seagrass meadows, coral reefs, and other coastal ecosystems, and it is important for protecting human communities and infrastructure against the impacts associated with rising sea levels, waves, storm surges and intensifying storms (high confidence) (Gutiérrez et al., 2012; Kennedy et al., 2013; Ferrario et al., 2014; Barbier, 2015; Cooper et al., 2016; Hauer et al., 2016; Narayan et al., 2016)686. Variation between socio-economic levels, however, is projected to be larger than variation between the two levels of global warming. Because few studies have assessed the potential to adapt to these risks, there was insufficient evidence to locate a transition to very high risk (purple). Sector Physical climate change drivers Nature of risk Global warming of 1.5°C Global warming of 2°C Global warming of 1.5°C vs 2°C of warming Confidence in risk statements Regions where risks are particularly high with 2°C of global warming Regions where change in risk when moving from 1.5°C to 2°C are particularly high Regions with little or no information RFC* Adaptation potential at 2°C Confidence in assigning adaptation potential Freshwater Precipitation, temperature, snowmelt Water Stress Around half compared to the risks at 2°C1 Additional 8% of the world population in 2000 exposed to new or aggravated water scarcity1 Up to 100% increase M Europe, Australia, southern Africa 3 I I M Fluvial flood 100% increase in the population affected compared to the impact simulated over the baseline period 1976–2005 170% increase in the population affected compared to the impact simulated over the baseline period 1976–2005 70% increase M USA, Asia, Europe Africa, Oceania 2 l/m l/m M Drought 350 ± 158 million, changes in urban population exposure to severe drought at the global scale 410 ± 213.5 million, changes in urban population exposure to severe drought at the global scale 60.5 ± 84.1 million (±84.1 based on the SSP1 scenario) (based on PDSI estimates) M Central Europe, southern Europe, Mediterranean, West Africa, East and West Asia, Southeast Asia (based on PDSI estimates) 2 l/m l/m L Terrestrial ecosystems Temperature, precipitation Species range loss 6% insects, 8% plants, 4% vertebrates 18% insects, 16% plants, 8% vertebrates, 16% plants lose >50% range 18% insects, 8% vertebrates, 16% plants lose >50% range3 Double or triple M Amazon, Europe, southern Africa 1,4 h l M Loss of ecosystem functioning and services m h M 4 Shifts of biomes (major ecosystem types) About 7% transformed5 13% (range 8–20%) transformed5 About double M Arctic, Tibet, Himalayas, South Africa, Australia 4 Heat and cold stress, warming, precipitation drought Wildfire h h Increased risk M Canada, USA and Mediterranean Mediterranean Central and South America, Australia, Russia, China, Africa 1, 2, 4, 5 I I M Ocean Warming and stratification of the surface ocean Loss of framework species (coral reefs) 70–90% loss at 1.5°C to 99% loss at 2°C and above Very h H Tropical/subtropical countries Tropical/subtropical countries Southern Red Sea, Somalia, Yemen, deep water coral reefs 1,2 h l H Loss of framework species (seagrass) m h Increase in risk M Tropical/subtropical countries Tropical/subtropical countries Southern Red Sea, Somalia, Yemen, Myanmar 1,2 m l H/M Loss of framework species (mangroves) m l/M Increase in risk M Tropical/subtropical countries Tropical/subtropical countries Southern Red Sea, Somalia, Yemen, Myanmar 1,3 m l L/M Disruption of marine fisheries h vh Large increase in risk M Global Global Deep sea 4 m l M/H Range migration of marine species and ecosystems m h Large increase in risk H Global Global Deep sea 1 m l M Loss of fin fish and fisheries h h/vh Large increase in risk H Global Global Deep sea, upwelling systems 4 m l/M Ocean acidification and elevated sea temperatures Loss of coastal ecosystems and protection m h Increase in risk M Low-latitude tropical/subtropical countries Low-latitude tropical/subtropical countries - risks not well defined 1 m m/l M Loss of bivalves and bivalve fisheries m/h h/vh Large increase in risk H Temperate countries with upwelling Temperate countries with upwelling Most regions – risks not well defined 4 m/h l/m M/H Changes to physiology and ecology of marine organisms l/m m Increase in risk H Global Global Deep sea 4 m l M Changes to upwelling productivity l m Increase in risk L/M Most upwelling systems 1 m l M Intensified storms, precipitation plus sea level rise Loss of coastal ecosystems h h/vh Large increase in risk H Tropical/subtropical countries Tropical/subtropical countries 1, 4 m l M Inundation and destruction of human/coastal infrastructure and livelihoods h h/vh Large increase in risk H Global Global 1, 5 m/h m M/L Loss of sea ice Loss of habitat h vh Large increase in risk H Polar regions Polar regions 1 l very l H Increased productivity but changing fisheries l/m m Large increase in risk very H Polar regions Polar regions 1, 4 l m H Coastal Sea level rise, increased storminess Area exposed (assuming no defences) 562–575th km2 when 1.5°C first reached6,7 598–613th km2 when 2°C first reached6,7 Increase of 25–38th km2 when temperatures are first reached, 10–17th km2 in 2100 increasing to 16–230th km2 in 23006,7,8 M/H (dependent on population datasets) Asia, small islands Asia, small islands Small islands 2, 3 m m M Population exposed (assuming no defences) 128–143 million when 1.5°C first reached 141–151 million when 2°C first reached Increasing; 8–13 million when temperatures are first reached, 0–6 million people in 2100 increasing to 35–95 million people in 23006 M/H (dependent on population datasets) Asia, small islands Asia, small islands Small islands 2, 3 m m M People at risk accounting for defences (modelled in 1995) 2–28 million people yr−1 if defences are not upgraded from the modelled 1995 baseline9 15–53 million people yr−1 if defences are not upgraded from the modelled 1995 baseline9 Increasing with time, but highly dependent on adaptation9 M/H (dependent on adaptation) Asia, small islands, potentially African nations Asia, small islands Small islands 2, 3, 4 m m M Food security and food production systems Heat and cold stress, warming, precipitation, drought Changes in ecosystem production m/h h Large increase M/H Global North America, Central and South America, Mediterranean basin, South Africa, Australia, Asia 2, 4, 5 h h m M/H Heat and cold stress, warming, precipitation drought Shift and composition change of biomes (major ecosystem types) m/h h Moderate increase L/M Global Global, tropical areas, Mediterranean Mediterranean Africa, Asia 1, 2, 3, 4 l/m l L/M Reduction of food production and quality h vh Large increase M/H Global South America, South-East Asia, Southern Africa, Middle East, Mediterranean, Central Asia Arid lands 4, 5 m H/L Increased risk Terrestrial Heat-related morbidity and mortality m/h vh Risk increased VH All regions at risk All regions Africa, 2, 3, 4 h h H Occupational heat stress m m/h Risk increased M Tropical Tropical Tropical regions Africa 2, 3, 4, 6 h m M Air quality Ozone-related mortality m (if precursor emissions remain the same) m/h (if precursor emissions remain the same) Risk increased M High income and emerging economies High income and emerging economies Africa, parts of Asia 2, 3, 4 l l M Temperature, precipitation Undernutrition m m/h Risk increased M Low-income countries in Africa and Asia Low-income countries in Africa and Asia Small islands 2, 3, 4 m l M Key economic sectors Temperature Tourism (heat, beach, and snow sports) m/h Risk increased M Coastal tourism, particularly in subtropical and tropical regions Coastal tourism, particularly in subtropical and tropical regions Africa 1, 2, 3 m l H Some elements of the assessment in Section 3.4 were synthesized into Figure 3.18 and 3.20, indicating the overall risk for a representative set of natural and human systems from increases in global mean surface temperature (GMST) and anthropogenic climate change. Similarly, Gang et al. AR5 assessed that climate change is projected to reduce raw water quality, posing risks to drinking water quality with conventional treatment (medium to high confidence) (Jiménez Cisneros et al., 2014)428. Mortality associated with exposure to particulate matter could increase or decrease in the future, depending on climate projections and emissions assumptions (Supplementary Material 3.SM, Table 3.SM.8; Tainio et al., 2013; Likhvar et al., 2015; Silva et al., 2016)1009. While not often considered, crop production is also negatively affected by the increase in both direct and indirect climate extremes. However, differences in flood risks among regions reflect the balance among the magnitude of the flood, the populations, their vulnerabilities, the value of assets affected by flooding, and the capacity to cope with flood risks, all of which depend on socio-economic development conditions, as well as topography and hydro-climatic conditions (Tanoue et al., 2016)399. Freshwater resources may also be affected by a 0.40 m rise in sea level (which may be experienced with a 1.5°C warming) in other Pacific atolls (Terry and Chui, 2012)780. (2015)556 found that rising water temperatures are projected to lead to shifts in fish community composition (high confidence), but they are vulnerable to loss of carbon to the atmosphere as a result of projected increases in the intensity of storms, wildfires, land degradation and pest outbreaks (Settele et al., 2014; Seidl et al., 2017)492. Overall, there is high confidence that strong increases in dryness are assessed with 1.5°C versus 2°C of global warming. There has also been progress since AR5 in identifying historical changes in streamflow and continental runoff (Section 3.3.5). (2014)1041 projected that a 2°C warmer world would reduce European tourism by 5% (€15 billion yr−1), with losses of up to 11% (€6 billion yr−1) in the UK. The new literature is used to confirm the levels of global warming at which risks are considered to increase from undetectable to moderate, from moderate to high, and from high to very high. Disagreement between models outweighs differences between scenarios even up to the year 2100 (Hewitt et al., 2016; Lovendusky and Bonan, 2017)502. Adaptation to climate change at these high rates, has not been documented, and recovery from mass mortality tends to take much longer (>15 years; Baker et al., 2008)728. The last group, fin fishes, is vitally important components of ocean foodwebs, contributes to the income of coastal communities, industries and nations, and are important to the food security and livelihood of hundreds of millions of people globally (FAO, 2016)668. However, the feedback between wetlands and sea level is complex, with parameters such as a lack of accommodation space restricting inland migration, or sediment supply and feedbacks between plant growth and geomorphology (Kirwan and Megonigal, 2013; Ellison, 2014; Martínez et al., 2014; Spencer et al., 2016)803 still being explored. Impacts have been detected in the tropics (AR5 WGII Chapters 7 and 18), and regional risks are projected to become high in some regions by 1.5°C of warming, and in many regions by 2.5°C, indicating a transition from moderate to high risk between 1.5°C and 2.5°C of warming (medium confidence). Threats related to sea level rise (SLR) for SIDS, for example from salinization, flooding, permanent inundation, erosion and pressure on ecosystems, will therefore persist well beyond the 21st century even under 1.5°C of warming (Section 3.4.5.3; Nicholls et al., 2018)831. Hence, there is an increasing need for long-term and sustainable investments in adaptation in Africa. There is limited information about the global and regional projected risks posed by droughts at 1.5°C and 2°C of global warming. In some Arctic land regions, the warming of cold extremes and the increase in annual minimum temperature at 1.5°C are stronger than the global mean temperature increase by a factor of two to three, meaning 3°C–4.5°C of regional warming at 1.5°C of global warming (e.g., northern Europe in Supplementary Material 3.SM, Figure 3.SM.5 see also Section 3.3.2.2 and Seneviratne et al., 2016)1175. At 2°C, risks of impacts associated with climate change to ocean systems are high (high confidence), while the risks associated with reduced coastal protection and recreation on tropical coral reefs are high, especially given the vulnerability of the ocean system, and others (e.g., seagrass and mangroves), to climate change (medium confidence) (Figure 3.18). A high degree of variability is projected between regions (Arnell et al., 2018)1054. Sea level rise (SLR) is accelerating in response to climate change (Section 3.3.9; Church et al., 2013)737 and will produce significant impacts (high confidence). Avoided damages from achieving 1.5°C versus 2°C are modest at about 0.35% (range 0.20–0.65%) by 2100. There is rarely a single cause for migration (Constable, 2017)1068. In the case of climate change on fisheries via impacts on net primary productivity (NPP), there are also direct effects of temperature on fish, which in turn have a range of impacts (Pörtner et al., 2014)628. At 1.5°C, compounding impacts from interactions between climate drivers may contribute to the loss of, or change in, critical natural and human systems (medium to high confidence). Risk levels will depend on the rate of warming and the (related) level of adaptation, so a transition in risk from moderate (yellow) to high (red) is located between 1.5°C and 3°C (medium confidence). The center represents expected non-linearity to changes in temperature. Crop yields are expected to change from a combination of elevated CO2 and 1.5°C warming, maize and potato yields were observed to increase by 45.7% and 11%, respectively (Singh et al., 2013; Abebe et al., 2016)867. Many of these cities are located in South and Southeast Asia (Hallegatte et al., 2013; Cazenave and Cozannet, 2014; Clark et al., 2016; Jevrejeva et al., 2016)761. Considering potential changes in natural snow only, winter overnight stays at 1.5°C are projected to decline by 1–2% in Austria, Italy and Slovakia, with an additional 1.9 million overnight stays lost under 2°C of warming (Jacob et al., 2018)1040. Disclosure statement: The selection of elements depicted in Figure 3.18 and 3.20 is not intended to be fully comprehensive and does not necessarily include all elements for which there is a substantive body of literature, nor does it necessarily include all elements which are of particular interest to decision-makers. Although peatlands cover only about 3% of the land surface, they hold one-third of the world's soil carbon stock (400 to 600 Pg) (Settele et al., 2014)550. Climate-induced sea level rise (SLR) and associated coastal flooding (related to RFCs 2, 3 and 4) have been detectable and attributable since approximately 1970 (Slangen et al., 