TS

Technical Summary

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TS.A Introduction

TS.A.1 Background

This technical summary complements and expands the key findings of the Working Group (WG) II contribution to the Sixth Assessment Report (AR6) presented in the Summary for Policymakers and covers literature accepted for publication by 1 September 2021. It provides technical understanding and is developed from the key findings of chapters and cross-chapter papers (CCPs) as presented in their executive summaries and integrates across them. The report builds on the WGII contribution to the Fifth Assessment Report (AR5) of the IPCC and three special reports of the AR6 cycle providing new knowledge and updates. The three special reports are the Special Report on Global Warming of 1.5°C (2018), an IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways in the context of strengthening the global response to the threat of climate change, sustainable development and efforts to eradicate poverty; the Special Report on Climate Change and Land, which is concerned with climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (2019); and the Special Report on the Ocean and Cryosphere in a Changing Climate (2019). The WGII assessment integrates with the WGI (the physical science basis) and WGIII (mitigation of climate change) contributions and contributes to the Synthesis Report.

The contribution of Working Group II (WGII) to the Sixth Assessment Report (AR6) of the IPCC summarizes the current understanding of observed climate change impacts on ecosystems, human societies and their cities, settlements, infrastructures and industrial systems, as well as vulnerabilities and future risks tied to different socioeconomic development pathways. The report is set against a current backdrop of rapid urbanisation, biodiversity loss, a growing and dynamic global human population, significant inequality and demands for social justice, rapid technological change, continuing poverty, land degradation and food insecurity, and risks from shocks such as pandemics and increasingly intense extreme events from ongoing climate change. The report also assesses existing adaptations and their feasibility and limits. Any success of adaptation is dependent on the achieved level of mitigation and the transformation of global and regional sustainability outlined in the Sustainable Development Goals (SDGs). Accordingly, adaptation is essential for climate resilient development. Compared to earlier IPCC assessments, this report integrates more strongly across the natural, social and economic sciences, highlighting the role of social justice and diverse forms of knowledge, such as Indigenous knowledge and local knowledge, and reflects the increasing importance of urgent and immediate action to address climate risk. {1.1.1}

Since AR5, climate action has increased at all levels of governance, including among non-governmental organisations, small and large enterprises, and citizens. Two international agreements—the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement and the 2030 Agenda for Sustainable Development—jointly provide overarching goals for climate action. The 2030 Agenda for Sustainable Development, adopted in 2015 by UN member states, sets out 17 SDGs, frames policies for achieving a more sustainable future and aligns efforts globally to prioritise ending extreme poverty, protect the planet and promote more peaceful, prosperous and inclusive societies. Since AR5, several new international conventions have identified climate change adaptation and risk reduction as important global priorities for sustainable development, including the Sendai Framework for Disaster Risk Reduction (SFDRR), the finance-oriented Addis Ababa Action Agenda, and the New Urban Agenda. The Convention on Biological Diversity and its Aichi targets recognise that biodiversity is affected by climate change, with negative consequences for human well-being, but biodiversity, through ecosystem services, contributes to both climate change mitigation and adaptation. {1.1.2}

TS.A.2 TS Structure of the Report

This technical summary is structured in five sections: Section A 'Introduction', Section B 'Observed Impacts and Adaptation', Section C 'Projected Impacts and Risks', Section D 'Contribution of Adaptation to Solutions' and Section E 'Climate Resilient Development'. Each section includes several headline statements followed by several bullet points providing details about the underlying assessments. All findings and figures are supported by and traceable to the underlying report, indicated by references {in curly brackets} to relevant sections of chapters and cross-chapter papers.

Confidence in the key findings of this assessment is communicated using the IPCC calibrated uncertainty language. This calibrated language is designed to consistently evaluate and communicate uncertainties that arise from incomplete knowledge due to a lack of information or from disagreement about what is known or even knowable. The IPCC calibrated language uses qualitative expressions of confidence based on the robustness of evidence for a finding and (where possible) uses quantitative expressions to describe the likelihood of a finding. Each finding is grounded in an evaluation of underlying evidence and agreement. A level of confidence is expressed using five qualifiers, very low, low, medium, high and very high, and typeset in italics, for example, *medium confidence*. The following terms have been used to indicate the assessed likelihood of an outcome or a result: *virtually certain* 99–100% probability, *very likely* 90–100%, *likely* 66–100%, *as likely as not* 33–66%, *unlikely* 0–33%, *very unlikely* 0–10%, *exceptionally unlikely* 0–1%. Assessed likelihood is typeset in italics, for example, *very likely*. This is consistent with AR5 and the other AR6 reports. (Figure TS.1) {1.3.4}

TS.A.3 Key Developments Since AR5

Interdisciplinary climate change assessment, which has played a prominent role in science–society interactions on the climate issue since 1988, has advanced in important ways since AR5. Building on a substantially expanded scientific and technical literature, this AR6 report emphasises at least three broad themes. (Figure TS.2) {1.1.4}

First, this AR6 assessment has an increased focus on risk and solution frameworks. The risk framing can move beyond the limits of single best estimates or most likely outcomes and include high-consequence outcomes for which probabilities are low or in some cases unknown.

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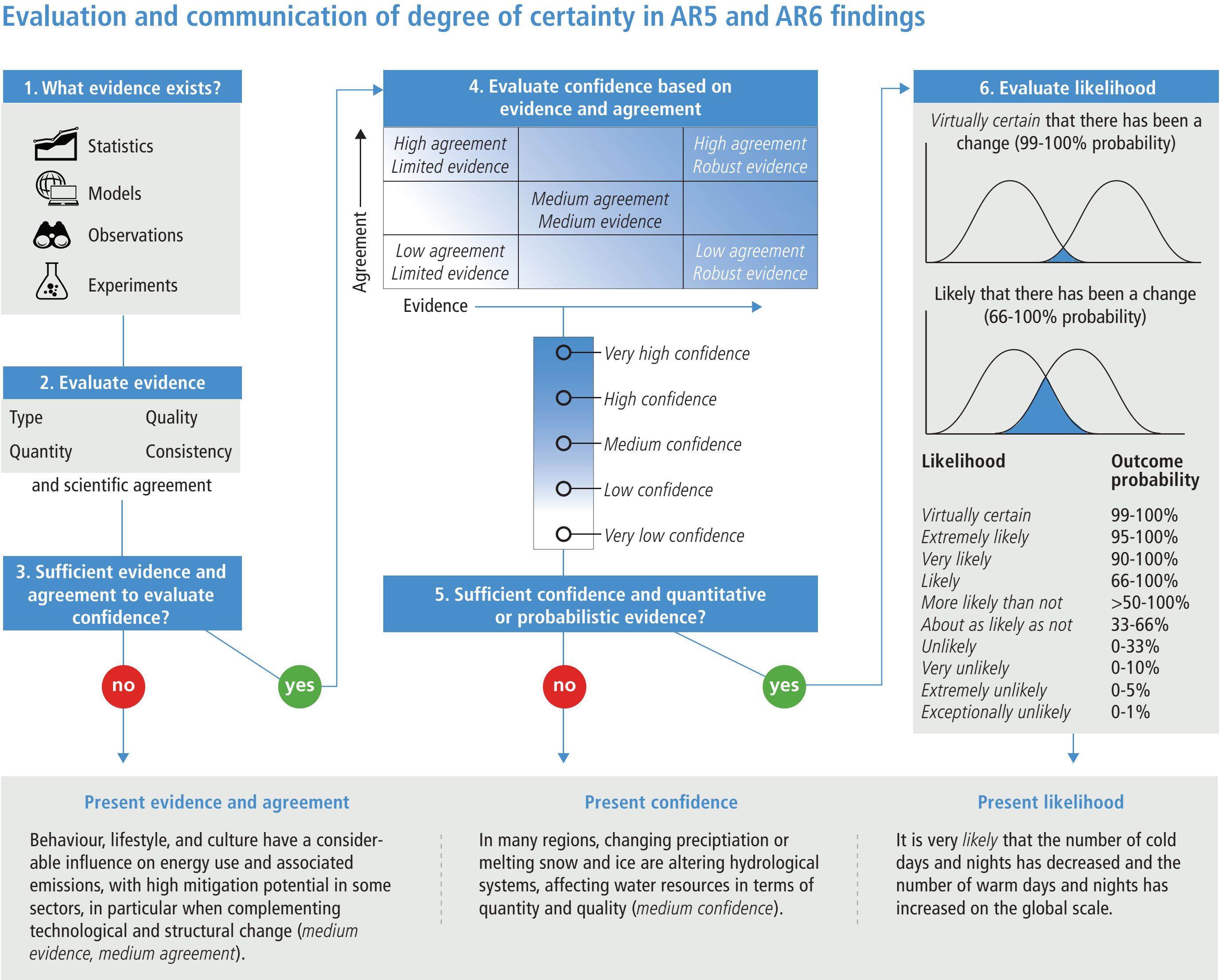

Figure TS.1 | The IPCC AR5 and AR6 framework for applying expert judgement in the evaluation and characterisation of assessment findings. This illustration depicts the process assessment authors apply in evaluating and communicating the current state of knowledge. {Figure 1.6}

In this report, the risk framing for the first time spans all three working groups, includes risks from the responses to climate change, considers dynamic and cascading consequences, describes with more geographic detail risks to people and ecosystems, and assesses such risks over a range of scenarios. The focus on solutions encompasses the interconnections among climate responses, sustainable development and transformation—and the implications for governance across scales within the public and private sectors. The assessment therefore includes climate-related decision-making and risk management, climate resilient development pathways, implementation and evaluation of adaptation, and also limits to adaptation and loss and damage. Specific focal areas reflect contexts increasingly important for the implementation of responses, such as cities. {1.3.1, 1.4.4, 16, 17, 18}

Second, emphases on social justice, equity and different forms of expertise have emerged. As climate change impacts and implemented responses increasingly occur, there is heightened awareness of the ways that climate responses interact with issues of justice and social progress. In this report, expanded attention is given to inequity in climate vulnerability and responses, the role of power and participation in processes of implementation, unequal and differential impacts and climate justice. The historic focus on scientific literature has also been increasingly accompanied by attention to and incorporation of Indigenous knowledge, local knowledge, and associated scholars. {1.3.2, 1.4.1, 17.5.2}

Third, AR6 has a more extensive focus on the role of transformation in meeting societal goals. {1.5}

The following overarching conclusions have been derived from the whole of the assessment of WGII:

i) The magnitude of observed impacts and projected climate risks indicate the scale of decision-making, funding and investment needed over the next decade if climate resilient development is to be achieved.

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From climate risk to climate resilient development: climate, ecosystems (including biodiversity) and human society as coupled systems

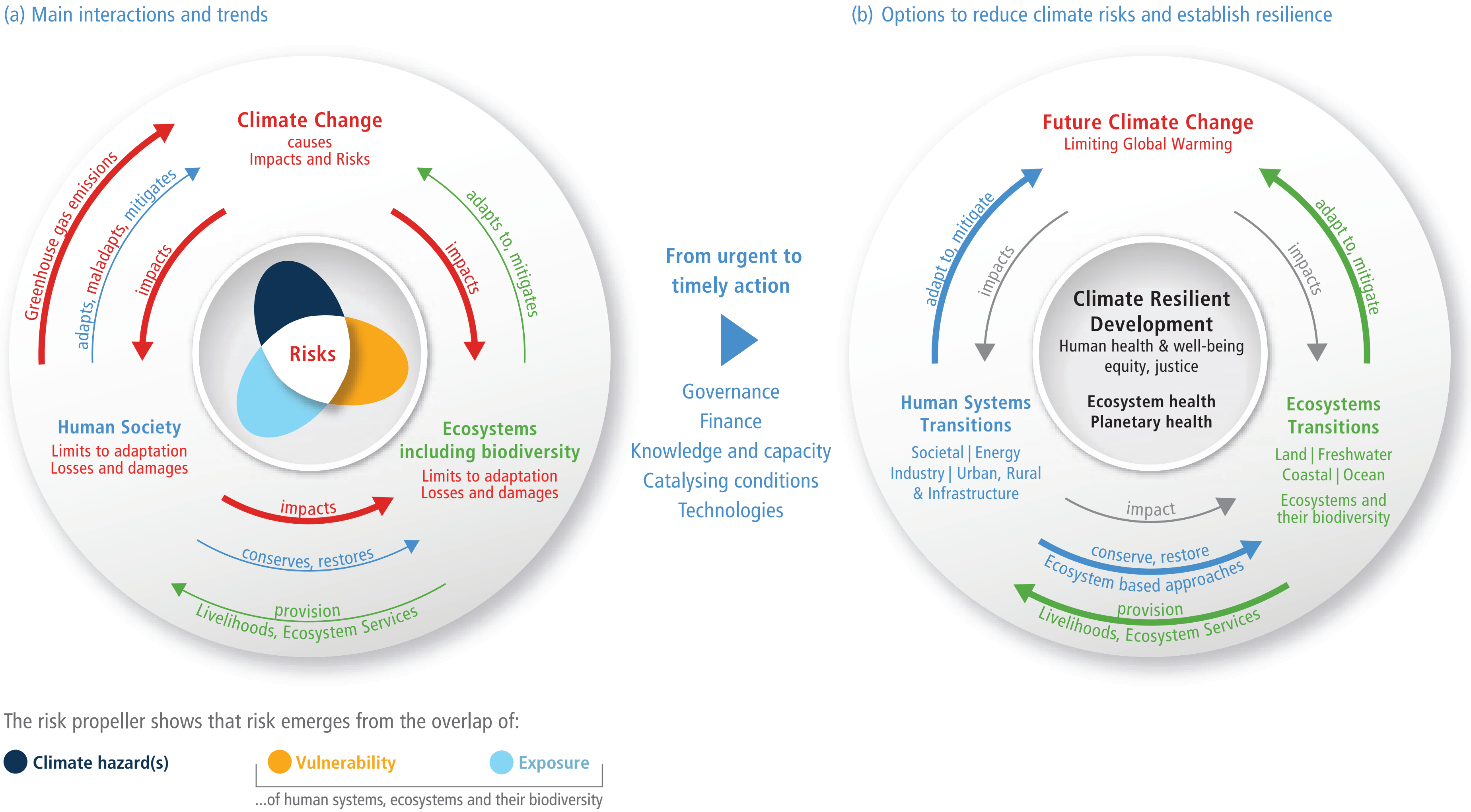

Figure TS.2 | This report has a strong focus on the interactions among the coupled systems climate, ecosystems (including their biodiversity) and human society. These interactions are the basis of emerging risks from climate change, ecosystem degradation and biodiversity loss and, at the same time, offer opportunities for the future.

(a) Human society causes climate change. Climate change, through hazards, exposure and vulnerability generates impacts and risks that can surpass limits to adaptation and result in losses and damages. Human society can adapt to, maladapt and mitigate climate change, ecosystems can adapt and mitigate within limits. Ecosystems and their biodiversity provision livelihoods and ecosystem services. Human society impacts ecosystems and can restore and conserve them.

(b) Meeting the objectives of climate resilient development thereby supporting human, ecosystem and planetary health, as well as human well-being, requires society and ecosystems to move over (transition) to a more resilient state. The recognition of climate risks can strengthen adaptation and mitigation actions and transitions that reduce risks. Taking action is enabled by governance, finance, knowledge and capacity building, technology and catalysing conditions. Transformation entails system transitions strengthening the resilience of ecosystems and society (Section E). In a) arrow colours represent principle human society interactions (blue), ecosystem (including biodiversity) interactions (green) and the impacts of climate change and human activities, including losses and damages, under continued climate change (red). In b) arrow colours represent human system interactions (blue), ecosystem (including biodiversity) interactions (green) and reduced impacts from climate change and human activities (grey). {1.2, Figure 1.2}

ii) Since AR5, climate risks are appearing faster and will get more severe sooner (*high confidence*). Impacts cascade through natural and human systems, often compounding with the impacts from other human activities. Feasible, integrated mitigation and adaptation solutions can be tailored to specific locations and monitored for their effectiveness while avoiding conflict with sustainable development objectives and managing risks and trade-offs (*high confidence*).

iii) Available evidence on projected climate risks indicates that opportunities for adaptation to many climate risks will *likely* become constrained and have reduced effectiveness should 1.5°C global warming be exceeded and that, for many locations on Earth, capacity for adaptation is already significantly limited. The maintenance and recovery of natural and human systems will require the achievement of mitigation targets.

Box TS.1 | Core Concepts of the Report

This box provides an overview of key definitions and concepts relevant to the WGII AR6 assessment, with a focus on those updated or new since AR5.

Risk in this report is defined as the potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems. In the context of climate change impacts, risks result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system. In the context of climate change responses, risks result from the potential for such responses not to achieve the intended objective(s) or from potential trade-offs or negative side-effects. **Risk management** is defined as plans, actions, strategies or policies to reduce the likelihood and/or magnitude of adverse potential consequences, based on assessed or perceived risks. {1.2.1, Annex II: Glossary}

Vulnerability is a component of risk, but also, independently, an important focus. Vulnerability in this report is defined as the propensity or predisposition to be adversely affected and encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (Annex II: Glossary). Over the past several decades, approaches to analysing and assessing vulnerability have evolved. An early emphasis on top-down, biophysical evaluation of vulnerability included—and often started with—exposure to climate hazards in assessing vulnerability. From this starting point, attention to bottom-up, social and contextual determinants of vulnerability, which often differ, has emerged, although this approach is incompletely applied or integrated across contexts. Vulnerability is now widely understood to differ within communities and across societies, also changing through time. In WGII AR6, assessment of the vulnerability of people and ecosystems encompasses the differing approaches that exist within the literature, both critiquing and harmonising them based on available evidence. In this context, **exposure** is defined as the presence of people; livelihoods; species or ecosystems; environmental functions, services and resources; infrastructure; or economic, social or cultural assets in places and settings that could be adversely affected. Potentially affected places and settings can be defined geographically, as well as more dynamically, for example through transmission or interconnections through markets or flows of people. {1.2.1, Annex II: Glossary}

Adaptation in this report is defined, in human systems, as the process of adjustment to actual or expected climate and its effects in order to moderate harm or exploit beneficial opportunities. In natural systems, adaptation is the process of adjustment to actual climate and its effects; human intervention may facilitate this (see Annex II: Glossary). Adaptation planning in human systems generally entails a process of iterative risk management. Different types of adaptation have been distinguished, including anticipatory versus reactive, autonomous versus planned and incremental versus transformational adaptation. Adaptation is often seen as having five general stages: (a) awareness, (b) assessment, (c) planning, (d) implementation and (e) monitoring and evaluation. Government, non-government, and private-sector actors have adopted a wide variety of specific approaches to adaptation that, to varying degrees, conform to these five general stages. Adaptation in natural systems includes *autonomous* adjustments through ecological and evolutionary processes. It also involves the use of nature through ecosystem-based adaptation. The role of species, biodiversity and ecosystems in such adaptation options can range from the rehabilitation or restoration of ecosystems (e.g., wetlands or mangroves) to hybrid combinations of so-called green and grey infrastructure (e.g., horizontal levees). The WGII AR6 emphasises the assessment of observed adaptation-related responses to climate change, governance and decision-making in adaptation and the role of adaptation in reducing key risks and global-scale reasons for concern, as well as limits to such adaptation. {1.2.1, 17.4}

Resilience in this report is defined as the capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure while also maintaining the capacity for adaptation, learning and transformation. Resilience is an entry point commonly used, although under a wide spectrum of meanings. Resilience as a system trait overlaps with concepts of vulnerability, adaptive capacity and, thus, risk, and resilience as a strategy overlaps with risk management, adaptation and transformation. Implemented adaptation is often organised around resilience as bouncing back and returning to a previous state after a disturbance. {1.2.1, Annex II: Glossary}

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Box TS.2 | AR6 Climate Dimensions, Global Warming Levels and Reference Periods

Assessments of climate risks consider possible future climate change, societal development and responses. This report assesses literature including that based on climate model simulations that are part of the fifth and sixth Coupled Model Intercomparison Project phase (CMIP5, CMIP6) of the World Climate Research Programme. Future projections are driven by emissions and/or concentrations from illustrative Representative Concentration Pathways (RCPs)[1] and Shared Socio-economic Pathways (SSPs)[2] scenarios, respectively[3]. Climate impacts literature is based primarily on climate projections assessed in AR5 or earlier, or assumed global warming levels, though some recent impacts literature uses newer projections based on the CMIP6 exercise. Given differences in the impacts literature regarding socioeconomic details and assumptions, WGII chapters contextualize impacts with respect to exposure, vulnerability and adaptation as appropriate for their literature, this includes assessments regarding sustainable development and climate resilient development. There are many emissions and socioeconomic pathways that are consistent with a given global warming outcome. These represent a broad range of possibilities as available in the literature assessed that affect future climate change exposure and vulnerability. Where available, WGII also assesses literature that is based on an integrative SSP-RCP framework where climate projections obtained under the RCP scenarios are analysed against the backdrop of various illustrative SSPs[2]. The WGII assessment combines multiple lines of evidence including impacts modelling driven by climate projections, observations, and process understanding. {1.2, 16.5, 18.2, CCB CLIMATE, WGI AR6 SPM.C, WGI AR6 Box SPM.1, WGI AR6 1.6, WGI AR6 12, WGI AR5}

A common set of reference years and time periods are adopted for assessing climate change and its impacts and risks: the reference period 1850–1900 approximates pre-industrial global surface temperature, and three future reference periods cover the near-term (2021–2040), mid-term (2041–2060) and long-term (2081–2100). {CCB CLIMATE}

Common levels of global warming relative to 1850–1900 are used to contextualize and facilitate analysis, synthesis and communication of assessed past, present and future climate change impacts and risks considering multiple lines of evidence. Robust geographical patterns of many variables can be identified at a given level of global warming, common to all scenarios considered and independent of timing when the global warming level is reached. {16.5, CCB CLIMATE, WGI AR6 Box SPM.1, WGI AR6 4.2, WGI AR6 CCB11.1}

WGI assessed increase in global surface temperature is 1.09 [0.95 to 1.20][4] °C in 2011–2020 above 1850–1900. The estimated increase in global surface temperature since AR5 is principally due to further warming since 2003–2012 (+0.19 [0.16 to 0.22]°C).[5] Considering all five illustrative scenarios assessed by WGI, there is at least a greater than 50% likelihood that global warming will reach or exceed 1.5°C in the near-term, even for the very low greenhouse gas emissions scenario[6]. {WGI AR6 SPM A1.2, WGI AR6 SPM B1.3, WGI AR6 Table SPM.1, WGI AR6 CCB2.3}

TS.B Observed Impacts

This section reports on how worldwide climate change is increasingly affecting marine, freshwater and terrestrial ecosystems and ecosystem services, water and food security, settlements and infrastructure, health and well-being, and economies and culture, especially through compound stresses and events. It refers to the increasing confidence since AR5 that detected impacts are attributable to climate change, including the impacts of extreme events. It illustrates how compound hazards have become more frequent in all world regions, with widespread consequences. Regional increases in temperature, aridity and drought have increased the frequency and intensity of fire. The interaction between fire, land use change, particularly deforestation, and climate change, is directly impacting human health, ecosystem functioning, forest structure, food security and the livelihoods of resource-dependent communities.

1 RCP-based scenarios are referred to as RCPy, where 'y' refers to the level of radiative forcing (in watts per square meter, or W m^{-2}) resulting from the scenario in the year 2100.

2 SSP-based scenarios are referred to as SSPx-y, where 'SSPx' refers to the Shared Socio-economic Pathway describing the socio-economic trends underlying the scenarios, and 'y' refers to the level of radiative forcing (in watts per square meter, or W m^{-2}) resulting from the scenario in the year 2100.

3 IPCC is neutral with regard to the assumptions underlying the SSPs, which do not cover all possible scenarios. Alternative scenarios may be considered or developed.

4 In the WGI report, square brackets [x to y] are used to provide the assessed *very likely* range, or 90% interval.

5 Since AR5, methodological advances and new datasets have provided a more complete spatial representation of changes in surface temperature, including in the Arctic. These and other improvements have also increased the estimate of global surface temperature change by approximately 0.1°C, but this increase does not represent additional physical warming since AR5.

6 Global warming of 1.5°C relative to 1850–1900 would be exceeded during the 21st century under the intermediate, high and very high greenhouse gas emissions scenarios considered in this report (SSP2-4.5, SSP3-7.0 and SSP5-8.5, respectively). Under the five illustrative scenarios, in the near term (2021–2040), the 1.5°C global warming level is *very likely* to be exceeded under the very high greenhouse gas emissions scenario (SSP5-8.5), *likely* to be exceeded under the intermediate and high greenhouse gas emissions scenarios (SSP2-4.5 and SSP3-7.0), *more likely than not* to be exceeded under the low greenhouse gas emissions scenario (SSP1-2.6) and *more likely than not* to be reached under the very low greenhouse gas emissions scenario (SSP1-1.9). Furthermore, for the very low greenhouse gas emissions scenario (SSP1-1.9), it is *more likely than not* that global surface temperature would decline back to below 1.5°C toward the end of the 21st century, with a temporary overshoot of no more than 0.1°C above 1.5°C global warming.

Climate change impacts are concurrent and interact with other significant societal changes that have become more salient since AR5, including a growing and urbanising global population; significant inequality and demands for social justice; rapid technological change; continuing poverty, land and water degradation, biodiversity loss; food insecurity; and a global pandemic.

Ecosystems and biodiversity

TS.B.1 Climate change has altered marine, terrestrial and freshwater ecosystems all around the world (*very high confidence*). Effects were experienced earlier and are more widespread with more far-reaching consequences than anticipated (*medium confidence*). Biological responses, including changes in physiology, growth, abundance, geographic placement and shifting seasonal timing, are often not sufficient to cope with recent climate change (*very high confidence*). Climate change has caused local species losses, increases in disease (*high confidence*) and mass mortality events of plants and animals (*very high confidence*), resulting in the first climate-driven extinctions (*medium confidence*), ecosystem restructuring, increases in areas burned by wildfire (*high confidence*) and declines in key ecosystem services (*high confidence*). Climate-driven impacts on ecosystems have caused measurable economic and livelihood losses and altered cultural practices and recreational activities around the world (*high confidence*). (Figure TS.3, Figure TS.5 ECOSYSTEMS) {2.3.1, 2.3.3, 2.4.2, 2.4.3, 2.4.4, 2.4.5, 3.2, 3.3.2, 3.3.3, 3.4.2, 3.4.3, Box 3.2, 3.5.3, 3.5.5, 3.5.6, 4.3.5, 9.6.1, 9.6.3, 10.4.2., 11.3.1, 11.3.2, 11.3.11, 11.3.2, 11.3.11, 12.3, 13.3.1, 13.4.1, 13.10.1, 14.2.1, 14.5.1, 14.5.2; 15.3.3., 15.3.4, 16.2.3, CCP1.2.1; CCP1.2.2, CCP1.2.4, Box CCP1.1, CCP3.2.1, CCP4.1.3, CCP5.2.1, CCP5.2.7, CP6.1, CCP6.2.1, CCP7.2.1, CCP7.3.2, Table 2.2, Table 2.3, Table 2.S. 1, CCP5.2.1, CCB EXTREMES, CCB ILLNESS, CCB NATURAL, CCB SLR}

TS.B.1.1 Anthropogenic climate change has exposed ecosystems to conditions that are unprecedented over millennia (*high confidence*), which has greatly impacted species on land and in the ocean (*very high confidence*). Consistent with expectations, species in all ecosystems have shifted their geographic ranges and altered the timing of seasonal events (*very high confidence*). Among thousands of species spread across terrestrial, freshwater and marine systems, half to two-thirds have shifted their ranges to higher latitudes (*very high confidence*), and approximately two-thirds have shifted towards earlier spring life events (*very high confidence*) in response to warming. The move of diseases and their vectors has brought new diseases into the high Arctic and at higher elevations in mountain regions to which local wildlife and humans are not resistant (*high confidence*). These processes have led to emerging hybridisation, competition, temporal or spatial mismatches in predator–prey, insect–plant and host–parasite relationships and invasion of alien plant pests or pathogens (*medium confidence*). (Figure TS.5 ECOSYSTEMS) {2.4.2, 2.4.3, 2.5.2, 2.5.4, 2.6.1, 3.2.4, 3.4.2, 3.4.3, 3.5.2, 4.3.5, 9.6.1, 10.4.2, 11.3.1, 11.3.2; 11.3.11, 12.3.1, 12.3.2, 12.3.7, 13.3.1, 13.4.1, 13.10.2, 14.5.1, 14.5.2; 15.3.3. 16.2.3, 16.2.3, CCP1.2.1, CCP 1.2.2, CCP1.2.4, CCP3.2.1, CCP4.1.3, CCP5.2.1, CCP.5.2.7, CCP6.2.1, CCP7.3.2, CCB EXTREMES, CCB ILLNESS, CCB MOVING PLATE}

TS.B.1.2 Observed responses of species to climate change have altered biodiversity and impacted ecosystem structure and resilience in most regions (*very high confidence*). Range shifts reduce biodiversity in the warmest regions and locations as adaptation limits are exceeded (*high confidence*). Simultaneously, these shifts homogenise biodiversity (*medium confidence*) in regions receiving climate-migrant species, alter food webs and eliminate the distinctiveness of communities (*medium confidence*). Increasing losses of habitat-forming species such as trees, corals, kelp and seagrass have caused irreversible shifts in some ecosystems and threaten associated biodiversity in marine systems (*high confidence*). Human-introduced invasive (non-native) species can reduce or replace native species and alter ecosystem characteristics if they fare better than endemic species in new climate-altered ecological niches (*high confidence*). Such invasive species effects are most prominent in geographically constrained areas, including islands, semi-enclosed seas and mountains, and they increase vulnerability in these systems (*high confidence*). Phenological shifts increase the risks of temporal mismatches between trophic levels within ecosystems (*medium confidence*), which can lead to reduced food availability and population abundances (*medium confidence*) and can further destabilise ecosystem resilience. (Figure TS.5 ECOSYSTEMS) {2.4.2, 2.4.3, 2.4.5, Box 2.1, 2.5.4, 3.3.3, 3.4.2, 3.4.3. Box 3.2, Box 3.4, 3.5.2, 3.5.3, 4.3.5, 9.6.1, 10.4.2, 11.3.1, 11.3.2, 11.3.11, 13.3.1, 13.4.1, 13.10.2, 14.5.1, 15.3.3, 15.3.4, 15.8, Box CCP1.1, CCP1.2.2, CCP1.2.1, CCP3.2.1, CCP5.2.1, CCB EXTREMES}

TS.B.1.3 At the warm (equatorward and lower) edges of distributions, adaptation limits to human-induced warming have led to widespread local population losses (extirpations) that result in range contractions (*very high confidence*). Among land plants and animals, local population loss was detected in around 50% of studied species and is often attributable to extreme events (*high confidence*). Such extirpations are most common in tropical habitats (55%) and freshwater systems (74%), but also high in marine (51%) and terrestrial (46%) habitats. Many mountain-top species have suffered population losses along lower elevations, leaving them increasingly restricted to a smaller area and at higher risk of extinction (*medium confidence*). Global extinctions due to climate change are already being observed, with two extinctions currently attributed to anthropogenic climate change (*medium confidence*). Climate-induced extinctions, including mass extinctions, are common in the palaeo record, underlining the potential of climate change to have catastrophic impacts on species and ecosystems (*high confidence*). (Figure TS.5 ECOSYSTEMS) {2.3.1, 2.3.3, 2.4.2, 2.4.5, 2.5.4, 3.3.3, 3.4.2, 3.4.3, Box 3.2, 9.6.1, 11.3.1, 12.3, 13.4.1, CCP1.2.1, CCP5.2.1, CCP5.2.7, CCP7.2.1, CCB EXTREMES, CCB PALEO}

TS.B.1.4 Ecosystem change has led to the loss of specialised ecosystems where warming has reduced thermal habitat, as at the poles, at the tops of mountains and at the equator, with the hottest ecosystems becoming intolerable for many species (*very high confidence*). For example, warming, reduced ice, thawing permafrost and a changing hydrological cycle have resulted in the contraction of polar and mountain ecosystems. The Arctic is showing increased arrival of species from warmer areas on land and in the sea, with a declining extent of tundra and ice-dependent species, such as the polar bear (*high confidence*). Similar patterns of change in the Antarctic terrestrial and marine environment are beginning to emerge,

TS

Impacts of climate change are observed in many ecosystems and human systems worldwide