2016)1114, during which time temperatures have risen by 0.3°C (medium confidence) (Section 3.3.9). The losses in sea ice at 1.5°C and 2°C of warming will result in habitat losses for organisms such as seals, polar bears, whales and sea birds (e.g., Larsen et al., 2014)1174. (2017)843 found smaller reductions in yield per degree of warming (1°C rather than 2°C of global warming). At 1.5°C of warming, these values fall to 6% (1–18%) of the insects, 4% (2–9%) of the vertebrates and 8% (4–15%) of the plants studied. Under regional warming, alpine species have been found to migrate upwards on mountain slopes (Reasoner and Tinner, 2009)1178, an adaptation response that is obviously limited by mountain height and habitability. In some cases, where species (such as pest and disease species) move into areas which have become climatically suitable they may become invasive or harmful to human or natural systems (Settele et al., 2014)486. Working Group II (WGII) of the IPCC Fifth Assessment Report (AR5) provided an assessment of the literature on the climate risk for natural and human systems across a wide range of environments, sectors and greenhouse gas scenarios, as well as for particular geographic regions (IPCC, 2014a, b)369. These authors concluded that even if anthropogenic greenhouse gas emissions stopped today, the effort for human societies to adapt to the most crucial effects of climate-driven species redistribution will be far-reaching and extensive. The costs of preventing workplace heat-related illnesses through worker breaks suggest that the difference in economic loss between 1.5°C and 2°C could be approximately 0.3% of global gross domestic product (GDP) in 2100 (Takakura et al., 2017)1006. Other vector-borne diseases Uncertainty remains about West Nile virus transmission, particularly along the current edges of its transmission areas, and extension of the transmission season, with the magnitude and pattern of changes varying by location and level of warming (Semenza et al., 2016)1014. Impacts of climate change were assessed to be similar across a range of submerged and emergent plants. (2014)1140 and five additional impact categories were aggregated in an AR5 assessment of the literature on global aggregate damages due to the lack of consideration of the potential for these events in many studies. (2014)532 also indicate significantly lower wildfire risks in North America for near-term warming (2030–2040, considered a proxy for 1.5°C of warming) than at 2°C (high confidence). Further details of risk transitions for ocean systems are described in Figure 3.18. Owing to the commitment to SLR, there is an overlapping uncertainty in projections at 1.5°C and 2°C (Schleussner et al., 2016b; Sanderson et al., 2017; Goodwin et al., 2018; Mengel et al., 2018; Nicholls et al., 2018; Rasmussen et al., 2018)738 and about 0.1 m difference in global mean sea level (GMSL) rise between 1.5°C and 2°C worlds in the year 2100 (Section 3.3.9, Table 3.3). The study by Warren et al. This includes systems identified in WGII AR5 (AR5 – Section 3.4 of Wong et al., 2014)804, such as beaches, barriers, sand dunes, rocky coasts, aquifers, lagoons and coastal ecosystems (for the last system, see Section 3.4.4.12). This literature is reflected in the risk in this system from high to very high between 1.5°C and 2°C of warming and contributes to a lowering of the transition from high to very high in RFC1 compared to in AR5. In the Arctic (related to RFC1), the increased rate of summer sea ice melt was detected and attributed to climate change by the year 2000 (corresponding to warming of 0.7°C), indicating moderate risk. The number of investigations into how the tree fraction may respond in the Arctic to different degrees of global warming is limited, and studies generally indicate that substantial increases will likely occur gradually (e.g., Lenton et al., 2008)1232. The impacts of climate change on food security in Africa, Asia and Latin America has been identified as being of substantial concern, with considerable risk to food security and food supplies (e.g., food security in the USA and Europe is being assessed as an important one (e.g., Hoegh-Guldberg et al., 2017)... (Section 3.4.5), leading to substantial challenges today and in the future for cities, deltas and small island states in particular (Sections 3.4.5.2 to 3.4.5.4), as well as for coastlines and their associated ecosystems (Sections 3.4.5.5 to 3.4.5.7). In summary, limiting warming to 1.5°C compared with 2°C may avoid advance in spring phenology (high confidence) by perhaps a few days (medium confidence) and hence decrease the risks of loss of ecosystem functionality due to phenological mismatch between trophic levels, and also of maladaptation coming from the sensitivity of many species to increased climate variability. Consequently, for adaptation purposes, it is necessary to enhance carbon sinks, especially in forests which are prime regulators within the water, energy and carbon cycles (Ellison et al., 2017)497. The framework's practical application is exemplified by Oppenheimer et al. This suggests a transition from moderate to high risk of regionally differentiated impacts between 1.5°C and 2°C for food security (medium confidence) (Figure 3.20). A caveat to the analyses of Pretis et al. Regional increases in temperature extremes can be robustly limited if global warming is constrained to 1.5°C, with regional warming of up to 3°C–4.5°C (Section 3.3.2, Table 3.2). Similarly, deep-water (50–150 m) or mesophotic coral reefs (Bongaerts et al., 2010; Holstein et al., 2016)732 may play an important role because they avoid shallow water extremes (i.e., heat and storms) to some extent, although the ability of these ecosystems to assist in repopulating damaged shallow water areas may be limited (Bongaerts et al., 2017)733. Coral-dominated reefs are found along coastlines between latitudes 30°S and 30°N, where they provide habitat for over a million species (Reaka-Kudla, 1997)707 and food, income, coastal protection, cultural context and many other services for millions of people in tropical coastal areas (Burke et al., 2011; Cinner et al., 2012; Kennedy et al., 2013; Pendleton et al., 2016)708. Statistically significant reductions in gross domestic product (GDP) per capita growth are projected across much of the African continent, Southeast Asia, India, Brazil and Mexico (low to medium confidence). The distribution and abundance of coral reefs has decreased by approximately 50% over the past 30 years (Gardner et al., 2005; Bruno and Selig, 2007; De'ath et al., 2012)711 as a result of pollution, storms, overfishing and unsustainable coastal development (Burke et al., 2011; Halpern et al., 2015; Cheal et al., 2017)712. AR5 (Niang et al., 2014)1243, as well as more recent research through the Coordinated Regional Downscaling Experiment for Africa (CORDEX-AFRICA), provides a more uncertain view, however, in terms of the rainfall futures of the Sahel under low mitigation futures. For example, saltmarshes in Connecticut and New York, USA, measured from 1900 to 2012, have accreted with SLR but have lost marsh surface relative to tidal datums, leading to increased marsh flooding and further accretion (Hill and Anisfeld, 2015)799. Under many models and scenarios, the aragonite saturation is projected to reach the surface by 2030 onwards, with a growing list of impacts and consequences for ocean organisms, ecosystems and people (Orr et al., 2005; Hauri et al., 2016)597. Averages of annual sediment loads are projected to be similar under 1.5°C and 2°C of warming, in particular in the Great Lakes region in the USA and in the Lower Mekong region in Southeast Asia (Cross-Chapter Box 6 in this chapter, Cousins et al., 2015; Shrestha et al., 2016)447. As a consequence, the distribution and abundance of key fisheries species may change, with implications for fisheries and other ecosystem services (Ling et al., 2009)590. The exposure of urban populations to most regions would be decreased at 1.5°C (350.2 ± 158.8 million people) compared to 2°C (410.7 ± 213.5 million people). Projections suggest that climate change is projected to expand the geographic range of chikungunya, with greater expansions occurring at higher degrees of warming (Tjaden et al., 2017)1013. Differences in price impacts of climate change are accompanied by differences in food security, with large regional and food trade (Mueller et al., 2011; Wright, 2011; Roberts and Schlenker, 2013)958. The mean net present value of the costs of damages from warming in 2100 for 1.5°C and 2°C (including damages associated with SLR) are assessed in Section 3.4.5.7. Sea level rise (SLR) and other oceanic climate changes are already resulting in salinization, flooding, and erosion, and in the future are projected to affect human and ecological systems, including health, heritage, freshwater availability, biodiversity, agriculture, fisheries and other services, with different impacts seen worldwide (high confidence). Other threats concern the increasing incidence of alien species and diseases (Kittinger et al., 2013; Weatherdon et al., 2016)931. Furthermore, human threat and migration are increasingly being considered as an adaptation response (Hauer et al., 2016; Geisler and Currens, 2017)818, with a growing emphasis on green adaptation. Similarly, extreme sea levels for small islands, particularly in the Caribbean, are linked to tropical cyclone occurrence (Khouakhi and Villarini, 2017)835. For extreme heat events, an additional 0.5°C of warming implies a shift from the upper bounds of observed natural variability to a new global climate regime (Schleussner et al., 2016b)1120, with distinct implications for the urban poor (Revi et al., 2014; Jean-Baptiste et al., 2018; UCCRN, 2018)1030. Nevertheless, their study indicates that socio-economic changes make a larger contribution to the potential increased consequences of future floods, and about half of the increase in potential economic losses could be mitigated by autonomous adaptation. The combination of environmental, social and economic pressures on people in the Mekong River basin highlights the complexity of climate change impacts and adaptation in this region, as well as the fact that projected impacts are expected to be much lower at 1.5°C than 2°C of warming. Summer sea ice in the Arctic, however, has been retreating rapidly in recent decades (Section 3.3.8), with an assessment of the literature revealing that a fundamental transformation is occurring in polar organisms and ecosystems, driven by climate change (high confidence) (Larsen et al., 2014)622. These changes are expected to stimulate fisheries productivity in high-latitude regions by mid-century (high confidence) (Cheung et al., 2009, 2010, 2016b; Lam et al., 2014)626, with evidence that this is already happening for several high-latitude fisheries in the Northern Hemisphere, such as the Bering Sea, although these 'positive' impacts may be relatively short-lived (Hollowed and Sundby, 2014; Sundby et al., 2016)627. Implemented specific strategies can partly or greatly alleviate the climate change impacts on these systems (Wei et al., 2017)852, whilst the degree of compensation is mainly dependent on the geographical area and crop type (Rose et al., 2016)853. In some cases, this can lead to improvements (e.g., coastal protection and nutrient runoff (medium-high confidence) (Brodie et al., 2012; Wong et al., 2014; Anthony, 2016)578; ARS, Table 5.1). Although oil and pollution will slow down, these increased cyclone regimes may have negative effects on coral reef ecosystems (Heron et al., 2017)... (2014)1140 ... Although dikes remain essential for reducing flood risk today, promoting sedimentation is an adaptation strategy (Brown et al., 2018)796 which may involve nature-based solutions. Spatial differences between the rates of heating suggest the possibility of temporary climate refugia (Caldeira, 2013; van Hooidonk et al., 2013; Cacciapaglia and van Woesik, 2015; Keppel and Kavousi, 2015)730, which may play an important role in terms of the regeneration of coral reefs, especially if these refuges are protected from risks unrelated to climate change. Locations at higher latitudes are reporting the arrival of reef-building corals, which may be valuable in terms of the role of limited refugia and coral reef structures but will have low biodiversity (high confidence) when compared to present-day tropical reefs (Kersting et al., 2017)731. Global observations indicate no overall clear effect of SLR on shoreline change (Le Cozannet et al., 2014), for example in Bicol, Philippines (Sato et al., 2016)... Projected benefits for these areas are estimated at around 36.5 billion yuan yr−1 in 1979–2005 to 250 billion yuan yr−1 in the 2030s (about 1.5°C) (Zhao et al., 2016)1007. Adaptation options include developing alternative livelihoods and food sources, ecosystem-based management/adaptation such as ecosystem restoration, and constructing coastal infrastructure that reduces the impacts of rising seas and intensifying storms (Rinkevich, 2015; Weatherdon et al., 2016)795. As a consequence, biome (major ecosystem type) shifts are likely in the Arctic, with increases in fire frequency, degradation of permafrost, and tree cover likely to occur at 1.5°C of warming and further amplification of these changes expected under 2°C of warming (e.g., Gerten et al., 2013; Bring et al., 2016)1176. A transition in risk from moderate to high levels of added risk from climate change is projected to occur between 1.5°C and 3°C (medium confidence). Occupational health: Higher ambient temperatures and humidity levels place additional stress on individuals engaging in physical activity. It is very likely that the AMOC will weaken over the 21st century. However, they have great potential to aid and benefit climate change mitigation and adaptation (medium confidence) (Sections 4.3.2.2 and 4.3.2.3). Warm-water coral reefs are found down to depths of 150 m and are dependent on light; making them distinct from the cold deep-water reef systems that extend down to depths of 2000 m or more. Further, a reduction in water supply might induce cattle water demand (Masike and Urich, 2008)904. Low river flows are projected to decrease in the Mediterranean under 1.5°C of global warming (Marx et al., 2018)1188, with associated significant decreases in high flows and floods (Thober et al., 2018)1189, largely in response to reduced precipitation. While impacts varied substantially among systems, sectors and regions, many changes over the past 50 years could be attributed to human-driven climate change and its impacts. Safe work activity and worker productivity during the hottest months of the year would be increasingly compromised with additional climate change (medium confidence) (Dunne et al., 