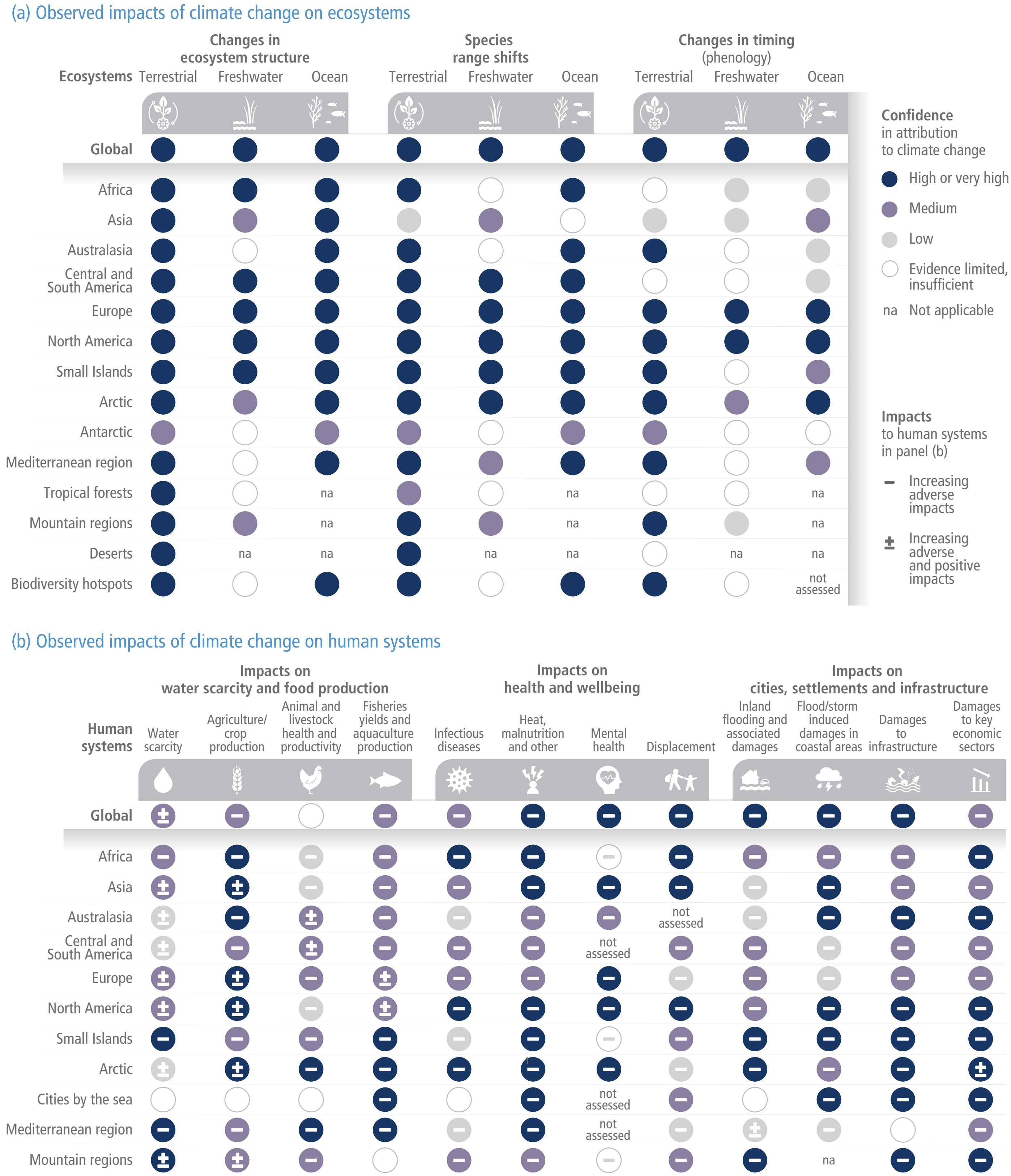

Figure TS.3 | Observed global and regional impacts on ecosystems and human systems attributed to climate change. Confidence levels reflect uncertainty in attribution of the observed impact to climate change. Global assessments focus on large studies, multi-species, meta-analyses and large reviews. For that reason they can be assessed with higher confidence than regional studies, which may often rely on smaller studies that have more limited data. Regional assessments consider evidence on impacts across an entire region and do not focus on any country in particular.

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(a) Climate change has already altered terrestrial, freshwater and ocean ecosystems at global scale, with multiple impacts evident at regional and local scales where there is sufficient literature to make an assessment. Impacts are evident on ecosystem structure, species geographic ranges and timing of seasonal life cycles (phenology) (for methodology and detailed references to chapters and cross-chapter papers see SMTS.1 and SMTS.1.1).

(b) Climate change has already had diverse adverse impacts on human systems, including on water security and food production, health and well-being, and cities, settlements and infrastructure. The + and – symbols indicate the direction of observed impacts, with a – denoting an increasing adverse impact and a ± denoting that, within a region or globally, both adverse and positive impacts have been observed (e.g., adverse impacts in one area or food item may occur with positive impacts in another area or food item). Globally, '–' denotes an overall adverse impact; 'Water scarcity' considers, e.g., water availability in general, groundwater, water quality, demand for water, drought in cities. Impacts on food production were assessed by excluding non-climatic drivers of production increases; Global assessment for agricultural production is based on the impacts on global aggregated production; 'Reduced animal and livestock health and productivity' considers, e.g., heat stress, diseases, productivity, mortality; 'Reduced fisheries yields and aquaculture production' includes marine and freshwater fisheries/production; 'Infectious diseases' include, e.g., water-borne and vector-borne diseases; 'Heat, malnutrition and other' considers, e.g., human heat-related morbidity and mortality, labour productivity, harm from wildfire, nutritional deficiencies; 'Mental health' includes impacts from extreme weather events, cumulative events, and vicarious or anticipatory events; 'Displacement' assessments refer to evidence of displacement attributable to climate and weather extremes; 'Inland flooding and associated damages' considers, e.g., river overflows, heavy rain, glacier outbursts, urban flooding; 'Flood/storm induced damages in coastal areas' include damages due to, e.g., cyclones, sea level rise, storm surges. Damages by key economic sectors are observed impacts related to an attributable mean or extreme climate hazard or directly attributed. Key economic sectors include standard classifications and sectors of importance to regions (for methodology and detailed references to chapters and cross-chapter papers see SMTS.1 and SMTS.1.2).

such as declining ranges of krill and emperor penguins (*medium confidence*). Coral reefs are suffering global declines, with abrupt shifts in community composition persisting for years (*very high confidence*). Deserts and tropical systems are decreasing in diversity due to heat stress and extreme events (*high confidence*). In contrast, arid lands are displaying varied responses around the globe in response to regional changes in the hydrological cycle (*high confidence*). {2.3.1, 2.3.3, 2.4.2, 2.4.3, 3.2.2, 3.4.2, 3.4.3, 3.5.3, 9.6.1, 10.4.3, 11.3.2, 11.3.11, 12.3.1, CCP1.2.4, CCP3.2.1, CCP3.2.2, CCP4.3.2, CCP5.2.1, CCP6.1, CCP6.2, CCB EXTREMES}

TS.B.1.5 Climate change is affecting ecosystem services connected to human health, livelihoods and well-being (*medium confidence*). In terrestrial ecosystems, carbon uptake services linked to CO_2 fertilisation effects are being increasingly limited by drought and warming and exacerbated by non-climatic anthropogenic impacts (*high confidence*). Deforestation, draining and burning of peatlands and tropical forests and thawing of Arctic permafrost have already shifted some areas from being carbon sinks to carbon sources (*high confidence*). The severity and outbreak extent of forest insect pests increased in several regions (*high confidence*). Woody plant expansion into grasslands and savannahs, linked to increased CO_2, has reduced grazing land, while invasive grasses in semiarid lands increased the risk of fire (*high confidence*). Coastal 'blue carbon' systems are already impacted by multiple climate and non-climate drivers (*very high confidence*). Warming and CO_2 fertilisation have altered coastal ecosystem biodiversity, making carbon storage or release regionally variable (*high confidence*). {2.2, Table 2.1, 2.4.2, 2.4.3, 2.4.4, Box 2.1, 3.4.2, 3.5.3, 3.5.5, Table Box 3.4.2, Box 3.4, 9.6.1, 10.4.3, 11.3.11, 11.3.7, 12.3.3, 12.4, Figure 12.8, Figure 12.9, 13.3.1, 13.5.1, 14.5.1, 15.3.3, 15.5.6, CCP1.2.2, CCP1.2.4, CCP5.2.1, CCP5.2.3, CCP7.3.1, Box CCP7.1}

TS.B.1.6 Human communities, especially Indigenous Peoples and those more directly reliant on the environment for subsistence, are already negatively impacted by the loss of ecosystem functions, replacement of endemic species and regime shifts across landscapes and seascapes (*high confidence*). Indigenous knowledge contains unique information sources about past changes and potential solutions to present issues (*medium confidence*). Tangible heritage, such as traditional harvesting sites or species and archaeological and cultural heritage sites, and intangible heritage, such as festivals and rites associated with nature-based activities, endemic knowledge and unique insights about plants and animals, are being lost (*high confidence*). As 80% of the world's remaining biodiversity is on Indigenous homelands, these losses have cascading impacts on cultural and linguistic diversity and Indigenous knowledge systems, food security, health, and livelihoods, often with irreparable damage and consequences (*medium evidence*, *high agreement*). Cultural losses threaten adaptive capacity and may accumulate into intergenerational trauma and irrevocable losses of sense of belonging, valued cultural practices, identity and home (*medium confidence*). {2.2, Table 2.1, 2.6.5, 3.5.6, 4.3.5, 4.3.8, 5.4.2, 6.3.3, Box 9.2, 9.12.1, 11.4.1, 11.4.2, 12.5.8, 13.8.1, Box 13.2, 14.4, 15.3.4, CCP5.2.5, CCP5.2.7, CCP6.2, Box CCP7.1}

TS.B.2 Widespread and severe loss and damage to human and natural systems are being driven by human-induced climate changes increasing the frequency and/or intensity and/or duration of extreme weather events, including droughts, wildfires, terrestrial and marine heatwaves, cyclones (*high confidence*) and flood (*low confidence*). Extremes are surpassing the resilience of some ecological and human systems and challenging the adaptation capacities of others, including impacts with irreversible consequences (*high confidence*). Vulnerable people and human systems and climate-sensitive species and ecosystems are most at risk (*very high confidence*). (Figure TS.3) {2.3, 2.3.1, 2.3.1, 2.3.3, 2.4.2, 2.4.5, 2.6.1, 3.2.2, 3.4.2, 3.4.3, 3.5.2, 3.5.3, 4.2.4, 4.2.5, 10.1, 11.2, 12.3, 13.1, 14.1, 15.1, 16.2.3, CCB EXTREMES, WGI AR6 SPM, WGI AR6 9, SROCC SPM}

TS.B.2.1 Extreme climate events comprising conditions beyond which many species are adapted are occurring on all continents, with severe impacts (*very high confidence*). The most severe impacts are occurring in the most climate-sensitive species and ecosystems, characterised by traits that limit their abilities to regenerate between events or to adapt, and those most exposed to climate hazards (*high confidence*). Losses of local plant and animal populations have been widespread, many associated with large increases in hottest yearly temperatures and heatwave events (*very high confidence*). Marine heatwave events have led to widespread, abrupt and extensive mortality of key habitat-forming species among tropical corals, kelps, seagrasses and mangroves, as well as mass mortality of wildlife species, including benthic sessile species (*high confidence*). On land, extreme heat events also have been implicated in the mass mortality of fruit bats

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and freshwater fish. (Figure TS.3, Figure TS.5 ECOSYSTEMS) {2.3.1, 2.3.3, 2.4.2, 2.4.4, 2.6, Table 2.2, Table 2.3, Table 2.S. 1, 3.4.2, 3.4.3, 3.5.2, 11.3.2, Figure 12.8, 12.4, Table 11.4, 13.3.1, 13.4.1, CCB EXTREMES}

TS.B.2.2 Some extreme events have already emerged which exceeded projected global mean warming conditions for 2100, leading to abrupt changes in marine and terrestrial ecosystems (*high confidence*). For some forest types an increase in the frequency, severity and duration of wildfires and droughts has resulted in abrupt and possibly irreversible changes (*medium to high confidence*). The interplay between extreme events, long-term climate trends and other human pressures has pushed some climate-sensitive ecosystems towards thresholds that exceed their natural regenerative capacity (*medium to high confidence*). Extreme events can alter or impede evolutionary responses to climate change and the potential for acclimation to extreme conditions both on land and in the ocean (*medium to high confidence*). (Figure TS.5 ECOSYSTEMS) {2.3.1, 2.3.3, 2.4.2, 2.4.3, 2.4.5, 2.4.4, 2.6.1, 3.2.2, 3.2.4, 3.4.2, 4.3.5, Table 3.15, 3.6.3, 11.3.1, 11.3.2, 13.3.1, 13.4.1, 14.5.1, CCB MOVING PLATE, CCB EXTREMES}

TS.B.2.3 Climate-related extremes have affected the productivity of agricultural, forestry and fishery sectors (*high confidence*). Droughts, floods, wildfires and marine heatwaves contribute to reduced food availability and increased food prices, threatening food security, nutrition and livelihoods of millions of people across regions (*high confidence*). Extreme events caused economic losses in forest productivity and crops and livestock farming, including losses in wheat production in 2012, 2016 and 2018, with the severity of impacts from extreme heat and drought tripling over the last 50 years in Europe (*high confidence*). Forests were impacted by extreme heat and drought impacting timber sales, for example, in Europe (*high confidence*). Marine heatwaves, including well-documented events along the west coast of North America (2013–2016) and east coast of Australia (2015–2016, 2016–2017 and 2020), have caused the collapse of regional fisheries and aquaculture (*high confidence*). Human populations exposed to extreme weather and climate events are at risk of food insecurity with lower diversity in diets, leading to malnutrition and increased risk of disease (*high confidence*). (Figure TS.6 WATER-FOOD) {2.4.4, 3.2.2, 3.4.2, 3.4.3, 3.5.3, 4.2.4, 4.2.5, 4.3.1, 5.2.1, 5.4.1, 5.4.2, 5.5.2, 5.8.1, 5.9.1, 5.12.1, 5.14.2, 5.14.6, 7.2.1, 7.2.2, 7.2.3, 7.2.4, 7.2.5, 9.7, 9.8.2, 9.8.5, 11.3.3, 11.5.1, 11.8.1, 12.3, Figure 12.7, Figure 12.9, Table SM12.5, 13.1.1, 13.3.1, 13.5.1, 13.10.2, 14.5.4, CCB MOVING PLATE, WGI AR6 9}

TS.B.2.4 Extreme climatic events have been observed in all inhabited regions, with many regions experiencing unprecedented consequences, particularly when multiple hazards occur at the same time or within the same space (*very high confidence*). Since AR5, the impacts of climate change and extreme weather events such as wildfires, extreme heat, cyclones, storms and floods have adversely affected or caused loss and damage to human health, shelter, displacement, incomes and livelihoods, security and inequality (*high confidence*). Over 20 million people have been internally displaced annually by weather-related extreme events since 2008, with storms and floods the most common drivers (*high confidence*). Climate-related extreme events are followed by negative impacts on mental health, well-being, life satisfaction, happiness, cognitive performance and aggression in exposed populations (*very high confidence*). (Figure TS.8 HEALTH, Figure TS.10 COMPLEX RISK) {2.3.0, 2.3.1, 2.3.3, 4.2.4, 4.2.5, 4.3, 7.1, 7.2.4, 7.2.6, 8.2.1, 8.2.2, 8.3.2, 8.3.3, Box 9.4, Table 9.7, 9.7, 9.9, 9.11, 11.2.1, 11.2.2, 11.3.8, Table 11.2, Table 11.3, Box 11.6, Box 9.8, 12.4.7, 13.1, 13.2.1, 13.7.1, 13.10.2, 14.5.6, 15.1, 15.2.1, 15.3.3, 16.2.3, CCB EXTREMES, CCB HEALTH, CCB MIGRATE}

Food systems, food security and forestry

TS.B.3 Climate change is already stressing food and forestry systems, with negative consequences for the livelihoods, food security and nutrition of hundreds of millions of people, especially in low and mid-latitudes (*high confidence*). The global food system is failing to address food insecurity and malnutrition in an environmentally sustainable way. (Figure TS.2, Figure TS.3, Figure TS.6 FOOD-WATER, Figure TS.7 VULNERABILITY) {4.3.1, 5.4.1, 5.5.1, 5.7.1, 5.8.1, 5.9.1, 5.10.1, 5.11.1, 5.12.1, 6.3.4.7; 7.2, 9.8.1, 9.8.2, 13.10, 9.8, 10.3.5, 12.3, 13.5.1, 14.5.1, 14.5.4, 15.3.3, 15.3.4, CCP5.2.3, CCP5.2.5, CCP6.2.7, CCB NATURAL}