2013; Kjellstrom et al., 2013, 2018; Sheffield et al., 2013; Habibi Mohraz et al., 2016)1004. In terms of mangroves, hypotheses such as the expected inundation, transformation and loss would, however, ... (2016)... Further, the assessment included coral reefs for which the adaptation potential ... the Great Barrier Reef. Oppenheimer et al. However, such estimates do not consider shoreline response (Section 3.4.5) or adaptation. (2018c)1132 used the integrated assessment model FAGE09 to estimate that avoided global economic damages of 22% (10–26%) accrue from constraining warming to 1.5°C rather than 2°C, 90% (77–93%) from 1.5°C rather than 3.66°C, and 87% (74–91%) from 2°C rather than 3.66°C. In some cases, restoration of coastal habitats and ecosystems can be a cost-effective way of responding to changes arising from increasing levels of exposure from rising sea levels, changes in storm conditions, coastal inundation and salinization (Arkema et al., 2013; Temmerman et al., 2013; Ferrario et al., 2014; Hinkel et al., 2014; Spalding et al., 2014; Elliff and Silva, 2017)813. Differences in global sea level between 1.5°C and 2°C depend on the time scale considered and are projected to fully materialize only after 2100 (Section 3.3.9). As a result, future scenarios surrounding climate change and global population growth increasingly project shortages of fish protein for many regions, such as the Pacific Ocean (Bell et al., 2013, 2018b)928 and Indian Ocean (McClanahan et al., 2015)929. Projections indicate that these challenges will require new tools in terms of legal and financial instruments, as well as integrated planning that involves not only human communities and infrastructure, but also associated ecosystem regions and values (Bell, 2012; Mills et al., 2016)698. Sensitivities to less ambitious global temperature goals are also briefly reviewed. At the global level, linear scaling is acceptable for net primary production, biomass burning and surface runoff, and impacts on terrestrial carbon storage are projected to be greater at 2°C than at 1.5°C (Tanaka et al., 2017)437. WGII AR5 concluded that climate change is projected to reduce groundwater resources significantly in most dry subtropical regions (Jiménez Cisneros et al., 2014)422. The AR5 analysis already suggested a significant benefit of limiting warming to 1.5°C, as doing so might keep risks closer to the moderate level. Slower rates of SLR will provide a greater opportunity for adaptation to be successful (medium confidence), but this may not be substantial enough on islands with a very low mean elevation. In Greece, Spain and Portugal, warming of 2°C is projected to decrease hydropower potential below 10%, while limiting global warming to 1.5°C would keep the reduction to 5% or less. Photosynthetic communities, such as seagrass, macroalgae, phytoplankton and microalgae dwelling on the underside of floating sea ice are changing, owing to increased temperatures, light and nutrient levels. Further, consequences of climate change for infrastructure, tourism, migration, crop yields and other impacts interact with underlying vulnerabilities, such as for individuals and communities engaged in pastoralism, mountain farming and artisanal fisheries, to affect livelihoods and poverty (Dasgupta et al., 2014)373. Recent large-scale die-offs (Duke et al., 2017; Lovelock et al., 2017)565, however, suggest that risks from climate change may have been underestimated for mangroves as well. Moreover, increased risks are projected in terms of drought, in particular for the pre-monsoon season (Sylla et al., 2015)1195, with both rural and urban populations affected, and more so at 2°C of global warming as opposed to 1.5°C (Liu et al., 2018)1196. Unique and threatened systems in small island states and in systems fed by glacier meltwater were also considered to contribute to this RFC in AR5, but there is little new information about these systems that pertains to 1.5°C of warming. Global warming of 1.5°C would therefore have smaller impacts on national economies. However, substantial uncertainty is associated with these results due to a large spread between the climate models (Tobin et al., 2018)392. Food security and agriculture are also closely linked to other aspects of sustainable development, including poverty eradication (SDG 1), health and well-being (SDG 3), clean water (SDG 6), decent work (SDG 8), and the protection of ecosystems on land (SDG 15) and in water (SDG 15) (UN, 2015, 2017; Pérez-Escamilla, 2017)942. Observations of the impacts of SLR in cities are difficult to record because multiple drivers of change can influence perceived impacts. There is, however, substantial uncertainty in the degree to which mangroves may be able to keep up with rising sea levels as the rate of SLR increases (Section 3.4.4.12) (Lovelock et al., 2015)... at which point this risk increases to very high when ..., in some settings, a result from the way ... depending on how rapidly ... it would see ... (Marzeion and Levermann, 2014)... and biogeochemical components, as well as by factors other than climate (Boyd, 2015)679. Cai et al. (2016)679 ... Lemoine and Traeger, 2016)1264, which included 1142 ... A world in which global warming is restricted to 1.5°C above pre-industrial levels would be a better place for coral reefs than that of a 2°C warmer world, in which coral reefs would mostly disappear (Donner et al., 2005; Hoegh-Guldberg et al., 2014; Frieler et al., 2013; Hughes et al., 2017a)704. Thus, even limiting warming to 1.5°C may not be sufficient to ... (Graham et al., ...). In ... (Vinuesa et al., ...) ... mitigate in the long run (medium confidence). The approach of ... (2019)... in the longer term, 50% of the ... at ... 1.5°C vs 2°C ... (Hughes et al., 2018)... Such an increase ... This ... Among the ... (Section 3.4.4.8) ... Open water vessel transit has the potential to take global as well as by ... to cause ... human ... as well as ... (Melia et al., 2016)1070. Qualitative physical observations of SLR (and other stresses) include inundation of parts of low-lying islands, land degradation due to saltwater intrusion in Kiribati and Tuvalu (Wairiu, 2017)764, and shoreline change in French Polynesia (Yates et al., 2013)765, Tuvalu (Kench et al., 2015, 2018)766 and Hawaii (Romine et al., 2013)767. AR5 concluded that there was low confidence in the attribution of global changes in droughts (Bindoff et al., 2013b)400. Changing water chemistry and temperature are already affecting the ability of pteropods to produce their shells, swim and survive (Bednaršek et al., 2016)669. In Lloyd et al. (2016)... (2014)... Confidence in each assessed level (identification of risk, or in each assessed adaptation potential, is indicated as very high (VH), high (H), medium (M), or low (L). There is high agreement and robust evidence that photosynthetic species will respond to changes in temperature and radiation (Section 3.4.4.7), and this is very likely to benefit fisheries productivity in the Northern Hemisphere spring bloom system (Section 3.4.4.7). These impacts may be enhanced through localized subsidence (Wong et al., 2014)759, which can also exacerbate freshwater resource issues in coastal areas (Section 3.4.2). Risks are projected to be highest in South and Southeast Asia, assuming there is no upgrade to current protection levels, for all levels of climate warming (Arnell et al., 2016; Brown et al., 2016)753. Tree growth in tundra-dominated landscapes is strongly constrained by the number of days with mean air temperature above 0°C. Climate change mitigation will reduce the need for extensive and, in places, immediate adaptation. The most severe impacts are projected for urban areas and some rural regions in sub-Saharan Africa and Southeast Asia. Based on the limited analyses available, there is medium confidence that the risks to sustainable development are considerably less at 1.5°C than 2°C (Section 5.2.2), including impacts on poverty and food security. Restricting overall warming to 1.5°C will still see a downward trend in average coral cover (70–90% decline by mid-century) but will prevent the total loss of coral reefs projected with warming of 2°C (Frieler et al., 2013)... (Hoegh-Guldberg et al., 2017)... Possible risks of climate change impacts for seagrass and mangrove ecosystems were recently assessed by an expert group led by Short et al. Projections for mid-to-high-latitude fisheries include increases in fishery catch potential at 1.5°C (Cheung et al., 2013; Hollowed et al., 2013; Lam et al., 2014; FAO, 2016)932. As presented in Section 3.4.4 and Box 3.4, reaching 2°C will increase the frequency of mass coral bleaching and mortality to a point at which it will result in the total loss of coral reefs from the world's tropical and subtropical regions. Lemoine and Traeger (2016)1265 included optimization calculations that minimize welfare impacts resulting from the combined costs of climate change and climate mitigation costs, showing that welfare is minimized if warming is limited to 1.5°C. (2014)1131 explained the inclusion of non-economic metrics related to impacts on ecosystems and species at the global level, in addition to economic metrics in global aggregate impacts. As corals disappear, so do fish and many other reef-dependent species, which directly impacts industries such as tourism and fisheries, as well as the livelihoods for many, often disadvantaged, coastal people (Wilson et al., 2006; Graham, 2014; Graham et al., 2015; Cinner et al., 2016; 716Pendleton et al., 2016)717. The extent to which morbidity and mortality are projected to increase varies by region, presumably because of differences in acclimatization, population vulnerability, the built environment, access to air conditioning and other factors (Russo et al., 2016; Mora et al., 2017; Byers et al., 2018; Harrington and Otto, 2018)1001. (2015)12 projected a robust increase in the net primary productivity (NPP) of temperate forests. Similar strandlands exist in the semi-arid regions of other continents, with the Sonora-Mojave creosotebush-white bursage desert scrub ecosystem in the USA being a prime example. Climate models have been used to assess whether a bifurcation exists that would lead to the irreversible loss of Arctic sea ice (Armour et al., 2011; Boucher et al., 2012; Ridley et al., 2012)1225 and to test whether the summer sea ice extent can recover after it has been lost (Schröder and Connolley, 2007; Sedláček et al., 2011; Tietsche et al., 2011)1227. Advancement in spring phenology of 2.8 ± 0.35 days per decade has been observed in plants and animals in recent decades in most Northern Hemisphere ecosystems (between 30°N and 72°N), and these shifts have been attributed to changes in climate (high confidence) (Settele et al., 2014)457. Some studies are beginning to locate 'refugial' areas where the climate remains suitable in the future for most of the species currently present. Exposures are projected to approximately double between 1.5°C and 2°C, and the land area affected by climate risks is expected to increase as warming progresses. Reduced ocean upwelling has implications for millions of people and industries that depend on fisheries for food and livelihoods (Bakun et al., 2015; FAO, 2016; Kämpf and Chapman, 2016)572, although there is low confidence in the projection of the size of the consequences at 1.5°C. The loss of coral reef systems is expected to increase the risks to coastal tourism in subtropical and tropical regions. (2016)751 also found that the population exposed to flooding increased substantially if warming were higher than 2°C, assuming no adaptation beyond current protection levels. (2018)1057 assessed future climate impacts on hydropower in Suriname and projected a decrease of approximately 40% in power capacity for a global temperature increase in the range of 1.5°C. You can track the progress of your request at: If you have any other questions, please contact us directly by email. Dibouti et al. 2018 also quantified the economic benefits of increased carbon in ... (2014)... these results are likely underestimated at present. Freshwater ... through direct effects from altered precipitation ... (Arias-Ortiz et al., 2018)643, and indirectly by burbling, while emergent communities such as mangroves and salt marshes were most susceptible to sea level variability and temperature extremes, which is consistent with other evidence (Di Nitto et al., 2014; Sierra-Correa and Cantera Kintz, 2015; Osorio et al., 2016; Sasmito et al., 2016)644, especially in the context of human activities that reduce sediment supply (Lovelock et al., 2015)645 or interrupt the shoreward movement of mangroves through the construction of coastal infrastructure. Changing weather patterns are associated with shifts in the geographic range, seasonality and transmission intensity of selected climate-sensitive infectious diseases (e.g., Semenza and Menne, 2009)993, and increasing morbidity and mortality are associated with extreme weather and climate events (e.g., K.R. Smith et al., 2014)994. Further, increased river salinity and saline intrusion in the Ganges-Brahmaputra-Meghna is likely with 2°C of warming (Dunn et al., 2018)791. Hsiang et al. Specifically, temperate forest phenology is projected to advance by 14.3 days in the near term (2010–2039) and 24.6 days in the medium term (2040–2069), so as a first approximation the difference between 2°C and 1.5°C of warming is about 10 days (Roberts et al., 2015)468. Regarding extreme weather events (RFC2), the transition from moderate to high risk is located between 1°C and 1.5°C of global warming (Figure 3.21), which is very similar to the AR5 assessment but is assessed with greater confidence (medium confidence). Since AR5, these studies have emerged using two entirely different approaches: (i) the use of the 'accumulation' or cyclone relocation (e.g., changes in rain and hydrological extremes) ... with projected runoff ... to 2100 if warming reaches 2°C than if it is constrained to 1.5°C. It concluded with medium confidence that greenhouse gas forcing has contributed to a global-scale intensification of heavy precipitation over the second half of the 20th century, for a global warming of approximately 0.5°C (Section 3.3.3). Hanasaki et al. Reductions in precursor emissions would reduce future ozone concentrations and associated mortality. There is high confidence that ozone-related mortality could increase if precursor emissions remain the same, and that higher temperatures could affect the transmission of some infectious diseases, with increases and decreases projected depending on the disease (e.g., malaria, dengue fever, West Nile virus and Lyme disease), region and degree of temperature change. (2013)1225 discussed the loss of Arctic sea ice in the context of potential tipping points. For example, Storlazzi et al. Huang et al. (2017); Izumi et al. (2017)1258. Patterns of change may be complex; for example, at 1.5°C, the cost to ... global cumulative ... (2018)... Interestingly, ... (Fujimori et al., 2018)... a 20% reduction in areas experiencing severe heat stress in East Asia, compared to significant increases in low latitudes at 2°C (Lee and Min, 2018)1005. A variety of risks (e.g., human) ... the risks to fishermen ... Climate impacts ... In contrast, ... higher prevalence of fleas ... Tropical Asia ... (2018)... Ultimately, coral reefs are underpinned by a mutualistic symbiosis between reef-building corals and dinoflagellates from the genus Symbiodinium (Hoegh-Guldberg et al., 2017)709. It is therefore that the limits ... (2016)... In addition, the ... of extremes ... (2016)1060 ... Increased supply of organic carbon molecules from coastal run-off can also increase the metabolic activity of coastal microbial communities (Altieri and Gedan, 2015; Bakun et al., 2015; Boyd, 2015)612. There are few studies on the adaptation limits to SLR where transformation change may be required (AR5 Section 5.5 of Wong et al., 2014)810; Nicholls et al., 2015)820. However, in 2046–2100, wind energy density is projected to decrease in eastern Europe (−30%) and increase in Baltic regions (+30%). The more pages you order, the less you pay. A brief summary of the accrual of RFCs with global warming, as assessed in WGII AR5, is provided in the following sections, which leads into an update of relevant literature published since AR5. Rising temperatures, thawing permafrost and changing weather patterns are projected to increasingly impact people, infrastructure and industries in the Arctic (W.N. Meier et al., 2014)1177 with these impacts larger at 2°C than at 1.5°C of warming (medium confidence). Under 2°C of global warming, losses of 8–14% are projected in global maize production (Bassu et al., 2014)1259. Boreal forests are likely to experience stronger local warming than the global average (WGII AR5, Collins et al., 2013)1252. Studies from 27 countries consistently project substantially decreased reliability of all areas that are dependent on natural snow, increased snowmaking requirements and investment in snowmaking systems, shortened and more variable ski seasons, a contraction in the number of operating ski areas, altered competitiveness among and within regional ski markets, and subsequent impacts on employment and the value of vacation properties (Steiger et al., 2017)1043. A temperature increase of one standard deviation increased the risk of interpersonal conflict by 2.4% and intergroup conflict by 11.3% (Burke et al., 2015a)1099. Generally, heat stress can be responsible for demersal animal mortality and ... (2014)... Unlike annual ... (Kurihara et al., 2014)... Chinese ... Such a ... However, this is ... at ... (2015)... 1.5°C and 2°C ... (Sanderson et al., 2017)... as well as increases in interannual and ... Regarding extreme events (RFC2) ... sea level rise, ... due ... to ... , and ... the coast ... (Lemoine and Traeger, 2016)... and 63% of species losing ... 1.5°C ... Adaptation options to warming ... coastal ... Nevertheless ... (2018)... the 20 ... (Schleussner et al., ...) ... were ... in ... 2°C ... Global drivers of ... (2018)... Sources ... these ... (Crutzen et al.)... (2016)... follicle development and ovulation in hens, ... (Wong et al., 2014)... Not ... , ... also ... ; ... dry and hot conditions ... over ... (2017)... In terms of cumulative ... fisheries ... low latitude surface temperature will lead to multiple levels of impact on a variety of organisms, from phytoplankton to marine mammals, with some of the most dramatic changes occurring in the Arctic Ocean and western Antarctic Peninsula (Turner et al., 2014, 2017b; Steinberg et al., 2015; Piñones and Fedorov, 2016)624. Coastal flooding is projected to cost thousands of billions of USD annually, with damage costs under constant protection estimated at 0.3–5.0% of global gross domestic product (GDP) in 2100 under an RCP2.6 scenario (Hinkel et al., 2014)752. There is a lack of precise, quantitative studies of projected impacts of SLR at 1.5°C and 2°C. (Yumashev et al., 2017)1069. Regions that are projected to benefit most robustly from restricted warming include the Mediterranean and southern Africa (Section 3.3.4). Climate change is projected to directly affect yield quantity and quality (low confidence), as well as indirectly influencing the livestock sector through feed quality changes and spread of pests and diseases (Kipling et al., 2016)899 (high confidence). Together with local stresses (Halpern et al., 2015)560, climate change poses a major threat to an increasing number of ocean ecosystems (e.g., warm water coral reefs; virtually certain, WGII AR5) and consequently to many coastal communities that depend on marine resources for food, livelihoods and a safe place to live. Aedes (mosquito) vector for dengue fever, chikungunya, yellow fever and Zika virus: Projections of the geographic distribution of Aedes aegypti and Ae. albopictus (principal vectors) differ depending on ... (e.g., Tjaden et al., 2017)... (2014)1013 ... Tropical ... (Kumar et al., 2018) ... . Changes in the prevalence of dengue fever generally conclude that there will be an increase in the number of mosquitos and a larger geographic range at 1.5°C, and they suggest that more individuals will be at risk of dengue fever, with regional differences (high confidence) (Fischer et al., 2011, 2013; Colón-González et al., 2013, 2018; Bouzid et al., 2014; Ogden et al., 2014a; Mweya et al., 2016)1012. A comprehensive discussion of risk and adaptation options for all natural and human systems is not possible in this chapter, however, the set of risks assessed in Section 3.4 are ... (WGII AR5) ... Losses exceeding 40% of ... (2015)... The ... sectors and ... avoided. The long-term ... (2018)... 2.7°C of ... 2°C ... with a 3.5% increase ... compared to the prior of ... at the end of the century, 20 ... (Mitchell et al., 2017)... compared to the impacts in the ... (2016)... a 10–40% ... In the Caribbean region (Karnauskas et al., 2018)1219, and may enhance the ability of SIDS to adapt (Benjamin and Thomas, 2016)1220. A critical issue for developing countries in particular is that advantages in some sectors are projected to be offset by increasing mitigation costs (Rogelj et al., 2013)... W. High-latitude fisheries are not only influenced by the effect of temperature on NPP but are also strongly influenced by the direct effects of temperature on fish and fisheries (Section 3.4.4.9; Barange et al., 2014; Pörtner et al., 2014; Weatherdon et al., 2016)570. At higher degrees of warming, in the order of 3°C, a different type of tipping point in permafrost may be reached. Through projected increases in rainfall and runoff, the ... which ... (2018)... at ... 1.5°C ... Kuwait, ... compared to (2005)... Taken together, ... and the inertia of the ... per ... , and ... (Gallup et al., 1999). For example, in Ethiopia, capital expenditures through 2050 might either decrease by approximately 3% under extreme wet scenarios or increase by up to 4% under a severe dry scenario (Block and Strzepek, 2012)1051. Increased atmospheric CO2 concentrations are expected to drive further increases in the land carbon sink (Ciais et al., 2013; Schimel et al., 2015)503, which could persist for centuries (Pugh et al., 2016)504. Other climate-sensitive health outcomes, such as diarrhoeal diseases, mental health issues and the full range of sources of poor air quality, were not considered because of the lack of projections of how risk could change at 1.5°C and 2°C. Oxygen levels in the ocean are maintained by a series of processes including ocean mixing, photosynthesis, respiration and solubility (Boyd et al., 2014, 2015; Pörtner et al., 2014; Breitburg et al., 2018)610. Water resource availability for livestock is expected to decrease owing to increased runoff and reduced groundwater resources. A large portion of rainfall over the world's largest rainforests is recirculated (e.g., Lenton et al., 2008)1245, which raises the concern that deforestation may trigger a threshold in reduced forest cover, leading to pronounced forest dieback. Extreme temperatures will also increase with ... potential for elevated impacts as a result of comparably small natural variability (Beyer et al., 2017a)824. Impact studies for major tropical cereals reveal that yields of maize and wheat begin to decline with 1°C to 2°C of local warming in the tropics. At approximately 1.5°C of global warming (2030), climate change is expected to be a poverty multiplier that makes poor people poorer and increases the poverty head count (Hallegatte et al., 2016; Hallegatte and Rozenberg, 2017)1073. At global warming of 1.5°C–2°C above pre-industrial levels, seagrasses are projected to reach moderate to high levels of risk (e.g., damage resulting from sea level rise, erosion, extreme temperatures, and storms), while risks to mangroves from climate change are projected to remain moderate (e.g., not keeping up with sea level rise, and more frequent heat stress mortality) although there is low certainty as to when or if this important ecosystem is likely to transition to higher levels of additional risk from climate change (Figure 3.18). In terms of sea level rise, by 2150, roughly 60,000 fewer people living in SIDS will be exposed in 1.5°C than in a 2°C world (Rasmussen et al., 2018)1218. Such events reorganize the distribution of regions of organized convection and affect weather patterns across the Pacific. Nineteen-thousand ... in response to ... and 1.5°C ... Indeed, a warming to ... and ... (2014)... impacts ... the ... also ... the ... is ... temperatures (McFarland et al., 2015)1059. Moreover, there is no strong direct relationship between the robustness of climate attribution and that of impact attribution (Hansen and Stone, 2016)371. Under RCP4.5 and RCP8.5, the annual energy yield of European wind farms as a whole, as projected to be installed by 2050, will remain stable (±5 yield for all climate models). Increasing temperatures will decrease the thermal efficiency of fossil, nuclear, biomass and solar power generation technologies, as well as buildings and other infrastructure (Arent et al., 2014)1050. While Antarctica is not permanently populated, the ramifications of changes to the productivity of vast regions, such as the Southern Ocean, have substantial implications for ocean foodwebs and fisheries globally. In the North Sea Basin, large-scale commercial shipping might not be possible until 2030 for bulk shipping and until 2050 for container ships under RCP8.5. A 0.05% increase in mean temperature is projected (from an increase in sheet temperature) is to elevated CO2 and non-CO2 emissions, associated with additional economic growth enabled by the North Sea Route. This phenological plasticity is not always adaptive and must be interpreted cautiously (Duputié et al., 2015)469, and considered in the context of accompanying changes in climate variability (e.g., increased risk of frost damage for plants or earlier emergence of insects resulting in mortality during cold spells). Fisheries and aquatic production systems (aquaculture) face similar challenges to those of crop and livestock sectors (Section 3.4.6.3; Asiedu et al., 2017a, b; Utete et al., 2018)895. Table summarizes the chapter text and with references supporting table entries found in the main chapter text. Globally, gross hydropower potential is projected to increase (by 2.4% under RCP2.6 and by 6.3% under RCP8.5 for the 2080s), with the most growth expected in Central Africa, Asia, India and northern high latitudes (van Vliet et al., 2016)1055. This implies that coastal areas currently protected by mangroves may experience growing risks over time. Limiting global warming to 1.5°C would therefore lead to a reduction of risks by the end of the century in areas that are sensitive to changes in ... regional water resources ... (Section 3.4.4) ... . Heat stress is projected ... in ... 2°C (Kovats et al., 2014) ... . Peng ... productivity and the soil quality (Ilsiso et al., 2017)499. The number of people at risk increases by approximately 18% in 2030 if a 2°C scenario is used and by 266% in 2300 if an RCP8.5 scenario is considered (Nicholls et al., 2018)750. The export of organic carbon to deeper layers of the ocean increases as NPP changes in the surface ocean, for example, with implications for foodwebs and oxygen levels (Boyd et al., 2014; Sydeman et al., 2014; Altieri and Gedan, 2015; Bakun et al., 2015)611. Salinization is projected to impact freshwater sources and pose risks to ecosystems and human systems (Section 3.4.5.4; Wong et al., 2014)786. These changes may be classified as incremental (i.e., they represent ... (Crosman et al., ...) ...), and ... can be ... as ... the ... sea ... level ... this threshold ... (Tebaldi et al., ...) ... 1,000 to 2,000 ... (2017)... high confidence). For example, the herbivorous sea urchin Centrostephanus rodgersii has been reached Tasmania from the Australian mainland, where it was previously unknown, owing to a strengthening of the East Australian Current (EAC) that connects the two regions (high confidence) (Ling et al., 2009)589. (2014)... 50% of global coral reefs are projected to be lost as a result ... (Frieler et al., 2013) ... , and ... and ... 