TS.B 3.1 Climate change impacts are negatively affecting agriculture, forestry, fisheries and aquaculture, increasingly hindering efforts to meet human needs (*high confidence*). Human-induced global warming has slowed the growth of agricultural productivity over the past 50 years in mid and low latitudes (*medium confidence*). Crop yields are compromised by surface ozone (*high confidence*). Methane emissions have negatively impacted crop yields by increasing temperatures and surface ozone concentrations (*medium confidence*). Warming is negatively affecting crop and grassland quality and harvest stability (*high confidence*). Warmer and drier conditions have increased tree mortality and forest disturbances in many temperate and boreal biomes (*high confidence*), negatively impacting provisioning services (*medium confidence*). Ocean warming has decreased sustainable yields of some wild fish populations (*high confidence*) by 4.1% between 1930 and 2010. Ocean acidification and warming have already affected farmed aquatic species (*high confidence*). (Figure TS.3, Figure TS.6 FOOD-WATER) {2.4.3, 2.4.4, 3.4.2, 3.4.3, 4.3.1, 5.2.1, 5.4.1, 5.5.1, 5.6.1, 5.7.1, 5.8.1, 5.9.1, 9.8.2, 9.8.5, 11.3.4, 11.3.5, Box 11.3, 13.3.1, 13.5.1, 14.5.1, 14.5.4, 15.3.4, CCP5.2.3, CCP5.2.5, CCP6.2.5, CCP6.2.8, CCB MOVING PLATE}

TS.B.3.2 Warming has altered the distribution, growing area suitability and timing of key biological events, such as flowering and insect emergence, impacting food quality and harvest stability (*high confidence*). There is *high confidence* that climate change is altering the distribution of cultivated and wild terrestrial, marine and freshwater species. At higher latitudes, warming has expanded the available area but has also altered phenology (*high confidence*), potentially causing plant–pollinator and pest mismatches (*medium confidence*). At low latitudes, temperatures have crossed upper tolerance thresholds, more frequently leading to heat stress and/or shifts in distribution and losses for crops, livestock, fisheries and aquaculture (*high confidence*). {2.4.2, 3.4.2, 3.4.3, 5.4.1, 5.7.4, 5.8.1, 5.12.3, 9.8.2, 12.3.1, 12.3.2, 12.3.6, 13.5.1, 13.5.1, 14.5.4, CCP5.2.5, CCP6.2.5, CCB MOVING PLATE}

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TS.B.3.3 Climate-related extremes have affected the productivity of all agricultural and fishery sectors, with negative consequences for food security and livelihoods (*high confidence*). The frequency of sudden food production losses has increased since at least the mid-20th century on land and sea (*medium evidence, high agreement*). The impacts of climate-related extremes on food security, nutrition and livelihoods are particularly acute and severe for people living in sub-Saharan Africa, Asia, small islands, Central and South America and the Arctic and small-scale food producers globally (*high confidence*). Droughts induced by the 2015–2016 El Niño, partially attributable to human influences (*medium confidence*), caused acute food insecurity in various regions, including eastern and southern Africa and the Dry Corridor of Central America (*high confidence*). In the northeast Pacific, a 5-year warm period (2013 to 2017) impacted the migration, distribution and abundance of key fish resources (*high confidence*). Increasing variability in grazing systems has negatively affected animal fertility, mortality and herd recovery rates, reducing livestock keepers' resilience (*medium confidence*). (Figure TS.6 FOOD-WATER) {3.5.5, 4.3.1, 5.2.1, 5.4.1, 5.4.2, 5.5.2, 5.8.1, 5.9.1, 5.12.1, 5.14.2, 5.14.6, 9.8.2, 9.8.5, 13.5.1, 14.5.4, CCP6.2, CCB MOVING PLATE, WGI AR6 11.2–11.8}

TS.B.3.4 Climate-related emerging food safety risks are increasing globally in agriculture and fisheries (*high confidence*). Higher temperatures and humidity caused by climate change increases toxigenic fungi on many food crops (*very high confidence*). Harmful algal blooms and water-borne diseases threaten food security and the economy and livelihoods of many coastal communities (*high confidence*). Increasing ocean warming and acidification are enhancing movement and bioaccumulation of toxins and contaminants into marine food webs (*medium confidence*) and with bio-magnification of persistent organic pollutants and methyl mercury already affecting fisheries (*medium confidence*). Indigenous Peoples and local communities, especially where food safety monitoring is underdeveloped, are among the most vulnerable to these risks, in particular in the Arctic (*high confidence*). (Figure TS.8 HEALTH) {3.5.5, 5.8.1, 5.9.1, 5.11.1, 7.2.2, 7.2.4, 14.5.6, CCP6.2.8, CCB ILLNESS}

TS.B.3.5 The impacts of climate change on food systems affect everyone, but some groups are more vulnerable. Women, the elderly and children in low-income households, Indigenous Peoples, minority groups, small-scale producers and fishing communities and people in high-risk regions more often experience malnutrition, livelihood loss and rising costs (*high confidence*). Increasing competition for critical resources, such as land, energy and water, can exacerbate the impacts of climate change on food security (*high confidence*). Examples include large-scale land deals, water use, dietary patterns, energy crops and use of feed crops. (Figure TS.10 COMPLEX RISK) {2.6.5, 4.8.3, 5.4.2, 5.5.2, 5.9.2, 5.12.2, 5.12.3, 5.13.1, 5.13.3, 5.13.4; 6.3.4, 9.8.1, Box 9.5, 12.3.1, 12.3.2, 14.5.2, 14.5.4, 14.5.6, 14.5.7, 14.5.8, 14.5.11, Box 14.6, 15.3.4, CCP5.2.3, CCP5.2.5, CCP6.2.7, CCP6.2.8}

Water systems and water security

TS.B.4 Currently, roughly half of the world's population are experiencing severe water scarcity for at least 1 month yr^{-1} due to climatic and other factors (*medium confidence*). Water insecurity is manifested through climate-induced water scarcity and hazards and is further exacerbated by inadequate water governance (*high confidence*). Extreme events and underlying vulnerabilities have intensified the societal impacts of droughts and floods, negatively impacted agriculture and energy production and increased the incidence of water-borne diseases. Economic and societal impacts of water insecurity are more pronounced in low-income countries than in middle- and high-income ones (*high confidence*). (Figure TS.2, Figure TS.3, Figure TS.6 WATER-FOOD) {Table 2.2, Table 2.3, 2.3.3. 2.4.2, 2.4.4, 4.1.1, Box 4.1, 4.2.1, 4.2.2, 4.2.3, 4.2.4, 4.2.5, 4.2.6, 4.3.1, 4.3.2, 4.3.3, 4.3.4, 4.3.5, 4.3.6, 4.3.8, 4.4.4, 5.9.1, 5.12.2, 5.12.3, 6.2.2, 6.2.3, 7.2.2, 7.2.4, 7.2.5, 7.2.6, 7.2.7, 8.3.2, 8.3.3, 9.7.1, 9.9.2, Box 9.4, 10.4.1, 10.4.4, Box 10.4, 10.5.4, Boxes 11.1–11.6, Table 11.2, 11.3, 11.3.1, 11.3.2, 11.4, Table 11.4, 11.3.3, 11.5.2, Table 11.2a, 11.3.3.1, Box, 11.3, Box 11.4, 12.3, 12.3.1, 12.3.2, 12.3.6, 12.3.7, 12.4, Table 12.4, 12.5.3.1, Figure 12.7, Figure 12.9, Figure 12.10, Figure 12.13, Table SM12.6, 13.3.1, 13.5.1, 13.6.1, 13.8.1, 13.10.1, 14.5.1–4,, 14.5.6, 14.7, Box 14.7, 15.3.3, 15.3.4, 16.2.3, CCP1.2.3, CCP3.1.2, CCP3.2.1, CCP5.2.2, CCP5.2.3, CCP5.2.7, CCP6.2.1, CCP6.2.5, CCP7.2.3, CCB DISASTER, CCB ILLNESS, CCB EXTREMES}

TS.B.4.1 Climate change has intensified the global hydrological cycle, causing several societal impacts, which are felt disproportionately by vulnerable people (*high confidence*). Human-induced climate change has affected physical aspects of water security through increasing water scarcity and exposing more people to water-related extreme events like floods and droughts, thereby exacerbating existing water-related vulnerabilities caused by other socioeconomic factors (*high confidence*). Many of these changes in water availability and water-related hazards can be directly attributed to anthropogenic climate change (*high confidence*). Water insecurity disproportionately impacts the poor, women, children, Indigenous Peoples and the elderly in low-income countries (*high confidence*) and specific marginal geographies (e.g., small island states and mountain regions). Water insecurity can contribute to social unrest in regions where inequality is high and water governance and institutions are weak (*medium confidence*). (Figure TS.6 WATER-FOOD, Figure TS.7 VULNERABILITY) {2.3.1, 2.3.3, 2.4.4, 4.1.1, 4.2.1, Box 4.1, 4.2.4, 4.3.6, 5.12.2, 5.12.3, 6.2.2, 6.2.3, 7.2.7, 9.7.1, 10.4.4, 12.5.3.1, 13.8.1, 15.3.3, 15.3.4, CCP5.2.2, CCB EXTREMES}

TS.B.4.2 Worldwide, people are increasingly experiencing unfamiliar precipitation patterns, including extreme precipitation events (*high confidence*). Nearly half a billion people now live in areas where the long-term average precipitation is now as high as was previously seen in only about 1 in 6 years (*medium confidence*). Approximately 163 million people now live in unfamiliarly dry areas (*medium confidence*) compared to 50 years ago. The intensity of heavy precipitation has increased in many regions since the 1950s (*high confidence*). Substantially more people (around 709 million) live in regions where annual maximum 1-d precipitation has increased than in regions where it has decreased (around 86 million) (*medium confidence*) since the 1950s. At the same time, more people (around 700 million) have been experiencing longer dry spells than shorter dry spells since the 1950s (*medium confidence*), leading to compound hazards related to both warming and precipitation extremes in most parts of the world

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(*medium confidence*). (Figure TS.6 WATER-FOOD) {2.3.1, 4.2.2, 4.2.3, 4.2.6, 4.3.1, 4.3.4, 6.2.2, 9.5.2–6, 13.2, 13.10, CCB EXTREMES}

TS.B.4.3 Glaciers are melting at unprecedented rates, causing negative societal impacts among communities that depend on cryospheric water resources (*high confidence*). Over the last two decades, the global glacier mass loss rate has been the highest since the glacier mass balance measurements began a century ago (*high confidence*). Melting of glaciers, snow decline and thawing of permafrost have threatened the water and livelihood security of local and downstream communities through changes in hydrological regimes and increases in the potential of landslides and glacier lake outburst floods. Cryosphere changes have impacted cultural uses of water among vulnerable mountain and Arctic communities and Indigenous Peoples (*high confidence*), who have long experienced historical, socioeconomic and political marginalisation (*medium to high confidence*). Cryosphere change has affected ecosystems, water resources, livelihoods and cultural uses of water in all cryosphere-dependent regions across the world (*very high confidence*). (Figure TS.3) {2.4.3, 2.6.5, 4.2.2, 4.3.8, 4.4.4, 6.2.2, 9.5.8, 10.5.4, 11.3.3, 10.4.4, Box 10.4, CCP5.2.2, CCP5.2.7, CCP6.2.5, 11.2.1, Table 11.2b, Table 11.9, 12.3.2, 12.3.7, Figure 12.9, Figure 12.13, Table SM12.6}

TS.B.4.4 Impacts of droughts and floods have intensified due to extreme events and underlying societal vulnerabilities (*high confidence*). Anthropogenic climate change has led to increased likelihood, severity and societal impacts of droughts (primarily agricultural and hydrological droughts) in many regions (*high confidence*). Between 1970 and 2019, drought-related disaster events worldwide caused billions of dollars in economic damages (*medium confidence*). Drylands are particularly exposed to climate change related droughts (*high confidence*). Recent heavy rainfall events that have led to catastrophic flooding were made more likely by anthropogenic climate change (*high confidence*). Observed mortality and losses due to floods and droughts are much greater in regions with high vulnerability and vulnerable populations such as the poor, women, children, Indigenous Peoples and the elderly due to historical, political and socioeconomic inequities (*high confidence*). {4.2.4, 4.2.5, 4.3.1, 4.3.2, 6.2.2, 7.2.2, 7.2.4, 7.2.5, 7.2.6, 11.2.1, 11.2.a, 13.2.1, 14.5.3, 15.3.4, CCP3.1.2, CCP3.2.1, 8.3.2, 8.3.3, 9.9.2, Box 9.4, 15.3.3, 15.3.4, 16.2.3, CCP5.2.6, CCP7.2.3, CCB DISASTER, CCB EXTREMES}

TS.B.4.5 Climate-induced changes in the hydrological cycle have negatively impacted freshwater and terrestrial ecosystems. Climate change and changes in land use and water pollution are key drivers of ecosystem loss and degradation (*high confidence*), with negative impacts observed on culturally significant terrestrial and freshwater species and ecosystems in the Arctic, mountain regions and other biodiversity hotspots (*high confidence*). Climate trends and extreme events have had major impacts on many natural systems (*high confidence*). For example, periodic droughts in parts of the Amazon since the 1990s, partly attributed to climate change, resulted in high tree mortality rates and basin-wide reductions in forest productivity, momentarily turning Amazon forests from a carbon sink into a net carbon source (*high confidence*). Fire risks have increased due to heat and drought conditions in many parts of the world (*medium confidence*). Increased precipitation has resulted in range shifts of species in some regions (*high confidence*). (Figure TS.10 COMPLEX RISK) {2.4.2, 2.4.3, 2.4.4; Table 2.2; Table 2.3, Table SM2.1, 4.3.3, 4.3.4, 4.3.5, 4.3.8, 9.6.1, 11.3.1, 11.3.2, Table 11.2b, Table 11.4, Table 11.6, Table 11.9, 12.3, 12.4, Figure 12.7, Figure 12.9, Figure 12.10, 13.3.1, 14.5.1, 14.5.2, 14.5.3, Box 14.7, CCP1.2.3, CCP5.2.3, CCP6.2.1}

TS.B.4.6 Hydrological cycle changes have impacted food and energy production and increased the incidence of water-borne diseases. Climate-induced trends and extremes in the water cycle have impacted agricultural production positively and negatively, with negative impacts outweighing the positive ones (*high confidence*). Droughts, floods and rainfall variability have contributed to reduced food availability and increased food prices, threatening food and nutrition security, and the livelihoods of millions globally (*high confidence*), with the poor in parts of Asia, Africa and South and Central America being disproportionately affected (*high confidence*). Drought years have reduced thermoelectric and hydropower production by around 4–5% compared to long-term average production since the 1980s (*medium confidence*), reducing economic growth in Africa and with billions in US dollars of existing and planned hydropower infrastructure assets in mountain regions worldwide and in Africa exposed to increasing hazards (*high confidence*). Changes in temperature, precipitation and water-related disasters are linked to increased incidences of water-borne diseases such as cholera, especially in regions with limited access to safe water, sanitation and hygiene infrastructure (*high confidence*). {4.3.1, 4.3.2, 4.3.3, 4.3.4, 4.3.5,4.3.6, 4.3.8, 5.9.1, 7.2.2, 9.7.1, Box 9.4, Box 9.5, 9.8.2, 9.10.2, 10.4.1, 11.3.3, Box 11.3, 11.4, 11.5.2, Table 11.2, Boxes 11.1–11.6, 13.2.1, 13.5.1, 13.6.1, 13.7.1, 14.5.3, CCP5.2.2}

Health and well-being

TS.B.5 Climate change has already harmed human physical and mental health (*very high confidence*). In all regions, health impacts often undermine efforts for inclusive development. Women, children, the elderly, Indigenous People, low-income households and socially marginalised groups within cities, settlements, regions and countries are the most vulnerable (*high confidence*). (Figure TS.7 VULNERABILITY, Figure TS.8 HEALTH) {2.4.2, 3.4.2, 3.5.3, 3.5.5, 3.5.6, 4.2.5, 4.3.3, Table 4.3, 5.5.2, 5.11.1, 5.12.3, Box 5.10, 7.2.1, 7.2.2, 7.2.3, 7.2.4, 7.2.5, 7.4.2, Box 7.1, Box 7.3, 8.2.1, 8.3.2, 8.3.4, Box 8.6, 9.1.5, 9.8.1, 9.10.1, 9.10.2, Figure 9.34, Figure 9.33, Box 9.1, 10.4.7, 11.3.6, Box 11.1, Table 11.10, 12.3.1, 12.3.2, 12.3.4, 12.3.5, 12.3.6, 12.3.7, 12.3.7, 12.3.8, Figure 12.4, Figure 12.6, Table 12.1, Table 12.2, Table 12.9, Table 12.11, 13.7.1, Figure 13.24, 14.4, 14.5.2, 14.5.4, 14.5.6, 14.5.7, 14.5.8, Box 14.2, Figure 14.8, 15.3.4, 16.2.3, CCP2.2.2, CCP5.1, Table CCP5.1, CCP5.2.3, CCP6.2.6, CCP6.3, CCB DISASTER, Table CCB DISASTER 4.1,CCB HEALTH, CCB ILLNESS, CCB MOVING PLATE, CCB SLR, CWGB URBAN}

TS.B.5.1 Observed mortality from floods, drought and storms is 15 times higher for countries ranked as highly vulnerable compared to less vulnerable countries in the last decade (*high confidence*). While an increase in drought has been observed in almost all continents to different extents, it is particularly the most vulnerable regions where such droughts result in relatively high

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mortality (*high confidence*). Between 1970 and 2019, 7% of all disaster events worldwide were drought related, yet they contributed to 34% of disaster-related deaths, mostly in Africa. (Figure TS.7 VULNERABILITY) {4.2.5, Table 4.3, 7.2.1, 7.2.3, 7.2.4, 8.3.2, Box 9.1, 9.10.2, 10.4.7, 12.3.1, 12.3.6, 16.2.3, Table CCP5.1, CCB DISASTER, Table CCB DISASTER 4.1, CCB ILLNESS}

TS.B.5.2 Mental health challenges increase with warming temperatures (*high confidence*), trauma associated with extreme weather (*very high confidence*) and loss of livelihoods and culture (*high confidence*). Distress sufficient to impair mental health has been caused by climate-related ecological grief associated with environmental change (e.g., solastalgia) or extreme weather and climate events (*very high confidence*), vicarious experience or anticipation of climate events (*medium confidence*) and climate-related loss of livelihoods and food insecurity (*very high confidence*). Vulnerability to mental health effects of climate change varies by region and population, with evidence that Indigenous Peoples, agricultural communities, first responders, women and members of minority groups experience greater impacts (*high confidence*). {7.2.5, 7.4.2, 8.3.4, Box 8.6, 9.10.2, 11.3.6, 13.7.1, 14.5.6, Figure 14.8, 15.3.4, CCP5.2.5, CCP6.2.6, CCP6.3}

TS.B.5.3 Increasing temperatures and heatwaves have increased mortality and morbidity (*very high confidence*), with impacts that vary by age, gender, urbanisation and socioeconomic factors (*very high confidence*). A significant proportion of warm-season heat-related mortality in temperate regions is attributed to observed anthropogenic climate change (*medium confidence*), with fewer data available for tropical regions in Africa (*high confidence*). For some heatwave events over the last two decades, associated health impacts have been partially attributed to observed climate change (*high confidence*). Highly vulnerable groups experiencing health impacts from heat stress include anyone working outdoors and, especially, those doing outdoor manual labour (e.g., construction work, farming). Potential hours of work lost due to heat have increased significantly over the past two decades (*high confidence*). Some regions are already experiencing heat stress conditions at or approaching the upper limits of labour productivity (*high confidence*). {7.2.1, 7.2.4 8.2.1, 9.1.5, 9.10.1, Figure 9.34, 10.4.7, 11.3.6.1, 12.3.1, 12.3.7, 12.3.8, Figure 12.6, Table 12.2, 13.7.1, 14.5.6, 14.5.8, 16.2.3, CWGB URBAN}

TS.B.5.4 Climate change has contributed to malnutrition in all its forms in many regions, including undernutrition, overnutrition and obesity, and to disease susceptibility (*high confidence*), especially for women, pregnant women, children, low-income households, Indigenous Peoples, minority groups and small-scale producers (*high confidence*). Extreme climate events have been key drivers in rising undernutrition of millions of people, primarily in Africa and Central America (*high confidence*). For example, anthropogenic warming contributed to climate extremes induced by the 2015–2016 El Niño, which resulted in severe droughts, leading to an additional 5.9 million children in 51 countries becoming underweight (*high confidence*). Undernutrition can in turn increase susceptibility to other health problems, including mental health problems, and impair cognitive and work performance, with resulting economic impacts (*very high confidence*). Children and pregnant women experience disproportionate adverse health and nutrition impacts (*high confidence*). {5.12.3, 7.2.4, 7.2.5, CCP5.2.3, CCP5.2.3.1, 14.4, 14.5.2, 14.5.4, 14.5.6, 14.5.7, Figure 14.8, 9.8.1, 9.10.2, 10.4.7, 15.3.4, CCP6.2.6, CCB HEALTH, CCB ILLNESS, CCB MOVING PLATE}

TS.B.5.5 Climate-related food safety risks have increased globally (*high confidence*). These risks include *Salmonella*, *Campylobacter* and *Cryptosporidium* infections (*medium confidence*) mycotoxins associated with cancer and stunting in children (*high confidence*) and seafood contamination with marine toxins and pathogens (*high confidence*). Climate-related food-borne disease risks vary temporally and are influenced, in part, by food availability, accessibility, preparation and preferences (*medium confidence*), as well as adequate food safety monitoring (*high confidence*). {3.4.2, 3.5.3, 3.5.5, 3.5.6, 5.11.1, Box 5.10, 7.2.1, 7.2.2, 13.7.1, Figure 13.24, 14.5.6, 15.3.4, CCP6.2.6, CCB SLR}

TS.B.5.6 Higher temperatures combined with land use/land cover change are making more areas suitable for the transmission of vector-borne diseases (*high confidence*). More extreme weather events have contributed to vector-borne disease outbreaks in humans through direct effects on pathogens and vectors and indirect effects on human behaviour and emergency response destabilisation (*medium confidence*). Climate change and variability are facilitating the spread of chikungunya virus in North, Central and South America, Europe and Asia (*medium to high confidence*); tick-borne encephalitis in Europe (*medium confidence*); Rift Valley fever in Africa; West Nile fever in southeastern Europe, western Asia, the Canadian prairies and parts of the USA (*medium confidence*); Lyme disease vectors in North America (*high confidence*) and Europe (*medium confidence*); malaria in eastern and southern Africa (*high confidence*); and dengue globally (*high confidence*). For example, in Central and South America, the reproduction potential for the transmission of dengue increased between 17% and 80% for the period 1950–1954 to 2016–2021, depending on the sub-region, as a result of changes in temperature and precipitation (*high confidence*). {2.4.2, 4.3.3, 7.2.1, 7.2.2, 9.10.2, 10.4.7, Table 11.10, 12.3.1, 12.3.2, 12.3.3, 12.3.5, 12.3.6, Figure 12.4, Table 12.9, Table 12.11, Table 12.1, 13.7.1, Figure 13.24, 14.5.6, 15.3.4, 16.2.3, CCB ILLNESS}

TS.B.5.7 Higher temperatures (*very high confidence*), heavy rainfall events (*high confidence*) and flooding (*medium confidence*) are associated with increased water-borne diseases, particularly diarrhoeal diseases, including cholera (*very high confidence*) and other gastrointestinal infections (*high confidence*) in high-, middle- and low-income countries. Water insecurity and inadequate water, sanitation and hygiene increase disease risk (*high confidence*), stress and adverse mental health (*limited evidence, medium agreement*), food insecurity and adverse nutritional outcomes and poor cognitive and birth outcomes (*limited evidence, medium agreement*). {4.3.3, 7.2.2, Box 7.3, 9.10.1, Figure 9.33, 10.4.7, 11.3.6, 12.3.4, 12.3.5, 13.7.1, Figure 13.24, 14.5.6, 16.2.3, CCP6.2.6, CCB ILLNESS, CWGB URBAN}

TS.B.5.8 Climate change driven range shifts of wildlife, exploitation of wildlife and loss of wildlife habitat quality have increased opportunities for pathogens to spread from wildlife to human populations, which has resulted in increased emergence of zoonotic disease epidemics and pandemics (*medium confidence*). Zoonoses that have been historically rare or never documented in Arctic and sub-Arctic regions of Europe, Asia and North America are emerging as a result of climate-induced environmental change (e.g., anthrax), spreading polewards and increasing in incidence (e.g., tularemia) (*very high confidence*). {2.4.2, 5.5.2, 7.2.2, Box 7.1, 10.4.7, 12.3.1, 12.3.4, CCP2.2.2, CCP6.2.6, CCB ILLNESS}

TS.B.5.9 Several chronic, non-communicable respiratory diseases are climate-sensitive based on their exposure pathways (e.g., heat, cold, dust, small particulates, ozone, fire smoke and allergens) (*high confidence*), although climate change is not the dominant driver in all cases. Exposure to wildfires and associated smoke has increased in several regions (*very high confidence*). The 2019–2020 southeastern Australian wildfires resulted in the deaths of 33 people, a further 429 deaths and 3230 hospitalisations due to cardiovascular or respiratory conditions and $1.95 billion in health costs. Spring pollen season start dates in northern mid-latitudes are occurring earlier due to climate change, increasing the risks of allergic respiratory diseases (*high confidence*). {2.4.4, 7.2.3, 14.5.6, Box 14.2, 11.3.6, Box 11.1, 12.3.3, 12.3.4, 12.3.6, 12.3.7, 13.7.1}

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Migration and displacement

TS.B.6 Since AR5 there is increased evidence that climate hazards associated with extreme events and variability act as direct drivers of involuntary migration and displacement and as indirect drivers through deteriorating climate-sensitive livelihoods (*high confidence*). Most climate-related displacement and migration occur within national boundaries, with international movements occurring primarily between countries with contiguous borders (*high confidence*). Since 2008, an annual average of over 20 million people have been internally displaced annually by weather-related extreme events, with storms and floods being the most common (*high confidence*). {1.1.1, 1.3, 7.2.6, 9.9.2, Box 9.8, Box 10.2, 12.3, 13.8.1, 15.3.4, 16.2.3, 18.2, CCP3.2, CCB MIGRATE}

TS.B.6.1 The most common climatic drivers for migration and displacement are drought, tropical storms and hurricanes, heavy rains and floods (*high confidence*). Extreme climate events act as both direct drivers (e.g., destruction of homes by tropical cyclones) and indirect drivers (e.g., rural income losses during prolonged droughts) of involuntary migration and displacement (*very high confidence*). The largest absolute number of people displaced by extreme weather each year occurs in Asia (South, Southeast and East), followed by sub-Saharan Africa, but small island states in the Caribbean and South Pacific are disproportionately affected relative to their small population size (*high confidence*). {4.3.7, 7.2.6, 9.9.2, Box 9.8, 12.3.1, 12.3.2, 12.3.3, 12.3.5, 12.5.8, 15.3.4, 16.2.3, CCB MIGRATE}

TS.B.6.2 The impacts of climatic drivers on migration are highly context-specific and interact with social, political, geopolitical and economic drivers (*high confidence*). Specific climate events and conditions cause migration to increase, decrease or flow in new directions (*high confidence*). One of the main pathways for climate-induced migration is through deteriorating economic conditions and livelihoods (*high confidence*). Climate change has influenced changes in temporary, seasonal or permanent migration, often rural to urban or rural to rural, that is associated with labour diversification as a risk-reduction strategy in Central America, Africa, South Asia and Mexico (*high confidence*). This movement is often followed by remittances (*medium confidence*). However, the same economic losses can also undermine household resources and savings, limiting mobility and compounding people's exposure and vulnerability (*high confidence*). {4.3.7, 5.5.4, 7.2.6, 8.2.1, Box 9.8, 12.3.1, 12.3.2, 12.3.3, 12.3.5, 12.5.8, 13.8.1, CCP5.2.5, CCB MIGRATE}

TS.B.6.3 Outcomes of climate-related migration are highly variable, with socioeconomic factors and household resources affecting migration success (*high confidence*). The more agency migrants have (i.e., the degree of voluntarity and freedom of movement), the greater the potential benefits for sending and receiving areas (*high agreement, medium evidence*). Displacement or low-agency migration is associated with poor health, well-being and socioeconomic outcomes for migrants and yields fewer benefits to sending or receiving communities (*high agreement, medium evidence*). Involuntary migration occurs when adaptation alternatives are exhausted or not viable and reflects non-climatic factors that constrain adaptive capacity and create high levels of exposure and vulnerability (*high confidence*). These outcomes are also shaped by policy and planning decisions at regional, national and local scales that relate to housing, infrastructure, water provisioning, schools and healthcare to support the integration of migrants into receiving communities (*high confidence*). {4.3.7, 5.5.3, 5.5.4, 5.10.1, 5.12.2, 7.2.6, 7.2.6, 8.2.1, 9.8.3, Box 8.1, 10.3, Box 12.2, CCB MIGRATE, CCB SLR}

TS.B.6.4 Immobility in the context of climatic risk reflects both vulnerability and lack of agency, but is also a deliberate choice (*high confidence*). Deliberate or voluntary, immobility represents an assertion of the importance of culture, livelihood and sense of place. Planned relocations by governments of settlements and populations exposed to climatic hazards are not presently commonplace, although the need is expected to grow. Existing examples of relocations of Indigenous Peoples in coastal Alaska and villages in the Solomon Islands and Fiji suggest that relocated people can experience significant financial and emotional distress as cultural and spiritual bonds to place and livelihoods are disrupted (*high confidence*). {7.2.6, 13.8.1, 15.3.4, CCP6.2.5, CCB MIGRATE}

Human vulnerability

TS.B.7 Vulnerability significantly determines how climate change impacts are being experienced by societies and communities. Vulnerability to climate change is a multi-dimensional, dynamic phenomenon shaped by intersecting historical and contemporary political, economic and cultural processes of marginalisation (*high confidence*). Societies with high levels of inequity are less resilient to climate change (*high confidence*). (Figure TS.7 VULNERABILITY) {2.6.5, 2.6.7, 5.12.3, 5.13.4, 7.1, Box 6.6, 6.4.3.5, 8.2.1, 8.2.2, 8.3.2, 8.3.3, 8.3.4, 13.8.2, 9.8.2, 9.11.4, Box 9.1, 10.3.3., 12.1.1, 12.2, 12.3, 12.5.5, 12.5.7, Figure 12.2, 14.4, 16.5.2, CCB COVID, CCB GENDER, CCB ILLNESS}

TS.B.7.1 About 3.3 billion people are living in countries with high human vulnerability to climate change (*high confidence*).