2°C ... global warming ... (Schleussner et al., ...) ... at 1.5°C. Approximately 70–90% of global coral reefs are projected to be at risk of long-term degradation due to coral bleaching at 1.5°C, with this value increasing to 99% at 2°C (Frieler et al., 2013; Schleussner et al., 2016b)... Christiansen, 2016; Brooks and Fröhlich, 2016; Burrows and Kinney, 2016; Reyer et al., 2017c; Wahl et al., 2017)1091. The decline in the number of former Olympic Winter Games host locations that could ensure climatically reliable for future Olympic and Paralympic Winter Games has been projected to be much greater under scenarios warmer than 2°C (Scott et al., 2015; Jacob et al., 2018)1042. WGII AR5 assessed that global flood risk will increase in the future, partly owing to climate change, with projected changes in the frequency of droughts longer than 12 months being more uncertain because these depend on accumulated precipitation over long periods (Jiménez Cisneros et al., 2014)401. In AR5, evidence of a climate change signal was limited, with more evidence of impacts of climate change on the places where indigenous people live and use traditional ecological knowledge (Olsson et al., 2014)1072. Existing adaptation interventions can be strengthened through greater flexibility of institutions dealing with land-use planning and agricultural production, improved monitoring of saline intrusion, and the installation of early warning systems that can be accessed by the local authorities or farmers (Renaud et al., 2015; Hoang et al., 2016; Leigh et al., 2017)... (2016)... cost of ... The loss of ... wetlands is ... in ... (Schuerch et al., 2018)... groundwater drought frequency has changed over the last few decades, although groundwater is projected to decrease as climate changes ... demand (Jiménez Cisneros et al., 2014)398. Reducing coastal pollution, and consequently the penetration of organic carbon into deep benthic habitats, is expected to reduce the loss of oxygen in coastal waters and hypoxic areas in general (high confidence) (Breitburg et al., 2018)... increase tourism ... Scott et al. ... and ... Robinson et al. (2016)... Most projection studies do not ... in ... and ... also to ... (Arnell and Gosling, 2016)... Lyme disease and other tick-borne diseases in parts of North America and Europe (Ogden et al., 2014b; Levi et al., 2015)1015. (2016b)875 projected that constraining warming to 1.5°C rather than 2°C would avoid significant risks of declining tropical crop yield in West Africa, Southeast Asia, and Central and South America. A recent observation-based study likewise showed that a 0.5°C increase in global mean temperature has had a detectable effect on changes in precipitation extremes at the global scale (Schleussner et al., 2017)1126, thus suggesting that there would be detectable differences in heavy precipitation at 1.5°C and 2°C of global warming. For in-depth discussion and uncertainty estimates, see Meehl et al. Sectoral climate change risk also aligns strongly with regions where tourism growth is projected to be the strongest over the coming decades, including sub-Saharan Africa and South Asia, pointing to an important potential barrier to tourism development. Some ecosystems, such as those from bathyal areas (i.e., 200–3000 m below the surface), are likely to undergo very large reductions in pH by the year 2100 (0.29 to 0.37 pH units), yet evidence of how deep-water ecosystems will respond is currently limited despite the potential planetary importance of these areas (low to medium confidence) (Hughes and Narayanaswamy, 2013; Sweetman et al., 2017)609. Small islands are impacted by multiple climatic stressors, with SLR being a more important stressor to some islands than others (Sections 3.4.10, 4.3.5.6, 5.2.1, 5.5.3.3, Boxes 3.5, 4.3 and 5.3). These adaptation options are broad and indirect, and the only other solution at large scale is to reduce the entry of CO2 into the ocean. Burke et al., 2015b, 2018)1162. Slower rates of rise due to climate change mitigation may provide a greater opportunity for adaptation (medium confidence), which could substantially reduce impacts. Limiting global warming to 1.5°C during the course of the century may, therefore, open the window for many ecosystems to adapt or reassort geographically. Lifestyle | Daily Life | News | The Sydney Morning HeraldWe're sorry, this feature is currently unavailable. Air quality: Because ozone formation is temperature dependent, projections focusing only on temperature increase generally conclude that ozone-related mortality will increase with additional warming, with the risks higher at 2°C than at 1.5°C (high confidence) (Supplementary Material 3.SM, Table 3.SM.9; Heal et al., 2013; Tainio et al., 2013; Likhvar et al., 2015; Silva et al., 2016; Dionisio et al., 2017; J.Y. Lee et al., 2017)1008. When drained, this carbon is released to the atmosphere. Elevated CO2 concentrations of 568–590 ppm (a range that corresponds approximately to RCP6 in the 2080s and hence a warming of 2.3°C–3.3°C (van Vuuren et al., 2011a872, AR5 WGI Table 12.2) alone reduced the protein, micronutrient and B vitamin content of the 18 rice cultivars grown most widely in Southeast Asia, where it is a staple food source, by an amount sufficient to create nutrition-related health risks for 600 million people (Zhu et al., 2018)873. Risks are expected to accumulate at higher temperatures for bivalve molluscs, with very high risks expected at 1.8°C of warming or more. A case study from Jamaica revealed that the difference in heat stress for livestock between 1.5°C and 2°C of warming is likely to exceed the limits for normal thermoregulation and result in persistent heat stress for these animals (Lallo et al., 2018)1262. New literature since AR5 has provided a closer focus on the comparative levels of risk to coral reefs at 1.5°C versus 2°C of global warming. Adaptation imperatives and costs in the Mekong will be higher under higher temperatures and associated impacts on agriculture and aquaculture, hazard exposure, and infrastructure. Biome transformation may in some cases be associated with novel climates and ecological communities (Prober et al., 2012)454. Both of these processes facilitate the establishment of woody species in tundra areas. In summary, in the absence of adaptation, in most cases, warming of 2°C poses greater risks to urban areas than warming of 1.5°C, depending on the vulnerability of the location (coastal or non-coastal) (high confidence), businesses, infrastructure sectors (energy, water and transport), levels of poverty, and the mix of formal and informal settlements. Temperature: It is expected that further increases in the number of warm days/nights and decreases in the number of cold days/nights, and an increase in the overall temperature of hot and cold extremes would occur under 1.5°C of global warming relative to pre-industrial levels (high confidence) compared to under the present-day climate (1°C of warming), with further changes occurring towards 2°C of global warming (Section 3.3). (2014)1109. There is also interest in ex situ conservation approaches involving the restoration of corals via aquaculture (Shafir et al., 2006; Rinkevich, 2014)659 or the use of 'assisted evolution' to help corals adapt to changing sea temperatures (van Oppen et al., 2015, 2017)660, although there are numerous challenges that must be surpassed if these approaches are to be cost-effective responses to preserving coral reefs under rapid climate change (low confidence) (Hoegh-Guldberg, 2012, 2014a; Bayraktarov et al., 2016)661. At 2°C and higher levels of warming (e.g., RCP8.5), however, there are high risks of failure to meet SDGs such as eradicating poverty and hunger, providing safe water, reducing inequality and protecting ecosystems, and these risks are projected to become severe and widespread if warming increases further to about 3°C (medium confidence) (Section 5.2.3). Substantial losses of Arctic Ocean summer ice were projected in WGI AR5 for global warming of 1.6°C, with a nearly ice-free Arctic Ocean being projected for global warming of more than 2.6°C. At a fundamental level, the pressure gradient between the Indian Ocean and Asian continent determines the strength of the Asian monsoon. (2016)642. The time scale for eventual loss of the ice sheets varies between millennia and tens of millennia and assumes constant surface temperature forcing during this period. Associated aggregate economic damages in decadal increments through the year 2100 are estimated in terms of the percentage loss of GDP at the median, 5th percentile and 95th percentile transient temperature (Hsiang et al., 2017)1271. Global economic impacts: WGII AR5 found that overall global aggregate impacts become moderate at 1°C–2°C of warming, and the transition to moderate risk levels was therefore located at 1.6°C above pre-industrial levels. In addition, anthropogenic carbon dioxide has decreased ocean pH and affected the concentration of ions in seawater such as carbonate (Sections 3.3.10 and 3.4.4.5), both over a similar depth range. In the second study, Pretis et al. This subsection reviews tipping points across these three areas within the context of the different sensitivities to 1.5°C versus 2°C of global warming. Droughts: When considering the difference between precipitation and evaporation (P–E) as a function of global temperature changes, the subtropics generally display an overall trend towards drying, whilst the northern high latitudes display a robust response towards increased wetting (Section 3.3.4, Figure 3.12). Hence, constraining global warming to approximately 1.5°C would maintain the functioning of prairie pothole ecosystems in terms of their productivity and biodiversity, although a 20% increase of precipitation could offset 2°C of global warming (high confidence) (Johnson and Poiani, 2016)558. One of the important themes that emerged from AR5 is that previous assessments may have under-estimated the sensitivity of natural and human systems to climate change. One study since AR5 has shown that constraining global warming to 1.5°C would maintain the functioning of prairie pothole ecosystems in North America in terms of their productivity and biodiversity, whilst warming of 2°C would not do so (Johnson et al., 2016)1125. Large-scale reductions in maize crop yield, including the potential collapse of this crop in some regions, may exist under 3°C or more of global warming (low confidence) (e.g., Thornton et al., 2011)1261. Production can also benefit from warming in higher latitudes, with more fertile soils, favouring crops, and grassland production, in contrast to the situation at low latitudes (Section 3.4.6), and similar benefits could arise for high-latitude fisheries production (high confidence) (Section 3.4.6.3). Increased ocean temperatures have intensified storms in some regions (Section 3.3.6), expanded the ocean volume and increased sea levels globally (Section 3.3.9), reduced the extent of polar summer sea ice (Section 3.3.8), and decreased the overall solubility of the ocean for oxygen (Section 3.3.10). Nitrogen, phosphorus and other nutrients will limit the terrestrial carbon cycle response to both elevated CO2 and altered climate (Goll et al., 2012; Yang et al., 2014; Wieder et al., 2015; Zaehle et al., 2015; Ellsworth et al., 2017)505. Adaptation to coastal change from SLR and other drivers is occurring today (high confidence) (see Cross-Chapter Box 9 in Chapter 4), including migration, ecosystem-based adaptation, raising infrastructure and defences, salt-tolerant food production, early warning systems, insurance and education (Section 5.4.2.1 of Wong et al., 2014)810. Climate trends also explain changes in the length of the growing season, with greater modifications found in the northern high-latitude areas (Qian et al., 2010; Mueller et al., 2015)864. Increased fire frequencies under global warming may interact with and accelerate deforestation, particularly during periods of El Niño-induced droughts (Lenton et al., 2008; Nobre et al., 2016)1248. Warm-water coral reefs face very high risks (Figure 3.18) from climate change. As a result, up to 10.4 million more people would be exposed to sea level rise at 2°C compared with 1.5°C in 2100 (medium confidence). The social, economic and environmental factors underlying migration are complex and varied; therefore, detecting the effect of observed climate change or assessing its possible magnitude with any degree of confidence is challenging (Cramer et al., 2014)1077. Projections of the impacts of climate change on leishmaniosis and Chagas disease indicate that climate change could increase or decrease future health burdens, with greater impacts occurring at higher degrees of warming (González et al., 2014; Ceccarelli and Rabinovich, 2015)1016. Cross-Chapter Box 6 in this chapter highlights that at 2°C of warming, new literature shows that risks of food shortage are projected to emerge in the African Sahel, the Mediterranean, central Europe, the Amazon, and western and southern Africa, and that these are much larger than the corresponding risks at 1.5°C. The Fynbos and succulent Karoo biomes of South Africa are threatened systems that were assessed in AR5. Substantial negative impacts are also projected for sorghum suitability in the western Sahel (Läderach et al., 2013; Sultan and Gaetani, 2016)1198. Liu et al., 2017)377. Global warming of 3°C is projected to reduce the extent of tropical rainforest in Central America, with biomass being reduced by about 40%, which can lead to a large replacement of rainforest by savanna and grassland (Lyra et al., 2017)1249. (2012)508 found a net loss of carbon in extra-tropical regions and the largest spread across model results in the tropics. Observed adaptation to multiple drivers of coastal change, including SLR, includes retreat (migration), accommodation and defence. Jevrejeva et al. Since AR5, planned and autonomous adaptation and forward planning have become more widespread (Araos et al., 2016; Nicholls et al., 2018)814, but continued efforts are required as many localities are in the early stages of adapting or are not adapting at all (Cross-Chapter Box 9 in Chapter 4; Araos et al., 2016)815. At 1.5°C, limits to adaptation will be reached for several key impacts in SIDS, resulting in residual impacts, as well as loss and damage (Section 1.1, Cross-Chapter Box 12 in Chapter 5). The existing studies have found few differences in projected risks posed on sediment load under 1.5°C and 2°C (low confidence) (Cousins et al., 2015; Shrestha et al., 2016)445. The median reduction in annual runoff is projected to almost double from about 9% (likely range 4.5–15.5%) at 1.5°C to 17% (likely range 8–25%) at 2°C (Schleussner et al., 2016b)1190. A large number of threatened systems, including mountain ecosystems, highly biodiverse tropical wet and dry forests, deserts, freshwater systems and dune systems. There is very high confidence that each additional unit of warming could increase heat-related morbidity and mortality, and that adaptation would reduce the magnitude of impacts. AR5 identified a large number of threatened systems, including mountain ecosystems, highly biodiverse tropical wet and dry forests, deserts, freshwater systems and dune systems. An increase in global warming from 2°C to 2040 would result in further yield losses and changes to crops (i.e., maize, sorghum, wheat, millet, groundnut and cassava). These risks to marine ecosystems are projected to become greater at 1.5°C and more so at 2°C (medium confidence) (Cheung et al., 2009; Pereira et al., 2010; Pinsky et al., 2013; Burrows et al., 2014)591. Warmer and drier conditions in particular facilitate fire, drought and insect disturbances, while warmer and wetter conditions increase disturbances from wind and pathogens (Seidl et al., 2017)528. High levels of adaptation are expected to be required to prevent impacts on food security and livelihoods in coastal populations (medium confidence). Under emissions scenarios, assuming there is no adaptation or protection at all (Sloth, [5th–95th percentiles]) Year 2050 2100 2200 2300 1.5°C Temperature rise ...

Storylines ... Temperature rise ... (millions) ... SSP1–5 (millions) ...

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GMST) has reached about 1°C above the pre-industrial period, and oceans have rapidly warmed from the ocean surface to the deep sea (high confidence) (Sections 3.3.7; Hughes and Narayanaswamy, 2013; Levin and Le Bris, 2015; Yasuhara and Danovaro, 2016; Sweetman et al., 2017)563. However, wind farm yields are projected to undergo changes of up to 15% in magnitude at country and local scales and of 5% at the regional scale (Tobin et al., 2015, 2016)1063. Tropical coral reefs, provide effective protection by dissipating about 97% of wave energy, with 86% of the energy being dissipated by reef crests alone (Ferrario et al., 2014; Narayan et al., 2016)688. Assuming constant population sizes, countries representing 73% of the world population will experience increasing flood risk, with an average increase of 580% at 4°C compared to the impact simulated over the baseline period 1976–2005. Assignment Essay Help Our professional team of writers ensures top-quality custom essay writing services.

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to do this at present, so the original, simple approach has been used here. This earlier study has now been updated and expanded to incorporate 105,501 species, including 19,848 insects, and new findings indicate that warming of 2°C by 2100 would lead to projected bioclimatic range losses of >50% in 18% (6–35%) of the 19,848 insects species, 8% (4–16%) of the 12,429 vertebrate species, and 16% (9–28%) of the 73,224 plant species studied (Warren et al., 2018a)477. Working Group II of AR5 concluded that there is little or no observational evidence that soil erosion and sediment load have been altered significantly by climate change (low to medium confidence) (Jiménez Cisneros et al., 2014)438. Temporary gains in the productivity of high-latitude fisheries are offset by a growing number of examples from low and mid-latitudes where increases in sea temperature are driving decreases in NPP, owing to the direct effects of elevated temperatures and/or reduced ocean mixing from reduced ocean upwelling, that is, increased stratification (low-medium confidence) (Cheung et al., 2010; Ainsworth et al., 2011; Lam et al., 2012, 2014, 2016; Bopp et al., 2013; Boyd et al., 2014; Chust et al., 2014; Hoegh-Guldberg et al., 2014; Poloczanska et al., 2014; Pörtner et al., 2014; Signorini et al., 2015)571. The degradation of ecosystem services by climate change and ocean acidification have generally been excluded from previous global aggregate economic analyses. Since AR5, observed impacts on tourism markets and destination communities continue to be not well analysed, despite the many analogue conditions (e.g., heatwaves, major hurricanes, wild fires, reduced snow pack, coastal erosion and coral reef bleaching) that are anticipated to occur more frequently with climate change. New evidence suggests moderate impacts on the global aggregate economy and global biodiversity by 1.5°C of warming, suggesting a lowering of the temperature level for the transition to moderate risk to 1.5°C (Figure 3.21). A single model projection (Drijfhout et al., 2015)1236 suggested that higher temperatures may induce a smaller ice fraction in soils in the tundra, leading to more rapidly warming soils and a positive feedback mechanism that results in permafrost collapse (low confidence). Risks to tropical crop yields in West Africa, Southeast Asia and Central and South America could be extensive Oppressive temperatures and accumulated heatwave duration very likely to directly impact human health, mortality and productivity Substantial reductions in crop yield very likely Small islands Land of 60,000 less people exposed by 2150 on SIDS compared to impacts under 2°C of global warming Risks for coastal flooding reduced by 20–80% for SIDS compared to 2°C of global warming Freshwater stress reduced by 25% Increase in the number of warm days for SIDS in the tropics Persistent heat stress in cattle avoided Loss of 70–90% of coral reefs Tens of thousands of people displaced owing to inundation of SIDSHigh risks for coastal floodingFreshwater stress reduced by 25% compared to 2°C of global warming Freshwater stress from projected aridity Further increase of about 70 warm days per year Persistent heat stress in cattle in SIDS Loss of most coral reefs and weaker remaining structures owing to ocean acidification Substantial and widespread impacts through inundation of SIDS, coastal flooding, freshwater stress, persistent heat stress and loss of most coral reefs (very likely) Fynbos biome About 30% of suitable climate area lost (medium confidence) Increased losses (about 45%) of suitable climate area (medium confidence) Up to 80% of suitable climate area lost (medium confidence) Tipping points refer to critical thresholds in a system that, when exceeded, can lead to a significant change in the state of the system, often with an understanding that the change is irreversible. Even at 1.5°C of global warming, the compounding impacts of changes in rainfall, temperature, tropical cyclones and sea level are likely to be significant across multiple natural and human systems. This section reviews recent literature that has estimated the economic benefits of constraining global warming to 1.5°C compared to 2°C. A substantial part of the global tourist industry is associated with tropical coastal regions and islands, where tropical coral reefs and related ecosystems play important roles (Section 3.4.9.1) (medium confidence). Taken together, the findings of studies on the effects of changes in temperature, precipitation, CO2 concentration and extreme weather events indicate that a global warming of 2°C is projected to result in a greater reduction in global crop yields and global nutrition than global warming of 1.5°C (high confidence; Section 3.6). Countries with the highest risks and where tourism represents a significant proportion of the national economy (i.e., more than 15% of GDP) include many SIDS and least developed countries. Region and/or Phenomenon Warming of 1.5°C or less Warming of 1.5°C–2°C Warming of 2°C–3°C Arctic sea ice Arctic summer sea ice is likely to be maintained Habitat losses for organisms such as polar bears, whales, seals and sea birds Benefits for Arctic fisheries The risk of an ice-free Arctic in summer is about 50% or higher Habitat losses for organisms such as polar bears, whales,seals and sea birds may be critical if summers are ice free Benefits for Arctic fisheries The Arctic is very likely to be ice free in summer Critical habitat losses for organisms such as polar bears, whales, seals and sea birds Benefits for Arctic fisheries Arctic land regions Cold extremes warm by a factor of 2–3, reaching up to 4.5°C (high confidence) Biome shifts in the tundra and permafrost deterioration are likely Cold extremes warm by as much as 8°C (high confidence) Larger intrusions of trees and shrubs in the tundra than under 1.5°C of warming are likely; larger but constrained losses in permafrost are likely Drastic regional warming is very likely A collapse in permafrost may occur (low confidence); a drastic biome shift from tundra to boreal forest is possible (low confidence) Alpine regions Severe shifts in biomes are likely Even more severe shifts are likely Critical losses in alpine habitats are likely Southeast Asia Risks for increased flooding related to sea level rise Increases in heavy precipitation events Significant risks of crop yield reductions are avoided Higher risks of increased flooding related to sea level rise (medium confidence) Stronger increases in heavy precipitation events (medium confidence) One-third decline in per capita crop production (medium confidence) Substantial increases in risks related to flooding from sea level rise Substantial increase in heavy precipitation and high-flow events Substantial reductions in crop yield Mediterranean Increase in probability of extreme drought Medium confidence in reduction in runoff of about 9% (likely range 4.5–15.5%) Risk of water deficit (medium confidence) Robust increase in probability of extreme drought (medium confidence) Medium confidence in further reductions (about 17%) in runoff (likely range 8–28%) Higher risks of water deficit (medium confidence) Robust and large increases in extreme drought. By analysing the differences in results with and without flood protection standards, Winsemius et al. Globally, millions of people may be at risk from sea level rise (SLR) during the 21st century (Hinkel et al., 2014; Hauer et al., 2016)1128, particularly if adaptation is limited. Warming has resulted in positive effects on crop yield in some high-latitude areas (Jaggard et al., 2007; Supit et al., 2010; Gregory and Marshall, 2012; C. Health detection and attribution studies conducted since AR5 have provided evidence, using multistep attribution, that climate change is negatively affecting adverse health outcomes associated with heatwaves, Lyme disease in Canada, and Vibrio emergence in northern Europe (Mitchell, 2016; Mitchell et al., 2016; Ebi et al., 2017)995. Risks to unique and threatened terrestrial ecosystems are generally projected to be higher under warming of 2°C compared to 1.5°C (Section 3.5.2.1), while at the global scale severe and widespread risks are projected to occur by 2°C of warming. The main climate impacts in the Mekong are expected to be on ecosystem health, through salinity intrusion, biomass reduction and biodiversity losses (Le Dang et al., 2013; Smajgl et al., 2015)976; agricultural productivity and food security (Smajgl et al., 2015)977; livelihoods such as fishing and farming (D. The economic damage in the United States from climate change is estimated to be, on average, roughly 1.2% cost of GDP per year per 1°C increase under RCP8.5 (Hsiang et al., 2017)1052. Moreover, southern Africa is likely to generally become drier with reduced water availability under low mitigation (Niang et al., 2014; Engelbrecht et al., 2015; Karl et al., 2015; James et al., 2017)1206, with this particular risk being prominent under 2°C of global warming and even under 1.5°C (Gerten et al., 2013)1207. There is some evidence that observed impacts on tourism assets, such as environmental and cultural heritage, are leading to the development of 'last chance to see' tourism markets, where travellers visit destinations before they are substantially degraded by climate change impacts or to view the impacts of climate change on landscapes (Lemelin et al., 2012; Stewart et al., 2016; Piggott-McKellar and McNamara, 2017)1037. Migration (internal and international) has always been important on small islands (Farbotko and Lazrus, 2012; Weir et al., 2017)769, with changing environmental and weather conditions being just one factor in the choice to migrate (Sections 3.4.10, 4.3.5.6 and 5.3.2; Campbell and Warrick, 2014)770. In some regions, cold-related mortality is projected to decrease with increasing temperatures, although increases in heat-related mortality generally are projected to outweigh any reductions in cold-related mortality with warmer winters, with the heat-related risks increasing with greater degrees of warming (Huang et al., 2012; Hajat et al., 2014; Vardoulakis et al., 2014; Gasparrini et al., 2015; Huynen and Martens, 2015; Schwartz et al., 2015)1003. Some projections of wetland change, with magnitudes (but not necessarily rates or timing) of SLR analogous to 1.5°C and 2°C of global warming, indicate a net loss of wetlands in the 21st century (e.g., Blankespoor et al., 2014; Cui et al., 2015; Arnell et al., 2016; Crosby et al., 2016)801, whilst others report a net gain with wetland transgression (e.g. Raabe and Stumpf, 2016802 in the Gulf of Mexico). We strive to ensure that every paper is crafted with getting you the highest grade in mind. Future changes in rainfall, especially dry season length, will determine responses of the Amazon forest (Good et al., 2013)535. Under the Shared Socio-Economic Pathway (SSP)2 population scenario, about 8% of the global population is projected to experience a severe reduction in water resources under warming of 1.7°C in 2021–2040, increasing to 14% of the population under 2.7°C in 2043–2071, based on the criteria of discharge reduction of either >20% or >1 standard deviation (Schewe et al., 2014)385. Projecting impacts in deltas needs an understanding of both fluvial discharge and SLR, making projections complex because the drivers operate on different temporal and spatial scales (Zaman et al., 2017; Brown et al., 2018b)789. Climate change threatens the capacity to achieve SDG 2 and could reverse the progress made already. A study using the single ecosystem model LPJmL (Gerten et al., 2013)452 illustrated that biome shifts in the Arctic, Tibet, Himalayas, southern Africa and Australia would be avoided by constraining warming to 1.5°C compared with 2°C (Figure 3.16b). Increasing temperatures are projected to directly impact climate-dependent tourism markets, including sun, beach and snow sports tourism, with lesser risks for other tourism markets that are less climate sensitive (high confidence). In fact, even if global warming is restricted to below 2°C, there could be a substantial increase in the occurrence of deadly heatwaves in cities if urban heat island effects are considered, with impacts being similar at 1.5°C and 2°C but substantially larger than under the present climate (Matthews et al., 2017)1256. UNESCO (2011)375 concluded that climate change can alter the availability of water and threaten water security. Under 2°C of global warming, regional warming in drylands is projected to be 3.2°C–4°C, and under 1.5°C of global warming, mean warming in drylands is projected to still be about 3°C. Recent trends confirm this finding; for example, the spatial and interspecific variance in bird populations in Europe and North America since 1980 were found to be well predicted by trends in climate suitability (Stephens et al., 2016)472. Shell dissolution, for example, has increased by 19–26% in both nearshore and offshore populations since the pre-industrial period (Feely et al., 2016)670. The regional economic benefits that could be obtained by limiting the global temperature increase to 1.5°C of warming, rather than 2°C or higher levels, are discussed in Section 3.5.3 in the light of the five RFCs explored in Section 3.5.2. Climate change hotspots that could be avoided or reduced by achieving the 1.5°C target are summarized in Section 3.5.4. The section concludes with a discussion of regional tipping points that could be avoided at 1.5°C compared to higher degrees of global warming (Section 3.5.5). These changes are associated with increases in maximum wind speed, wave height and the inundation, although trends in these variables vary from region to region (Section 3.3.5). Risks due to climatic change are unevenly distributed and are generally greater at lower latitudes and for disadvantaged people and communities in countries at all levels of development. The transition from undetectable to moderate risk (related to RFCs 3 and 4), shown as white to yellow in Figure 3.20, is based on