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Approximately 1.8 billion people reside in regions classified as having low vulnerability. Global concentrations of high vulnerability are emerging in transboundary areas encompassing more than one country as a result of interlinked issues concerning health, poverty, migration, conflict, gender inequality, inequity, education, high debt, weak institutions, lack of governance capacities and infrastructure. Complex human vulnerability patterns are shaped by past developments, such as colonialism and its ongoing legacy (*high confidence*), are worsened by compounding and cascading risks (*high confidence*) and are socially differentiated. For example, low-income, young, poor and female-headed households face greater livelihood risks from climate hazards (*high confidence*). (Figure TS.7 VULNERABILITY) {4.3.1, 5.5.2, 5.12.3, 5.13.3, Box 5.13, 8.3.2, 8.4.5, Box 9.1, 9.4.1, 9.8.1, 9.11.4, 10.3.3, 12.2, 12.3, 12.5.5, 12.5.7, Figure 12.2, 14.4}

TS.B.7.2 Climate change is impacting Indigenous Peoples' ways of life (*very high confidence*), cultural and linguistic diversity (*medium confidence*), food security (*high confidence*) and health and well-being (*very high confidence*). Indigenous knowledge and local knowledge can contribute to reducing the vulnerability of communities to climate change (*medium to high confidence*). Supporting Indigenous self-determination, recognising Indigenous Peoples' rights and supporting Indigenous knowledge-based adaptation are critical to reducing climate change risks and effective adaptation (*very high confidence*). {1.3.2, 2.6.5, 4.3.8, 4.6.9, 4.8.4, 5.5.2, 5.8.2, 5.10.2, 5.14.2, 6.4.7, Box 8.7, Box 9.2, 11.4.1, 11.4.2, Table 11.10, Table 11.11, Table 11.12, 12.3, 12.4, Figure 12.9, 13.8.1, 13.8.2, Box.14.1, 15.3.4, CCP5.2.2, CCP5.2.5, CCP6.2, Box CCP6.2, CCP6.3, CCP6.4}

TS.B.7.3 The intersection of gender with race, class, ethnicity, sexuality, Indigenous identity, age, disability, income, migrant status and geographical location often compounds vulnerability to climate change impacts (*very high confidence*), exacerbates inequity and creates further injustice (*high confidence*). There is evidence that present adaptation strategies do not sufficiently include poverty reduction and the underlying social determinants of human vulnerability such as gender, ethnicity and governance (*high confidence*). {1.2.1, 1.4.1, 4.8.3, 4.8.5, 4.8.6, 4.6.3, 6.1.5, 6.3, 6.4, Box 9.1, 9.4.1, Box 9.8, 11.7.2, 18.4, 18.5, CCP5.2.7, CCB GENDER}

TS.B.7.4 Climate variability and extremes are associated with more prolonged conflict through food price spikes, food and water insecurity, loss of income and loss of livelihoods (*high confidence*), with more consistent evidence for low-intensity organised violence within countries than for major or international armed conflict (*medium confidence*). Compared to other socioeconomic factors, the influence of climate on conflict has been assessed as being relatively weak (*high confidence*) but is exacerbated by insecure land tenure, weather-sensitive economic activities, weak institutions and fragile governance, poverty and inequality (*medium confidence*). The literature also suggests a larger climate-related influence on the dynamics of conflict than on the likelihood of initial conflict outbreak (*low confidence*). There is insufficient evidence at present to attribute armed conflict to human-induced climate change. {4.1, 4.3.1, 4.3.6, 5.8.3, 5.12.4, Box 5.9, Box 6.3; Box 9.9; 7.2.7, 12.5.8, 12.7.4, 16.2.3}

Cities, settlements and infrastructure

TS.B.8 Cities and settlements (particularly unplanned and informal settlements and in coastal and mountain regions) have continued to grow at rapid rates and remain crucial both as concentrated sites of increased exposure to risk and increasing vulnerability and as sites of action on climate change (*high confidence*). More people and key assets are exposed to climate-induced impacts, and loss and damage in cities, settlements and key infrastructure since AR5 (*high confidence*). Sea level rise, heatwaves, droughts, changes in runoff, floods, wildfires and permafrost thaw cause disruptions of key infrastructure and services such as energy supply and transmission, communications, food and water supply and transport systems in and between urban and peri-urban areas (*high confidence*). The most rapid growth in urban vulnerability and exposure has been in cities and settlements where adaptive capacity is limited, including informal settlements in low- and middle-income communities and in smaller and medium-sized urban communities (*high confidence*). (Figure TS.9 URBAN) {4.3.4, 8.2, 8.3, 6.1.4, Box 6.1, 9.9.1, 9.9.2, 10.4.6, 11.6, Table 11.14, 12.6.1, 13.6.1, 14.5.5, 16.2, 16.5, CCP2.2, CCP5.2.5, CCP5.2.6, CCP5.2.7, CCP6.2.3, CCP6.2.4, Box CCP6.1, CCP6.2.5, CCP6.3.1, Table CCP6.5, Table CCP6.6}

TS.B.8.1 Globally, urban populations grew by more than 397 million people between 2015 and 2020, with more than 90% of this growth taking place in less developed regions. The most rapid growth in urban vulnerability has been in unplanned and informal settlements and in smaller to medium urban centres in low- and middle-income nations where adaptive capacity is limited (*high confidence*). Since AR5, observed impacts of climate change on cities, peri-urban areas and settlements have extended from direct, climate-driven impacts to compound, cascading and systemic impacts (*high confidence*). Patterns of urban growth, inequity, poverty, informality and precariousness in housing are uneven and shape cities in key regions, such as within Africa and Asia. In sub-Saharan Africa, about 60% of the urban population lives in informal settlements, while Asia is home to the largest share of people—529 million—living in informal settlements. The high degree of informality limits adaptation and increases differential vulnerability to climate change (*high confidence*). Globally, exposure to climate-driven impacts such as heatwaves, extreme precipitation and storms in combination with rapid urbanisation and lack of climate-sensitive planning, along with continuing threats from urban heat islands, is increasing the vulnerability of marginalised urban populations and key infrastructure to climate change, for example, more frequent and/or extreme rainfall and drought stress existing design and capacity of current urban water systems and heighten urban and peri-urban water insecurity (*high confidence*). COVID-19 has had a substantial urban impact and generated new climate-vulnerable populations (*high confidence*). (Figure TS.9 URBAN) {4.3.4, 6.1.4 6.2, 6.2.2, 9.9.1, 9.9.3, 10.4.6, 12.4, 12.6.1, 14.5.5, 14.5.6, 17.2.1, CCB COVID}

TS.B.8.2 People, livelihoods, ecosystems, buildings and infrastructure within many coastal cities and settlements are

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already experiencing severe compounding impacts, including from sea level rise and climate variability (*high confidence*). Coastal cities are disproportionately affected by interacting, cascading and climate-compounding climate- and ocean-driven impacts, in part because of the exposure of multiple assets, economic activities and large populations concentrated in narrow coastal zones (*high confidence*), with about a tenth of the world's population and physical assets in the Low Elevation Coastal Zone (less than 10 m above sea level). Early impacts of accelerating sea level rise have been detected at sheltered or subsiding coasts, manifesting as nuisance and chronic flooding at high tides, water-table salinisation, ecosystem and agricultural transitions, increased erosion and coastal flood damage (*medium confidence*). Coastal settlements with high inequality, for example a high proportion of informal settlements, as well as deltaic cities prone to land subsidence (e.g., Bangkok, Jakarta, Lagos, New Orleans, Mississippi, Nile, Ganges-Brahmaputra deltas) and small island states are highly vulnerable and have experienced impacts from severe storms and floods in addition to, or in combination with, those from accelerating sea level rise (*high confidence*). Currently, coastal cities already dependent on extensive protective works face the prospects of significantly increasing costs to maintain current protection levels, especially if the local sea level rises to the point that financial and technical limits are reached; systemic changes, such as relocation of millions of people, will be necessary (*medium confidence*). (Figure TS.9 URBAN) {4.3.4, Box 6.3, 6.3.1, 6.4.5, Box 6.4, 6.4.3, 6.4.5, Figure 6.5, Box 9.8, 10.3.7, 11.7.2, 12.1.1, 13.8.1.1, 15.7, CWGB URBAN}

TS.B.8.3 Climate impacts on urban population health, livelihoods and well-being are felt disproportionately, with the most economically and socially marginalised being most affected (*high confidence*). Vulnerabilities vary by location and are shaped by intersecting processes of marginalization, including gender, class, race, income, ethnic origin, age, level of ability, sexuality and non-conforming gender orientation (*high confidence*). (Figure TS.9 URBAN) {4.3.4, Box 6.3, 6.3.1, 6.4.5, Box 6.4, 6.4.3, 6.4.5, Figure 6.5, Box 9.8, 10.3.7, 11.7.2, 12.1.1, 13.8.1.1, 15.7, CWGB URBAN}

TS.B.8.4 Infrastructure systems provide critical services to individuals, society and the economy in both urban and rural areas; their availability and reliability directly or indirectly influence the attainment of all SDGs (*high confidence*). Due to the connectivity of infrastructure systems, climate impacts, such as with thawing permafrost or severe storms affecting energy and transport networks, can propagate outside the reach of the hazard footprint and cause larger impacts and widespread regional disruption (*high confidence*). Interdependencies between infrastructure systems have created new pathways for compounding climate risk, which has been accelerated by trends in information and communication technologies, increased reliance on energy, and complex (often global) supply chains (*high confidence*). (Figure TS.10 COMPLEX RISK) {2.3, 4.6.2, 6.2, 6.3, Box 6.2, 9.7.3, 9.9.3, 9.9.5, 10.4.6, 10.5, 10.6, 11.3.3, 11.3.5, 11.5.1, Box 11.4, 12.3, 12.5, 13.2, 13.6.1, 13.10.2, Box 14.5, 14.5.5, 15.3, 16.5.2.3, 16.5.2.4, 16.5.3, 16.5.4, 17.2, 17.5, 18.3, 18.4, CCP2.2, CCP4.1, CCP5.3, CCP6.2}

Economic sectors

TS.B.9 The effects of climate change impacts have been observed across economic sectors, although the magnitude of the damage varies by sector and by region (*high confidence*). Recent extreme weather and climate-induced events have been associated with large costs through damaged property, infrastructure and supply chain disruptions, although development patterns have driven much of these increases (*high confidence*). Adverse impacts on economic growth have been identified from extreme weather events (*high* confidence) with large effects in developing countries (*high confidence*). Widespread climate impacts have undermined economic livelihoods, especially among vulnerable populations (*high confidence*). Climate impacts and projected risks have been insufficiently internalised into private- and public-sector planning and budgeting practices and adaptation finance (*medium confide*nce). (Figure TS.3) {3.5.5, 4.3.1, 4.3.2, 4.3.4, 6.2.4, 6.4.5, Table 6.11, 8.3.3, 8.3.5, 9.11.1, 9.11.4, CCP5.2.7, Box 10.7, 11.5.1, 13.10.1, 13.11.1, Box 14.5, Box 14.6, 14.5.8, 15.3.4, 16.2.3, CCB FINANCE, CWGB ECONOMIC }

TS.B.9.1 Economic losses of climate change arise from adverse impacts on inputs, such as crop yields (*very high confidence*), water availability (*high confidence*) and outdoor labour productivity due to heat stress (*high confidence*). Greater economic losses are observed for sectors with high direct climate exposure, including regional losses to agriculture, forestry, fisheries, energy and tourism (*high confidence*). Many industrial and service sectors are indirectly affected through supply disruptions, especially during and following extreme events (*high confidence*). Costs are also incurred from adaptation, disaster spending, recovery and rebuilding of infrastructure (*high confidence*). Estimates of the global effects of climate change on aggregate measures of economic performance and gross domestic product (GDP) range from negative to positive, in part due to uncertainty in how weather variability and climate impacts manifest in GDP (*high confidence*). Climate change is estimated to have slowed trends of decreasing economic inequality between developed and developing countries (*low confidence*), with particularly negative effects for Africa (*medium confidence*). {4.2.2, 4.3.1, 4.3.2, 4.7.5, 9.6.3, 9.11.1,, 11.3.4 11.5.2, Box 11.1, 13.6.1, 14.5.1, 14.5.2, 14.5.3, 15.3.3, 15.3.4, 14.5.8, Box 14.6, Box 14.7, 16.2.3, CCP4.4, CCP4.5, CCP5.2.5, CCP6.2.5}

TS.B.9.2 A growing range of economic and non-economic losses has been detected and attributed to climate extremes and slow-onset events under observed increases in global temperatures in both low- and high-income countries (*medium confidence*). Extreme weather events, such as tropical cyclones, droughts and severe fluvial floods, have reduced economic growth in the short term (*high confidence*) and will continue to reduce it in the coming decades (*medium confidence*) in both developing and industrialised countries. Patterns of development have augmented the exposure of more assets to extreme hazards, increasing the magnitude of the losses (*high confidence*). Small Island Developing States have reported economic losses and a wide range of damage from tropical cyclones and increases in sea level rise (*high confidence*). Wildfires partly attributed to climate change have caused substantial economic

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damage in recent years in North America, Australia and the Arctic (*high confidence*). {4.2.4, 4.2.5, 4.7.5, 8.2, 8.3.4, 8.4.1, 8.4.5, Box 8.5, 9.11.1, Box 10.7, Box 11.1, 11.5.2, Table 11.13, 13.10.1, Box 14.6, 15.7, 15.8, 16.2.3, 16.5.2, CCB DISASTER, CWGB ECONOMIC}

TS.B.9.3 Economic livelihoods that are more climate sensitive have been disproportionately degraded by climate change (*high confidence*). Climate-sensitive livelihoods are more concentrated in regions that have higher socioeconomic vulnerabilities and lower adaptive capacities, exacerbating existing inequalities (*medium confidence*). Extreme events have also had more pronounced adverse effects in poorer regions and on more vulnerable populations (*medium confidence*). These greater economic effects have further reduced the ability of these populations to adapt to existing impacts (*medium confidence*). Within populations, the poor, women, children, elderly and Indigenous populations have been especially vulnerable due to a combination of factors, including gendered divisions of paid and/or unpaid labour (*high confidence*). {4.3.1, 4.3.8, 8.3.5, 9.1.1, 13.8.1, Box 14.6, 16.2.3, CCB GENDER, CWGB ECONOMIC}

TS.B.9.4 Current planning and budgeting practices have given insufficient consideration to climate impacts and projected risks, placing more assets and people in regions with current and projected climate hazards (*medium confidence*). Existing adaptation has prevented greater economic losses (*medium confidence*), yet adaptation gaps remain due to limited financial resources, including gaps in international adaptation finance and competing priorities in budget allocations (*medium confidence*). Insufficient consideration of these impacts, however, has placed more assets in areas that are highly exposed to climate hazards (*medium confidence*). {4.7.1, 6.4.5, Box 8.3, 9.4.1, 10.5, 10.6, 11.8.1, 13.11.1, Box 14.6, 15.3.3, 16.4.3, CCP5.2.7, CCB FINANCE}

TS.C Projected Impacts and Risks

This section identifies future impacts and risks under different degrees of climate change. As a result, 127 key risks have been found across regions and sectors. These are integrated as eight overarching risks (called Representative Key Risks, RKRs) which relate to low-lying coastal systems; terrestrial and ocean ecosystems; critical physical infrastructure, networks and services; living standards and equity; human health; food security; water security; and peace and migration. Risks are projected to become severe with increased warming and under ecological or societal conditions of high exposure and vulnerability. The intertwined issues of biodiversity loss and climatic change together with human demographic changes, particularly rapid growth in low-income countries, an ageing population in high-income countries and rapid urbanisation are seen as core issues in understanding risk distribution at all scales. {16.5.2, Table 16.A.4, SMTS.2}

Ecosystems and biodiversity

TS.C.1 Without urgent and ambitious emissions reductions, more terrestrial, marine and freshwater species and ecosystems will face conditions that approach or exceed the limits of their historical experience (*very high confidence*). Threats to species and ecosystems in oceans, coastal regions and on land, particularly in biodiversity hotspots, present a global risk that will increase with every additional tenth of a degree of warming (*high confidence*). The transformation of terrestrial and ocean/coastal ecosystems and loss of biodiversity, exacerbated by pollution, habitat fragmentation and land use changes, will threaten livelihoods and food security (*high confidence*). (Figure TS.5 ECOSYSTEMS) {2.5.1, 2.5.2, 2.5.3, Figure 2.6, Figure 2.7, Figure 2.8, 2.5.4, Figure 2.11, Table 2.5, 3.2.4, 3.4.2, 3.4.3, 4.5.5, 9.6.2, 12.4, 13.10.2, 14.5.1, 14.5.2, 15.3.3, 16.4.2, 16.4.3, CCP1.2.4, CCP5.3.2, CCP5.2.7, CCP 7.3.5}

TS.C.1.1 Near-term warming will continue to cause plants and animals to alter their timing of seasonal events (*high confidence*) and to move their geographic ranges (*high confidence*). Risks escalate with additional near-term warming in all regions and domains (*high confidence*). Without urgent and deep emissions reductions, some species and ecosystems, especially those in polar and already-warm areas, will face temperatures beyond their historical experience in coming decades (e.g., >20% of species on some tropical landscapes and coastlines at 1.5°C global warming). Unique and threatened ecosystems are expected to be at high risk in the very near term at 1.2°C global warming levels (*very high confidence*) due to mass tree mortality, coral reef bleaching, large declines in sea-ice-dependent species and mass mortality events from heatwaves. Even for less vulnerable species and systems, projected climate change risks surpass hard limits to natural adaptation, increasing species at high risk of population declines (*medium confidence*) and loss of critical habitats (*medium to high confidence*) and compromising ecosystem structure, functioning and resilience (*medium confidence*). At a global warming of 2°C with associated changes in precipitation global land area burned by wildfire is projected to increase by 35% (*medium confidence*). (Figure TS.5 ECOSYSTEMS) {2.5.1, 2.5.2, 2.5.3, 2.5.4, 2.6.1, Figure 2.6, Figure 2.7, Figure 2.8, Figure 2.9, Figure 2.11, Table 2.5, 3.4.2, 3.4.3, 3.5.5, 4.5.5, 9.6.2, 11.3.1, 11.3.2, 12.3, 13.10.2, 14.5.1, 14.5.2, 15.3.3, 16.4.2, 16.4.3, CCP1.2.1, CCP1.2.4, CCP5.3.2, CCP7.3, CCB DEEP, CCB SLR}