AR5 WGII Chapter 7, which indicated with high confidence that climate change impacts on crop yields have been detected and attributed to climate change, and the current assessment has provided further evidence to confirm this (Section 3.4.6). The original expert group's assessment (Supplementary Material 3.SM.3.2) was used as input for this new assessment, which focuses on the implications of global warming of 1.5°C as compared to 2°C. These statistics imply a tipping point in the extent and scale of heatwave impacts. Soil carbon storage is expected to be larger if global warming is restricted to 1.5°C, although some of the associated changes will be countered by enhanced gross primary production due to elevated CO2 concentrations (i.e., the 'fertilization effect') and higher temperatures, especially at mid-and high latitudes (medium confidence). The elements included are supported by a substantive enough body of literature providing at least medium confidence in the assessment. Figure 3.17 shows different responses of the terrestrial carbon cycle to climate change in different regions. Temperature has had a positive and statistically significant effect on outmigration over recent decades in 163 countries, but only for agriculture-dependent countries (R. Regional dry spells are projected to expand from 7% at 1.5°C to 11% at 2°C for the same reference period. The second group, bivalve molluscs (e.g., clams, oysters and mussels), are filter-feeding invertebrates. These changes can lead to increased phytoplankton productivity as a result of the increased concentration of dissolved nutrients. It is projected to lose about 20%, 45% and 80% of its current suitable climate area under 1°C, 2°C and 3°C of global warming, respectively, compared to 1961–1990 (high confidence) (Engelbrecht and Engelbrecht, 2016)545. This tipping point has been estimated to exist between 3°C and 4°C of global warming (low confidence) (Lucht et al., 2006; Kriegler et al., 2009)1255, but given the complexities of the various forcing mechanisms and feedback processes involved, this is thought to be an uncertain estimate. Wang et al., 2017)1152. For some sectors, there is a lack of precise evidence of change at 1.5°C and 2°C of global warming. Anderegg et al. Risks to coral reef recreational services from climate change are considered here, as well as in Box 3.5, Section 3.4.9 and Supplementary Material 3.SM.3.2. Adaptations to the broad global changes in carbon uptake by the ocean are limited and are discussed later in this report with respect to changes in NPP and implications for fishing industries. Consequently, the effect of global warming of 1.5°C versus 2°C must be considered in the light of multiple factors that may accumulate and interact over time to produce complex risks, hazards and impacts on human and natural systems. Maintaining the sediment supply to coastal areas would also assist mangroves in keeping pace with sea level rise (Shearman et al., 2013; Lovelock et al., 2015; Sasmito et al., 2016)662. (2018)417 estimated damage from flooding in Europe for the baseline period (1976–2005) at 5 billion euro of losses annually, with projections of relative changes in flood impacts that will rise with warming levels, from 116% at 1.5°C to 137% at 2°C. Strategies for reducing the impact of climate change on framework organisms include reducing stresses not directly related to climate change (e.g., coastal pollution, overfishing and destructive coastal development) in order to increase their ecological resilience in the face of accelerating climate change impacts (World Bank, 2013; Ellison, 2014; Anthony et al., 2015; Sierra-Correa and Cantera Kintz, 2015; Kroon et al., 2016; O'Leary et al., 2017)655, as well as protecting locations where organisms may be more robust (Palumbi et al., 2014)656 or less exposed to climate change (Bongaerts et al., 2010; van Hooidonk et al., 2013; Beyer et al., 2018)657. The number of studies utilising RCP scenarios at the regional or watershed scale have gradually increased since AR5 (e.g., Boehlert et al., 2015; Teshager et al., 2016; Marcinkowski et al., 2017)430. For example, record levels of sea ice loss in the Antarctic (Notz and Stroeve, 2016; Turner et al., 2017b)674 translate into a loss of habitat and hence reduced abundance of krill (Piñones and Fedorov, 2016)675, with negative ramifications for the seabirds and whales which feed on krill (Croxall, 1992; Trathan and Hill, 2016)676 (low-medium confidence). Additionally, projected total energy demands for heating and cooling at the global scale do not change much with increases in global mean surface temperature (GMST) of up to 2°C. However, recent publications based on observational and modelling evidence assessed that human emissions have substantially increased the probability of drought years in the Mediterranean region (Section 3.3.4). All of these changes contribute to disruption of ecosystem functioning and loss of cultural, provisioning and regulating services provided by these ecosystems to humans. The daily probability of exceeding the chloride standard for drinking water taken from Lake IJsselmeer (Andijk, the Netherlands) is projected to increase by a factor of about five at 2°C relative to the present-day warming level of 1°C since 1990 (Bonte and Zwolsman, 2010)433. Increased disturbance from fire, pests and heat-related mortality may affect, in particular, the southern boundary of boreal forests (medium confidence) (Gauthier et al., 2015)1253, with these impacts accruing with greater warming and thus impacts at 2°C would be expected to be greater than those at 1.5°C (medium confidence). The projected risks to human health of warming of 1.5°C and 2°C, based on studies of temperature-related morbidity and mortality, air quality and vector borne diseases assessed in and since AR5, are summarized in Supplementary Material 3.SM, Tables 3.SM.8, 3.SM.9 and 3.SM.10 (based on Ebi et al., 2018)997. Regarding Central America, Lyra et al. Further, Guiot and Cramer (2016)544 concluded that biome shifts unprecedented in the last 10,000 years can only be avoided if global warming is constrained to 1.5°C (medium confidence) – whilst 2°C of warming will result in a decrease of 12–15% of the Mediterranean biome area. This value was almost halved – with 50% greater reliability – when warming was constrained to 1.5°C. Aalto et al. Limited research on the risks of warming of 1.5°C and 2°C was conducted following AR5 for most key economic sectors and services, for livelihoods and poverty, and for rural areas. These impacts would be reduced considerably under 1.5°C but may be increased by escalating risks from climate-related extreme weather events and SLR (Sections 3.4.5.3, 3.4.9.4 and 3.5.3) Marine systems and associated livelihoods in SIDS face higher risks at 2°C compared to 1.5°C (medium to high confidence). By limiting warming to 1.5°C instead of 2°C in 2050, risks of coastal flooding (measured as the flood amplification factors for 100-year flood events) are reduced by 20–80% for SIDS (Rasmussen et al., 2018)1222. (2013)476 simulated climatically determined geographic range loss under 2°C and 4°C of global warming for 50,000 plant and animal species, accounting for uncertainty in climate projections and for the potential ability of species to disperse naturally in an attempt to track their geographically shifting climate envelope. There is medium confidence that livestock in southern Africa will experience increased water stress under both 1.5°C and 2°C of global warming, with negative economic consequences (e.g., Boone et al., 2018)1209. Some western Pacific islands and those in the northern Indian Ocean may see increased freshwater availability, while islands in most other regions are projected to see a substantial decline (Holding et al., 2016; Karnauskas et al., 2016)826. However, observations of trends in actual crop yields indicate that reductions as a result of climate change remain more common than crop yield increases, despite increased atmospheric CO2 concentrations (Porter et al., 2014)868. Given the sensitivity of corals to heat stress, even short periods of overshoot (i.e., decades) are expected to be extremely damaging to coral reefs. A steady increase in the risks associated with bivalve fisheries and aquaculture at mid-latitudes is coincident with increases in temperature, ocean acidification, introduced species, disease and other drivers (Lacoue-Labarthe et al., 2016; Clements and Chopin, 2017; Clements et al., 2017; Parker et al., 2017)921. Special attention needs to be given to strengthening social safety nets and livelihood assets whilst ensuring that adaptation plans are mainstreamed into broader development goals (Sok and Yu, 2015; Kim et al., 2017)991. Further, it is difficult to reliably separate the impacts of ocean warming and acidification. Moderate risks posed by 1.5°C of warming are expected to continue to increase with higher levels of warming (Sections 3.3.5 and 3.4.2), with projected risks being threefold the current risk in economic damages due to flooding in 19 countries for warming of 2°C, indicating a transition to high risk at this level (medium confidence). Indirect risks may arise from interactions between urban and natural systems. Generally, vulnerability to decreases in water and food availability is projected to be reduced at 1.5°C versus 2°C (Cheung et al., 2016a; Betts et al., 2018)945, especially in regions such as the African Sahel, the Mediterranean, central Europe, the Amazon, and western and southern Africa (medium confidence) (Sultan and Gaetani, 2016; Lehner et al., 2017; Betts et al., 2018; Byers et al., 2018; Rosenzweig et al., 2018)946. Further, temperature increases are projected to reduce the protein and micronutrient content of major cereal crops, which is expected to further affect food and nutritional security (Myers et al., 2017; Zhu et al., 2018)970. The first group of organisms, pteropods, are small pelagic molluscs that suspension feed and produce a calcium carbonate shell. General assessments of climate-related risks for mangroves prior to this special report concluded that they face greater risks from deforestation and unsustainable coastal development than from climate change (Alongi, 2008; Hoegh-Guldberg et al., 2014; Gattuso et al., 2015)1111. The approach of Oppenheimer et al. In addition, integrated coastal zone management should recognize the importance and economic expediency of using natural ecosystems such as mangroves and tropical coral reefs to protect coastal human communities (Arkema et al., 2013; Temmerman et al., 2013; Ferrario et al., 2014; Hinkel et al., 2014; Elliff and Silva, 2017)664. Insufficient consideration of the multiple drivers of conflict often leads to inconsistent associations being reported between climate change and conflict (e.g., Hsiang et al., 2013; Hsiang and Burke, 2014; Buhaug, 2015, 2016; Carleton and Hsiang, 2016; Carleton et al., 2016)1090. Pecl et al. The Baltic and Scandinavian countries are projected to experience the most positive impacts on hydropower production. Further, compound flooding (the combined risk of flooding from multiple sources) has increased significantly over the past century in major coastal cities (Wahl et al., 2015)809 and is likely to increase with further development and SLR at 1.5°C and 2°C unless adaptation is undertaken. There are considerable differences in the adaptation responses to tropical cyclones across SIDS (Cross-Chapter Box 11 in Chapter 4). Based on a World Bank (2013)1197 study for sub-Saharan Africa, a 1.5°C warming by 2030 might reduce the present maize cropping areas by 40%, rendering these areas no longer suitable for current cultivars. In fact, it has been estimated that an increase of the regional land mass albedo to 0.5 over India would represent a tipping point resulting in the collapse of the monsoon system (Lenton et al., 2008)1239. Although Rosenzweig et al. The projected risks of heat-related morbidity and mortality are generally higher under warming of 2°C than 1.5°C (high confidence), with projections of greater exposure to high ambient temperatures and increased morbidity and mortality (Section 3.4.7). This pattern is projected to persist for a century after stabilization at 1.5°C, thereby challenging the limits to adaptation, and thus indicates high risk even at the 1.5°C threshold. (2010)903 observed reduced milk yields and increased cow mortality as the result of heat stress on dairy cow production over some UK regions. (2014)877 found that an increase in air temperature negatively influences the modelled maize yield response by –0.5 t ha−1°C–1 and Challinor et al. As land masses warm faster than the oceans, a general strengthening of this gradient, and hence of monsoons, may be expected under global warming (e.g., Lenton et al., 2008)1238. Antarctic krill, Euphausia superba, are among the most abundant species in terms of mass and are consequently an essential component of polar foodwebs (Atkinson et al., 2009)667. However, there is limited literature on the risks of warming of 1.5°C and 2°C in urban areas. (2013)1228 to conclude that there is little evidence for a tipping point in the transition from perennial to seasonal ice cover. Climate projections include increased annual average temperatures and precipitation in the Mekong (Zhang et al., 2017)973, as well as increased flooding and related disaster risks (T.F. Smith et al., 2013; Ling et al., 2015; Zhang et al., 2016)974. Hence, the number of insect species projected to lose over half of their geographic range is reduced by two-thirds when warming is limited to 1.5°C compared with 2°C, while the number of vertebrate and plant species projected to lose over half of their geographic range is halved (Warren et al., 2018a)478 (medium confidence). Using an econometric analysis of the relationship between regional tourism demand and climate conditions, Ciscar et al. Deoxygenation is expected to have greater impacts as ocean warming and acidification increase (high confidence), with impacts being larger and more numerous than today (e.g., greater challenges for aquaculture and fisheries from hypoxia), and as the number of hypoxic areas continues to increase. Recent studies using independent complementary approaches have shown that there is a regional-scale threshold in the Mediterranean region between 1.5°C and 2°C of warming (Guiot and Cramer, 2016; Schleussner et al., 2016b)543. Li et al., 2016; Chung et al., 2017; Kendrovski et al., 2017; Mishra et al., 2017; Arnell et al., 2018; Mitchell et al., 2018b)999. In another study, an increase in precipitation anomalies from the long-term mean, was strongly associated with an increase in outmigration, whereas no significant effects of temperature anomalies were reported (Coniglio and Pesce, 2015)1082. Additional factors such as changes in albedo induced by aerosols and snow-cover change may also affect temperature gradients and consequently pressure gradients and the strength of the monsoon. (2017)880 indicated that the impact of temperature increases on crop failure of maize hybrids would be much greater as temperatures increase by 2°C compared to 1.5°C (high confidence). Greece, Spain and Bulgaria are projected to have the largest reduction at 2°C of warming (Tobin et al., 2018)395. Tropical populations may have to move distances greater than 1000 km if global mean temperature rises by 2°C from 2011–2030 to the end of the century. Church et al. An important reason why developed countries in the tropics and subtropics are projected to benefit substantially from restricting global warming to 1.5°C is that present-day temperatures in these regions are above the threshold thought to be optimal for economic production (M. Mitigation of these risks involves marine spatial planning, fisheries repair, sustainable aquaculture, and the development of alternative livelihoods (Kittinger, 2013; McClanahan et al., 2015; Song and Chuenpagdee, 2015; Weatherdon et al., 2016)930. These changes pose significant risks for poor people in both rural regions and urban areas of Southeast Asia (Section 3.4.10.1), with these risks being larger at 2°C of global warming compared to 1.5°C (medium confidence). Wave-driven coastal flooding risks for reef-lined islands may increase as a result of coral reef degradation and SLR (Quataert et al., 2015)844. Climate change impacts on livestock are expected to increase. Wang et al., 2016; Lemasson et al., 2017; Ong et al., 2017; X. Sea level rise is expected to be lower at 1.5°C than 2°C, lowering risks for coastal metropolitan agglomerations (Schleussner et al., 2016b)1033. Even if a wetter Sahel should materialize under 3°C of global warming (low confidence), it should be noted that there would be significant offsets in the form of strong regional warming and related adverse impacts on crop yield, livestock mortality and human health under such low mitigation futures (Engelbrecht et al., 2015; Sylla et al., 2016; Weber et al., 2018)1244. Chen et al., 2014)1180. The hydrological impacts of climate change in Europe are projected to increase in spatial extent and intensity across increasing global warming levels of 1.5°C, 2°C and 3°C (Donnelly et al., 2017)1130. There is also the potential for highly invasive species to become established in new areas as the climate changes (Murphy and Romanuk, 2014)483, but there is no literature that quantifies this possibility for 1.5°C of global warming. The degradation or loss of beach and coral reef assets is expected to increase risks for coastal tourism, particularly in subtropical and tropical regions (high confidence). Particularly vulnerable regions are Central and South America, Mediterranean Basin, South Africa, South Australia where the drought risk will increase (see Figure 3.12). Over the past century, substantial growth in populations, industrial and agricultural activities, and living standards have exacerbated water stress in many parts of the world, especially in semi-arid and arid regions such as California in the USA (AghaKouchak et al., 2015378; Mehran et al., 2015)379. (2014)1127. (2017)1122 presented a very similar assessment to that of WGII AR5, but with further discussion of the potential to create 'embers' specific to socio-economic scenarios in the future. Lana et al. While changes to ocean chemistry are likely to be of central importance, the literature on how climate change might influence ocean chemistry over the short and long term is limited (medium confidence). Under scenarios SSP1–5, Arnell and Lloyd-Hughes (2014)408 found that the number of people exposed to increased flooding in 2050 under warming of about 1.5°C could be reduced by 26–34 million compared to the number exposed to increased flooding associated with 2°C of warming. (2017)881 found that limiting warming to 1.5°C compared to 2°C would reduce maize yield losses over drylands. In accordance with an overall drying trend, an increasing drought risk is projected for Caribbean SIDS (Lehner et al., 2017)828, and moderate to extreme drought conditions are projected to be about 9% longer on average at 2°C versus 1.5°C for islands in this region (Taylor et al., 2018)829. In the case of 'less mobile' ecosystems (e.g., coral reefs, kelp forests and intertidal communities), shifts in biogeographical ranges may be limited, with mass mortalities and disease outbreaks increasing in frequency as the exposure to extreme temperatures increases (very high confidence) (Hoegh-Guldberg, 1999; Garrabou et al., 2009; Rivetti et al., 2014; Maynard et al., 2015; Krumhansl et al., 2016; Hughes et al., 2017b; see also Box 3.4)566. This has recently been seen for key ecosystems such as tropical coral reefs (Box 3.4), which have changed from coral-dominated ecosystems to assemblages dominated by other organisms such as seaweeds, with changes in associated organisms and ecosystem services (high confidence) (De'ath et al., 2012; Bozec et al., 2015; Cheal et al., 2017; Hoegh-Guldberg et al., 2017; Hughes et al., 2017a, b)581. In that last period (2000s), 1.1 billion people (17% of the global population) who mostly live in South and East Asia, North Africa and the Middle East faced serious water shortage and high water stress (Kummu et al., 2016)380. With the events of the last past three years in mind, risks are now considered to be undetectable to moderate (i.e., moderate risks now start at 1.3°C as opposed to 1.8°C; medium confidence). Whilst islands are highly vulnerable to SLR (high confidence), they are also reactive to change. Overall, Alfieri et al., (2017)405 reported that the projected changes are not homogeneously distributed across the world land surface. Migration: In AR5, the potential impacts of climate change on migration and displacement were identified as an emerging risk (Oppenheimer et al., 2014)1076. Further, a range of processes (Section 3.4.11) are acting synergistically, including factors not related to climate change, such as runoff and coastal eutrophication (e.g., from coastal farming and intensive aquaculture). A case study of Jamaica with lessons for other Caribbean SIDS demonstrated that the difference between 1.5°C and 2°C is likely to challenge livestock thermoregulation, resulting in persistent heat stress for livestock (Lallo et al., 2018)1223. In summary, warming of 2°C poses greater risks to human health than warming of 1.5°C, often with the risks varying regionally, with a few exceptions (high confidence). (2017)404 additionally concluded that the largest increases in flood risks would be found in the US, Asia, and Europe in general, while decreases would be found in only a few countries in eastern Europe and Africa. Burke et al., 2018; Pretis et al., 2018)1153. A global analysis of sea level rise (SLR) risk to 720 UNESCO Cultural World Heritage sites projected that about 47 sites might be affected under 1°C of warming, with this number increasing to 110 and 136 sites under 2°C and 3°C, respectively (Marzeion and Levermann, 2014)1045. (2015)493 demonstrated that total ecosystem respiration at the global scale has increased in response to increases in night-time temperature (1 PgC yr–1°C–1, P=0.02). Concentrations of oxygen in the ocean are declining (high confidence) owing to three main factors related to climate change: (i) heat-related stratification of the water column (less ventilation and mixing), (ii) reduced oxygen solubility as ocean temperature increases, and (iii) impacts of warming on biological processes that produce or consume oxygen such as photosynthesis and respiration (high confidence) (Bopp et al., 2013; Pörtner et al., 2014; Altieri and Gedan, 2015; Deutsch et al., 2015; Schmidtko et al., 2017; Shepherd et al., 2017; Breitburg et al., 2018)611. Climate change alone could force more than 3 million to 16 million people into extreme poverty, mostly through impacts on agriculture and food prices (Hallegatte et al., 2016; Hallegatte and Rozenberg, 2017)1074. Chen et al., 2014; Sun et al., 2015; He and Zhou, 2016; Daliakopoulos et al., 2017)860, and may make it possible to have more than one harvest per year (B. This assessment builds on the recent expert consensus of Gattuso et al. While many risks have been defined through laboratory and mesocosm experiments, there is a growing list of impacts from the field (medium confidence) that include community-scale impacts on bacterial assemblages and processes (Endres et al., 2014)600, coccolithophores (K.J.S. Meier et al., 2014)601, pteropods and polar foodwebs (Bednaršek et al., 2012, 2014)602, phytoplankton (Moy et al., 2009; Riebesell et al., 2013; Richier et al., 2014)603, benthic ecosystems (Hall-Spencer et al., 2008; Linares et al., 2015)604, seagrass (Garrard et al., 2014)605, and macroalgae (Webster et al., 2013; Ordonez et al., 2014)606, as well as excavating sponges, endolithic microalgae and reef-building corals (Dove et al., 2013; Reyes-Nivia et al., 2013; Fang et al., 2014)607, and coral reefs (Box 3.4; Fabricius et al., 2011; Allen et al., 2017)608. These trends are projected to become more pronounced at warming of 1.5°C, and more so at 2°C, above the pre-industrial period (Hoegh-Guldberg et al., 2007; Donner, 2009; Frieler et al., 2013; Horta E Costa et al., 2014; Vergés et al., 2014, 2016; Zarco-Perello et al., 2017)567 and are likely to result in decreases in marine biodiversity at the equator but increases in biodiversity at higher latitudes (Cheung et al., 2009; Burrows et al., 2014)568. It also provides habitat to a large number of organisms and ecosystems that provide goods and services worth trillions of USD per year (e.g., Costanza et al., 2014; Hoegh-Guldberg et al., 2015)559. Sea level rise is expected to be lower for 1.5°C versus 2°C, lowering risks for coastal metropolitan agglomerations. (2014)510 found substantial uptake of carbon by vegetation under future scenarios when considering the effects of both climate change and elevated CO2. Freshwater ecosystems are considered to be among the most threatened on the planet (Settele et al., 2014)549. AR5 (Settele et al., 2014)471 concluded that the geographical ranges of many terrestrial and freshwater plant and animal species have moved over the last several decades in response to warming: approximately 17 km poleward and 11 m up in altitude per decade. Few projections were available for specific temperatures above pre-industrial levels; Supplementary Material 3.SM, Table 3.SM.7 provides the conversions used to translate risks projected for particular time slices to those for specific temperature changes (Ebi et al., 2018)998. Southeast Asia is a region highly vulnerable to increased flooding in the context of sea level rise (Arnell et al., 2016; Brown et al., 2016, 2018a)1181. For example, species of reef-building corals have been observed to shift their geographic ranges, yet this has not resulted in the shift of entire coral ecosystems (high confidence) (Woodroffe et al., 2010; Yamano et al., 2011)565. El Niño–Southern Oscillation (ENSO): Extreme El Niño events are associated with significant warming of the usually cold eastern Pacific Ocean, and they occur about once every 20 years (Cai et al., 2015)1151. Carbon uptake by the ocean is decreasing (Iida et al., 2015)681, and there is increasing concern from observations and models regarding associated changes to ocean circulation (Sections 3.3.7 and 3.4.4., Rahmstorf et al., 2015b)682;. Other influences, such as high rates of ocean acidification coupled with shoaling of the aragonite saturation horizon, are likely to also play key roles (Kawaguchi et al., 2013; Piñones and Fedorov, 2016)677. For populations vulnerable to poverty, the exposure to climate risks in multiple sectors could be an order of magnitude greater (8–32 fold) in the high poverty and inequality scenarios (SSP3; 765–1,220 million) compared to under sustainable socio-economic development (SSP1; 23–85 million). Asian and African regions are projected to experience 85–95% of global exposure, with 91–98% of the exposed and vulnerable population (depending on SSP/GMT combination), approximately half of which are in South Asia. Extreme precipitation in small island regions is often linked to tropical storms and contributes to the climate hazard (Khouakhi et al., 2017)834. International trade in food might be a key response measure for alleviating hunger in developing countries under 1.5°C and 2°C stabilization scenarios (IFPRI, 2018)1157. The literature consistently highlights the complexity of migration decisions and the difficulties in attributing causation (e.g., Nicholson, 2014; Baldwin and Fornalé, 2017; Bettini, 2017; Constable, 2017; Islam and Shamsuddoha, 2017; Suckall et al., 2017)1078. Studies comparing the health risks associated with reduced food security at 1.5°C and 2°C concluded that risks would be higher and the globally undernourished population larger at 2°C (Hales et al., 2014; Ishida et al., 2014; Hasegawa et al., 2016)968. The differences between average annual sediment load under 1.5°C and 2°C of warming are not clear, owing to complex interactions among climate change, land cover/surface and soil management (Cousino et al., 2015; Shrestha et al., 2016)446. Risk magnitude is provided either as assessed levels of risk (very high: vh, high: h, medium: m, or low: l) or as quantitative examples of risk levels taken from the literature. Generally, there is high confidence that vulnerability to decreases in water and food availability is reduced at 1.5°C versus 2°C for southern Africa (Betts et al., 2018)1211, whilst at 2°C these are expected to be higher (high confidence) (Lehner et al., 2017; Betts et al., 2018; Byers et al., 2018; Rosenzweig et al., 2018)1212. This body of evidence suggests that the temperature range of 1.5°C–2°C may be regarded as representing moderate risk, in that it may trigger MISI in Antarctica or irreversible loss of the Greenland ice sheet and it may be associated with sea level rise by as much as 1–2 m over a period of two centuries. The MRC has facilitated impact assessment studies, regional capacity building and local project implementation (Schipper et al., 2010)985, although the mainstreaming of adaptation into development policies has lagged behind needs (Gass et al., 2011)986. As ocean waters have increased in sea surface temperature (SST) by approximately 0.9°C they have also decreased by 0.2 pH units since 1870–1899 ('pre-industrial'; Table 1 in Gattuso et al., 2015; Bopp et al., 2013)598. As a result of population and economic growth, increased exposure of people and assets has caused more damage due to flooding. The groundwater-fed lakes in northeastern central Europe have been affected by climate and land-use changes, and they showed a predominantly negative lake-level trend in 1999–2008 (Kaiser et al., 2014)421. In temperate climates, warming is expected to lengthen the forage growing season but decrease forage quality, with important variations due to rainfall changes (Craine et al., 2010; Hatfield et al., 2011; Izaurralde et al., 2011)912. The forest may be especially vulnerable to combined pressure from multiple stressors, namely changes in climate and continued anthropogenic disturbance (Borma et al., 2013; Nobre et al., 2016)536.

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