TS.C.1.2 Risks to ecosystem integrity, functioning and resilience are projected to escalate with every tenth of a degree increase in global warming (*very high confidence*). Beginning at 1.5°C warming, natural adaptation faces hard limits, driving high risks of biodiversity decline, mortality, species extinction and loss of related livelihoods (*high confidence*). At 1.6°C (median estimate), >10% of species are projected to become endangered, increasing to >20% at 2.1°C, representing severe biodiversity risk (*medium confidence*). These risks escalate with warming, most rapidly and severely in areas at both extremes of temperature and precipitation (*high confidence*). With warming of 3°C, >80% of marine species across large parts of the tropical Indian and Pacific Ocean will experience potentially dangerous climate conditions (*medium confidence*). Beyond 4°C warming, projected impacts expand, including extirpation of approx. 50% of tropical marine species (*medium confidence*) and biome shifts (changes in the major vegetation form of an ecosystem) across 35% of global land area (*medium confidence*). These will lead to a shift of much of the Amazon rainforest to drier and lower-biomass vegetation (*medium confidence*), poleward shifts of boreal forest into treeless tundra across the Arctic and upslope shifts of montane forests into alpine grassland

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(*high confidence*). (Figure TS.5 ECOSYSTEMS) { 2.3.2, 2.5, 2.5.1, 2.5.2, 2.5.3, 2.5.4, 3.4.2, 3.4.3, 9.6.2, 11.3.1, 11.3.2, 12.3, 13.3.1, 13.4.1, 13.10.2, 16.4.3, 16.5.2, Figure 2.6, Figure 2.7, Figure 2.8, Figure 2.11, Figure 3.18, Table 2.6.7, Box 3.2, 9.6.2, Box 11.2, CCP1.2.1, CCP1.2.2, CCP5.3.1, CCP5.3.2.3, CC6P4, CCP7.3, CCB EXTREMES}

TS.C.1.3 Damage and degradation of ecosystems exacerbate the projected impacts of climate change on biodiversity (*high confidence*). Space for nature is shrinking as large areas of forest are lost to deforestation (*high confidence*), peat draining and agricultural expansion, land reclamation and protection structures in urban and coastal settlements (*high confidence*). Currently less than 15% of the land and 8% of the ocean are under some form of protection, and enforcement of protection is often weak (*high confidence*). Future ecosystem vulnerability will strongly depend on developments in society, including demographic and economic change (*high confidence*). Deforestation is projected to increase the threat to terrestrial ecosystems, as is increasing the use of hard coastal protection of cities and settlements by the sea for coastal ecosystems. Coordinated and well-monitored habitat restoration, protection and management, combined with consumer pressure and incentives, can reduce non-climatic impacts and increase resilience (*high confidence*). Adaptation and mitigation options, such as afforestation, dam construction and coastal infrastructure placements, can increase vulnerability, compete for land and water and generate risks for the integrity and functioning of ecosystems (*high confidence*). {2.2, 2.3, 2.3.1, 2.3.2, 2.4.3, 2.5.4, 2.6.2, 2.6.3, 2.6.4, 2.6.5, 2.6.6, 2.6.7, Figure 2.1, 3.4.2, 3.5, 3.6.3, 4.5.5, 9.6.2, 9.6.3, 9.6.4, 9.7.2, 11.3.1, 12.3.3, 12.3.4, 13.3.2, 13.4.2, 13.10.2, 13.11.3, 14.5.2, 14.5.4, CCP5.2.1, CCP5.2.5, CCP5.3.2, CCP5.4.1, CCB NATURAL, CCB SLR}

TS.C.1.4 Changes induced by climate change in the physiology, biomass, structure and extent of ecosystems will determine their future carbon storage capacity (*high confidence*). In terrestrial ecosystems, the fertilisation effects of high atmospheric CO_2 concentrations on carbon uptake will be increasingly saturated and limited by warming and drought (*medium confidence*). Increases in wildfires, tree mortality, insect pest outbreaks, peatland drying and permafrost thaw (*high confidence*) all exacerbate self-reinforcing feedbacks between emissions from high-carbon ecosystems and warming with the potential to turn many ecosystems that are currently net carbon sinks into sources (*medium confidence*). In coastal areas beyond 1.5°C warming, blue carbon storage by mangroves, marshes and seagrass habitats are increasingly threatened by rising sea levels and the intensity, duration and extent of marine heatwaves, as well as adaptation options (including coastal development) (*high confidence*). Changes in ocean stratification are projected to reduce nutrient supply and alter the magnitude and efficiency of the biological carbon pump (*medium confidence*). {2.5.2, 2.5.3, 2.5.4, Figure 2.9, Figure 2.11, 3.2.2, 3.4.2, 3.4.3, Box 3.4, 9.5.10, 9.6.2, 10.4.2, 10.4.3, 11.3.1, 11.3.4, Box 11.5, 12.3.3, 12.3.4, 12.3.5, 12.3.6, Table 12.6, 13.3.1, 14.5.1, 15.3.3, CCB SLR, CCP1.2.4, CCP1.3, CCP7.3, WGI AR6 5.4}

TS.C.1.5 Extinction risk increases disproportionately from global warming of 1.5°C to 3°C and is especially high for endemic species and species rendered less resilient by human-induced non-climate stressors (*very high confidence*). The median values for percentage of species at very high risk of extinction are 9% at 1.5°C, 10% at 2°C, 12% at 3°C, 13% at 4°C and 15% at 5°C (*high confidence*), with the likely range of estimates having a maximum of 14% at 1.5°C and rising to a maximum of 48% at 5°C. Extinction risks are higher for species in biodiversity hotspots (*medium confidence*), reaching 24% of species at very high extinction risk above 1.5°C, with yet higher proportions for endemic species of 84% in mountains (*medium confidence*) and 100% on islands (*medium confidence*). Thousands of individual populations are projected to be locally lost, which will reduce species diversity in some areas where there are no species moving in to replace them, for example, in tropical systems (*high confidence*). Novel species interactions at the cold edge of species' distribution may also lead to extirpations and extinctions of newly encountered species (*low confidence*). Palaeo records indicate that at extreme warming levels (>5°C), mass extinctions of species occur (*medium confidence*). Among the thousands of species at risk, many are species of ecological, cultural and economic importance. {2.3.1, 2.3.3, 2.5.1, 2.5.2, 2.5.3, 2.5.4, Figure 2.1, Figure 2.6, Figure 2.7, Figure 2.8, Figure 2.11, 3.4.2, 3.4.3, 4.5.5, 9.6.2, 13.3.1, 13.4.1, 13.10.1, 13.10.2, CCP1.2.1, CCP1.2.4, CCP5.3.1, CCB PALEO}

TS.C.2 Cumulative stressors and extreme events are projected to increase in magnitude and frequency (*very high confidence*) and will accelerate projected climate-driven shifts in ecosystems and loss of the services they provide to people (*high confidence*). These processes will exacerbate both stress on systems already at risk from climate impacts and non-climate impacts like habitat fragmentation and pollution (*high confidence*). The increasing frequency and severity of extreme events will decrease the recovery time available for ecosystems (*high confidence*). Irreversible changes will occur from the interaction of stressors and the occurrence of extreme events (*very high confidence*), such as the expansion of arid systems or total loss of stony coral and sea ice communities. {2.3, 2.3.1, 3.2.2, 3.4.2, 3.4.3, 13.3.1, 13.4.1, 13.10.2, 14.5.2, 14.5.5, 14.5.9, Box 14.2, Box 14.4}

TS.C.2.1. Ecosystem integrity is threatened by the positive feedback between direct human impacts (land use change, pollution, overexploitation, fragmentation and destruction) and climate change (*high confidence*). In the case of the Amazon forest, this could lead to large-scale ecological transformations and shifts from a closed, wet forest into a drier and lower-biomass vegetation (*medium confidence*). If these pressures are not successfully addressed, the combined and interactive effects between climate change, deforestation and forest degradation, and forest fires are projected to lead to a reduction of over 60% of the area covered by forest in response to 2.5°C global warming level (*medium confidence*). Some habitat-forming coastal ecosystems, including many coral reefs, kelp forests and seagrass meadows, will undergo irreversible phase shifts due to marine heatwaves with global warming levels >1.5°C and are at high risk this century even in <1.5°C scenarios that include periods of temperature overshoot beyond 1.5°C (*high confidence*). Under SSP1–2.6, coral reefs are at risk of widespread decline, loss of structural integrity and transitioning to net erosion by mid-century due to the increasing intensity and frequency of marine heatwaves (*very high confidence*). Due to these impacts, the rate of sea level rise is *very likely*

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to exceed that of reef growth by 2050, absent adaptation. In response to heatwaves, bleaching of the Great Barrier Reef is projected to occur annually if warming increases above 2.0°C, resulting in widespread decline and loss of structural integrity (*very high confidence*). Global warming of 3.0°C–3.5°C increases the likelihood of extreme and lethal heat events in western and northern Africa (*medium confidence*) and across Asia. Drought risks are projected to increase in many regions over the 21st century (*very high confidence*). {2.5.2, 2.5.4, 3.4.2, 3.4.3, 9.5.3, 9.10, 10.2.1, 10.3.7, 11.3.1, 11.3.2, Box 11.2, Table 11.14, 13.3.1, 13.4.1, 14.5.3, Box 14.3, CCP7.3.6}

TS.C.2.2 Pests, weeds and disease occurrence and distribution are projected to increase with global warming, amplified by climate change induced extreme events (e.g., droughts, floods, heatwaves and wildfires), with negative consequences for ecosystem health, food security, human health and livelihoods (*medium confidence*). Invasive plant species are predicted to expand both in latitude and altitude (*high confidence*). Climatically disrupted ecosystems will make organisms more susceptible to disease via reduced immunity and biodiversity losses, which can increase disease transmission. Risks of climate-driven emerging zoonoses will increase. Depending on location and human–wildlife interactions, climate-driven shifts in distributions of wild animals increase the risk of emergence of novel human infectious diseases, as has occurred with SARS, MERS and SARS-CoV-2 (*medium confidence*). Changes in the rates of reproduction and distribution of weeds, insect pests, pathogens and disease vectors will increase biotic stress on crops, forests and livestock (*medium evidence, high agreement*). Pest and disease outbreaks will require greater use of control measures, increasing the cost of production, food safety impacts and the risk of biodiversity loss and ecosystem impacts. These control measures will become costlier under climate change (*medium confidence*). {2.4.2, 2.5.1, 2.5.2, 3.5.5, 4.2.4, 4.2.5, 4.3.1, 5.4.1, 5.4.3, 5.5.2, 5.9.4, 5.12, 11.3.1, 13.5.1, 14.5.4, 14.5.6, CCB ILLNESS, CCB MOVING PLATE, CCB COVID}

TS.C.2.3 The ability of natural ecosystems to provide carbon storage and sequestration is increasingly impacted by heat, wildfire, droughts, loss and degradation of vegetation from land use and other impacts (*high confidence*). Limiting the global temperature increase to 1.5°C, compared to 2°C, could reduce projected permafrost CO_2 losses by 2100 by 24.2 GtC (*low confidence*). A temperature rise of 4°C by 2100 is projected to increase global burned area 50–70% and fire frequency by approx. 30%, potentially releasing 11–200 GtC from the Arctic alone (*medium confidence*). Changes in plankton community structure and productivity are projected to reduce carbon sequestration at depth (*low* to *medium confidence*). {2.5.2, 2.5.3, 2.5.4, Figure 2.11, Table 2.5, 3.4.2, 3.4.3, 3.4.2, 4.2.4, 13.3.1, 13.4.1, Box 14.7, Box 3.4}

TS.C.2.4 Climate change impacts on marine ecosystems are projected to lead to profound changes and irreversible losses in many regions, with negative consequences for human ways of life, economy and cultural identity (*medium confidence*). For example, by 2100, 18.8% ± 19.0% to 38.9% ± 9.4% of the ocean will *very likely* undergo a change of more than 20 days (advances and delays) in the start of the phytoplankton growth period under SSP1-2.6 and SSP5-8.5 respectively (*low confidence*). This altered timing increases the risk of temporal mismatches between plankton blooms and fish spawning seasons (*medium* to *high confidence*) and increases the risk of fish recruitment failure for species with restricted spawning locations, especially in mid- to high latitudes of the northern hemisphere (*low confidence*) but provide short-term opportunities to countries benefiting from shifting fish stocks (*medium confidence*). {3.4.2, 3.4.3, 3.5.6, 5.8.3, 5.9.3, 11.3.1, 13.4.1, 13.5.1, 14.5.2, CCP6.3, CCB MOVING SPECIES}

TS.C.2.5 Warming pathways that temporarily increase global mean temperature over 1.5°C above pre-industrial for multi-decadal time spans imply severe risks and irreversible impacts in many ecosystems (*high confidence*). Major risks include loss of coastal ecosystems such as wetlands and marshlands from committed sea level rise associated with overshoot warming (*medium confidence*), coral reefs and kelps from heat-related mortality and associated ecosystem transitions (*high confidence*), disruption of water flows in high-elevation ecosystems from glacier loss and shrinking snow cover, and local extinctions of terrestrial species. {2.5, 3.4.2, 3.4.4, 4.7.4, 9.6.2, 12.3, 13.10.2, CCP5.3.1}

Food systems and food security

TS.C.3 Climate change will increasingly add pressure on food production systems, undermining food security (*high confidence*). With every increment of warming, exposure to climate hazards will grow substantially (*high confidence*), and adverse impacts on all food sectors will become prevalent, further stressing food security (*high confidence*). Regional disparity in risks to food security will grow with warming levels, increasing poverty traps, particularly in regions characterised by a high level of human vulnerability (*high confidence*). (Figure TS.4) {4.5.1, 4.6.1, 5.2.2, 5.4.3, 5.4.4, 5.5.3, 5.8.3, 5.9.3, 5.12.4, 7.3.1, 9.8.2, 9.8.5, 13.5.1, 14.5.4, 16.5.2, 16.6.3, CCB MOVING PLATE}

TS.C.3.1 Climate change will increasingly add pressure on terrestrial food production systems with every increment of warming (*high confidence*). Some current global crop and livestock areas will become climatically unsuitable depending on the emissions scenario (*high confidence*; 10% globally by 2050, by 2100 over 30% under SSP-8.5 versus below 8% under SSP1-2.6). Compared to 1.5°C global warming level, 2°C global warming level will even further negatively impact food production where current temperatures are already high as in lower latitudes (*high confidence*). Increased and potentially concurrent climate extremes will increase simultaneous losses in major food-producing regions (*medium confidence*). The adverse effects of climate change on food production will become more severe when global temperatures rise by more than 2°C (*high confidence*). At 3°C or higher global warming levels, exposure to climate hazards will grow substantially (*high confidence*), further stressing food production, notably in sub-Saharan Africa and South and South East Asia (*high confidence*). (Figure TS.4) {4.5.1, 4.6.1, 5.2.2, 5.4.3, 5.4.4, 5.5.3, 5.8.3, 5.9.3, 5.12.4, 9.8.2, 9.8.5, 11.3.4, 13.5.1, 14.5.4, 16.5.2, 16.6.3, CCB MOVING PLATE}

TS.C.3.2 Climate change will significantly alter aquatic food provisioning services, with direct impacts on food-insecure people (*high confidence*). Global ocean animal biomass will

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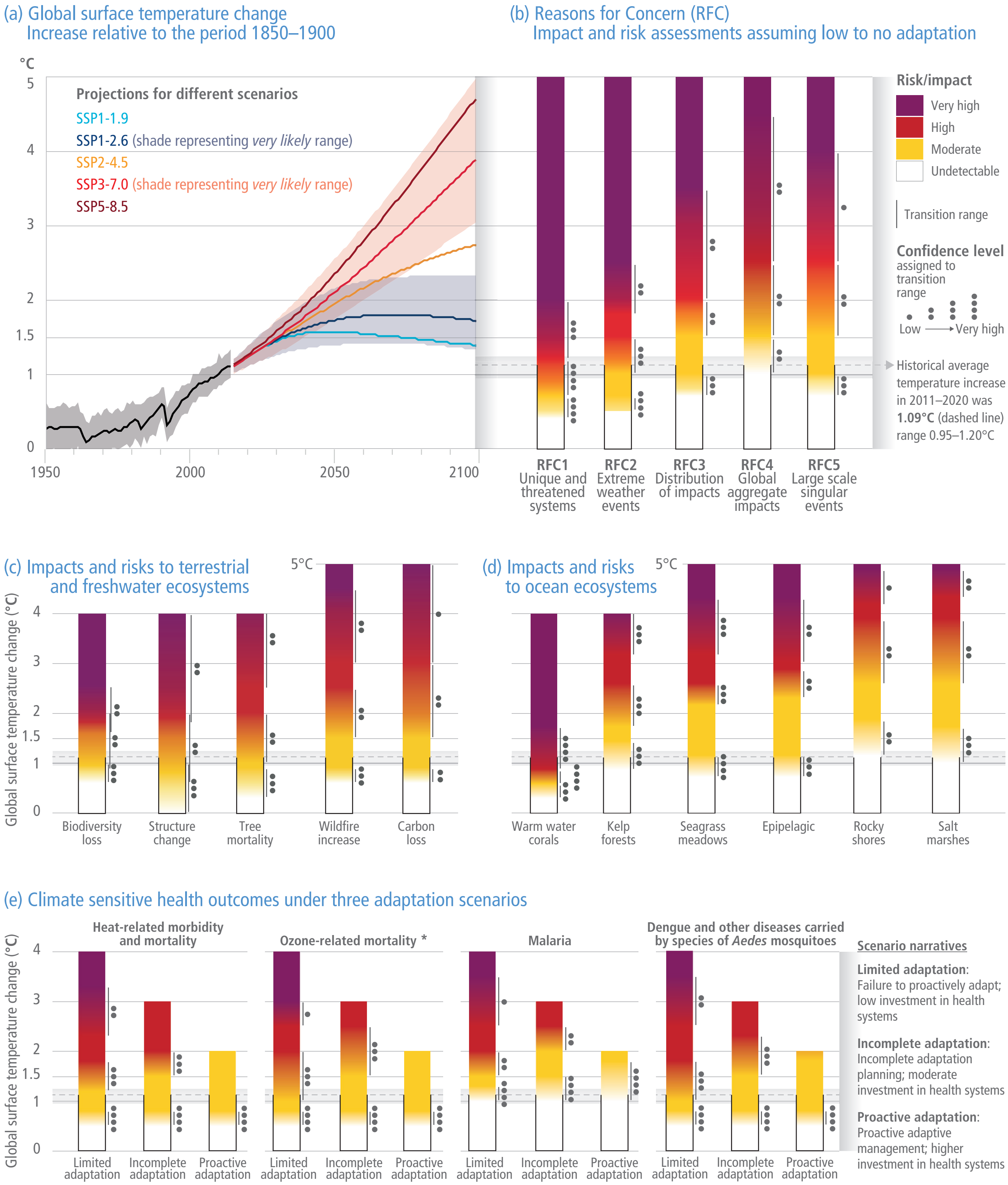
TS

Global and regional risks for increasing levels of global warming



* Mortality projections include demographic trends but do not include future efforts to improve air quality that reduce ozone concentrations.

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(f) Examples of regional key risks

Absence of risk diagrams does not imply absence of risks within a region. The development of synthetic diagrams for Small Islands, Asia and Central and South America was limited due to the paucity of adequately downscaled climate projections, with uncertainty in the direction of change, the diversity of climatologies and socioeconomic contexts across countries within a region, and the resulting few numbers of impact and risk projections for different warming levels.

The risks listed are of at least *medium confidence* level:

Small Islands
- Loss of terrestrial, marine and coastal biodiversity and ecosystem services
- Loss of lives and assets, risk to food security and economic disruption due to destruction of settlements and infrastructure
- Economic decline and livelihood failure of fisheries, agriculture, tourism and from biodiversity loss from traditional agroecosystems
- Reduced habitability of reef and non-reef islands leading to increased displacement
- Risk to water security in almost every small island

North America
- Climate-sensitive mental health outcomes, human mortality and morbidity due to increasing average temperature, weather and climate extremes, and compound climate hazards
- Risk of degradation of marine, coastal and terrestrial ecosystems, including loss of biodiversity, function, and protective services
- Risk to freshwater resources with consequences for ecosystems, reduced surface water availability for irrigated agriculture, other human uses, and degraded water quality
- Risk to food and nutritional security through changes in agriculture, livestock, hunting, fisheries, and aquaculture productivity and access
- Risks to well-being, livelihoods and economic activities from cascading and compounding climate hazards, including risks to coastal cities, settlements and infrastructure from sea level rise

Europe
- Risks to people, economies and infrastructures due to coastal and inland flooding
- Stress and mortality to people due to increasing temperatures and heat extremes
- Marine and terrestrial ecosystems disruptions
- Water scarcity to multiple interconnected sectors
- Losses in crop production, due to compound heat and dry conditions, and extreme weather

Central and South America
- Risk to water security
- Severe health effects due to increasing epidemics, in particular vector-borne diseases
- Coral reef ecosystems degradation due to coral bleaching
- Risk to food security due to frequent/extreme droughts
- Damages to life and infrastructure due to floods, landslides, sea level rise, storm surges and coastal erosion

Australasia
- Degradation of tropical shallow coral reefs and associated biodiversity and ecosystem service values
- Loss of human and natural systems in low-lying coastal areas due to sea level rise
- Impact on livelihoods and incomes due to decline in agricultural production
- Increase in heat-related mortality and morbidity for people and wildlife
- Loss of alpine biodiversity in Australia due to less snow

Asia
- Urban infrastructure damage and impacts on human well-being and health due to flooding, especially in coastal cities and settlements
- Biodiversity loss and habitat shifts as well as associated disruptions in dependent human systems across freshwater, land, and ocean ecosystems
- More frequent, extensive coral bleaching and subsequent coral mortality induced by ocean warming and acidification, sea level rise, marine heat waves and resource extraction
- Decline in coastal fishery resources due to sea level rise, decrease in precipitation in some parts and increase in temperature
- Risk to food and water security due to increased temperature extremes, rainfall variability and drought

Africa
- Species extinction and reduction or irreversible loss of ecosystems and their services, including freshwater, land and ocean ecosystems
- Risk to food security, risk of malnutrition (micronutrient deficiency), and loss of livelihood due to reduced food production from crops, livestock and fisheries
- Risks to marine ecosystem health and to livelihoods in coastal communities
- Increased human mortality and morbidity due to increased heat and infectious diseases (including vector-borne and diarrhoeal diseases)
- Reduced economic output and growth, and increased inequality and poverty rates
- Increased risk to water and energy security due to drought and heat

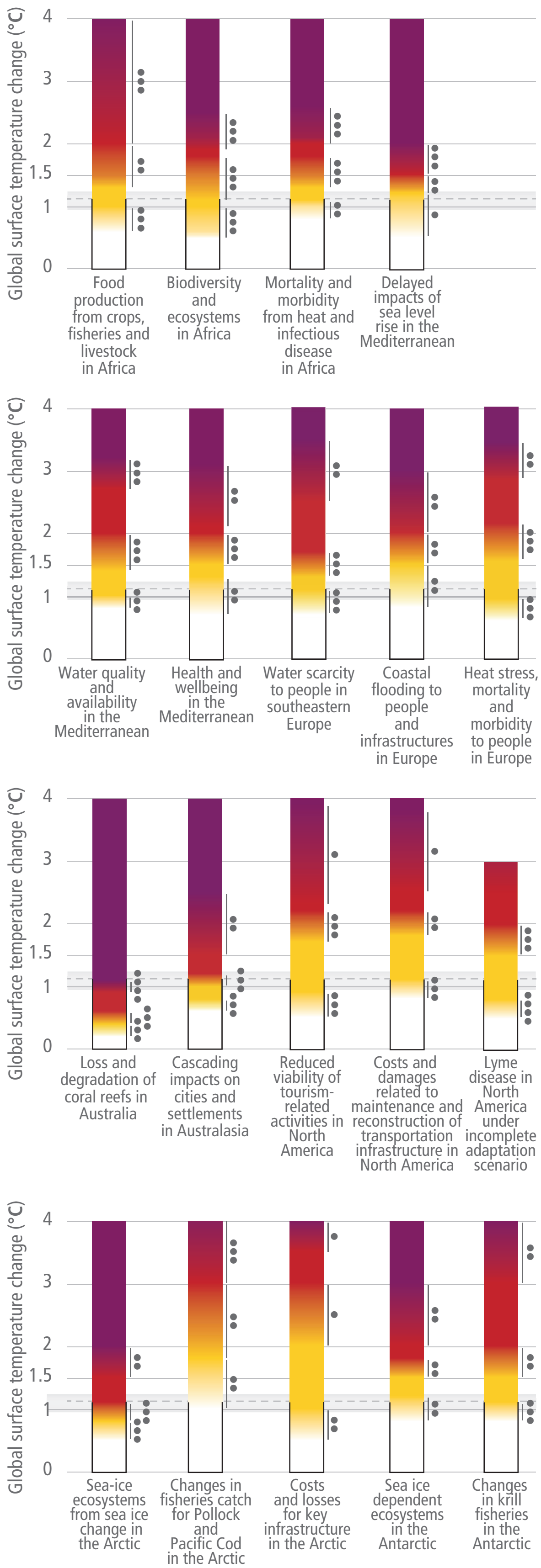

Figure TS.4 | Synthetic diagrams of global and sectoral assessments and examples of regional key risks. Diagrams show the change in the levels of impacts and risks assessed for global warming of 0–5°C global surface temperature change relative to pre-industrial period (1850–1900) over the range.

(a) Global surface temperature changes in °C relative to 1850–1900. These changes were obtained by combining CMIP6 model simulations with observational constraints based on past simulated warming, as well as an updated assessment of equilibrium climate sensitivity (Box TS.2). Changes relative to 1850–1900 based on 20-year averaging periods are calculated by adding 0.85°C (the observed global surface temperature increase from 1850–1900 to 1995–2014) to simulated changes relative to 1995–2014. *Very likely* ranges are shown for SSP1-2.6 and SSP3-7.0 (WGI AR6 Figure SPM.8). Assessments were carried out at the global scale for (b), (c), (d) and (e).

(b) The Reasons for Concern (RFC) framework communicates scientific understanding about accrual of risk for five broad categories. Diagrams are shown for each RFC, assuming low to no adaptation (i.e., adaptation is fragmented, localized and comprises incremental adjustments to existing practices). However, the transition to a very high risk level has an emphasis on irreversibility and adaptation limits. Undetectable risk level (white) indicates no associated impacts are detectable and attributable to climate change; moderate risk (yellow) indicates associated impacts are both detectable and attributable to climate change with at least *medium confidence*, also accounting for the other specific criteria for key risks; high risk (red) indicates severe and widespread impacts that are judged to be high on one or more criteria for assessing key risks; and very high risk level (purple) indicates very high risk of severe impacts and the presence of significant irreversibility or the persistence of climate-related hazards, combined with limited ability to adapt due to the nature of the hazard or impacts/risks. The horizontal line denotes the present global warming of 1.09°C which is used to separate the observed, past impacts below the line from the future projected risks above it. RFC1: Unique and threatened systems: ecological and human systems that have restricted geographic ranges constrained by climate-related conditions and have high endemism or other distinctive properties. Examples include coral reefs, the Arctic and its Indigenous Peoples, mountain glaciers and biodiversity hotspots. RFC2: Extreme weather events: risks/impacts to human health, livelihoods, assets and ecosystems from extreme weather events such as heatwaves, heavy rain, drought and associated wildfires, and coastal flooding. RFC3: Distribution of impacts: risks/impacts that disproportionately affect particular groups due to uneven distribution of physical climate change hazards, exposure or vulnerability. RFC4: Global aggregate impacts: impacts to socio-ecological systems that can be aggregated globally into a single metric, such as monetary damages, lives affected, species lost or ecosystem degradation at a global scale. RFC5: Large-scale singular events: relatively large, abrupt and sometimes irreversible changes in systems caused by global warming, such as ice sheet disintegration or thermohaline circulation slowing. Assessment methods are described in SM16.6 and are identical to AR5, but are enhanced by a structured approach to improve robustness and facilitate comparison between AR5 and AR6. Risks for (c) terrestrial and freshwater ecosystems and (d) ocean ecosystems.

For **(c)** and **(d)**, diagrams shown for each risk assume low to no adaptation. The transition to a very high risk level has an emphasis on irreversibility and adaptation limits.

(e) Climate-sensitive human health outcomes under three scenarios of adaptation effectiveness. The assessed projections were based on a range of scenarios, including SRES, CMIP5, and ISIMIP, and, in some cases, demographic trends. The diagrams are truncated at the nearest whole °C within the range of temperature change in 2100 under three SSP scenarios in panel (a).

(f) Examples of regional key risks. Risks identified are of at least *medium confidence* level. Key risks are identified based on the magnitude of adverse consequences (pervasiveness of the consequences, degree of change, irreversibility of consequences, potential for impact thresholds or tipping points, potential for cascading effects beyond system boundaries); likelihood of adverse consequences; temporal characteristics of the risk; and ability to respond to the risk, e.g., by adaptation. The full set of 127 assessed global and regional key risks is given in SMTS.4 and SM16.7. Diagrams are provided for some risks. The development of synthetic diagrams for Small Islands, Asia and Central and South America were limited by the availability of adequately downscaled climate projections, with uncertainty in the direction of change, the diversity of climatologies and socio-economic contexts across countries within a region, and the resulting low number of impact and risk projections for different warming levels. Absence of risks diagrams does not imply absence of risks within a region. (Box TS.2) {Figure 2.11, Figure SM3.1, Figure 7.9, Figure 9.6, Figure 11.6, Figure 13.28, 16.5, 16.6, Figure 16.15, SM16.3, SM16.4, SM16.5, SM16.6 (methodologies), SM16.7, Figure CCP4.8, Figure CCP4.10, Figure CCP6.5, WGI AR6 2, WGI AR6 SPM A.1.2, WGI AR6 Figure SPM.8}

decrease by 5.7% ± 4.1% and 15.5% ± 8.5% under SSP1-2.6 and SSP5-8.5 respectively by 2080–2099 relative to 1995–2014 (*medium confidence*), affecting food provisioning, revenue value and distribution. Catch composition will change regionally, and the vulnerability of fishers will partially depend on their ability to move, diversify and leverage technology (*medium confidence*). Global marine aquaculture will decline under increasing temperature and acidification conditions by 2100, with potential short-term gains for finfish aquaculture in some temperate regions and overall negative impacts on bivalve aquaculture due to habitat reduction (*medium confidence*). Changes in precipitation, sea level rise, temperature and extreme events will negatively affect food provisioning from inland aquatic systems (*medium confidence*), which provide a significant source of livelihoods and food for direct human consumption, particularly in Asia and Africa. {3.4.2, 3.4.3, 3.5.3, 3.6.2, 3.6.3, 5.8.3, 5.9.3, 5.13, 9.8.5, 13.5.1, 14.5.2, CCP6.2.3, CCP6.2.4, CCP6.2.5, CCP6.2.6, CCP6.2.8, CCB MOVING PLATE, CCB SLR}

TS.C.3.3 Climate change will increasingly add significant pressure and regionally different impacts on all components of food systems, undermining all dimensions of food security (*high confidence*). Extreme weather events will increase risks of food insecurity via spikes in food prices, reduced food diversity and reduced income for agricultural and fishery livelihoods (*high confidence*), preventing achievement of the UN SDG 2 ('Zero Hunger') by 2030 in regions with limited adaptive capacities, including Africa, small island states and South Asia (*high confidence*). With about 2°C warming, climate-related changes in food availability and diet quality are estimated to increase nutrition-related diseases and the number of undernourished people by 2050, affecting tens (under low vulnerability and low warming) to hundreds of millions of people (under high vulnerability and high warming, i.e., SSP-3-RCP6.0), particularly among low-income households in low- and middle-income countries in sub-Saharan Africa, South Asia and Central America (*high confidence*), for example, between 8 million under SSP1-6.0 to up to 80 million people under SSP3-6.0. At 3°C or higher global warming levels, adverse impacts on all food sectors will become prevalent, further stressing food availability (*high confidence*), agricultural labour productivity and food access (*medium confidence*). Regional disparity in risks to food security will grow at these higher warming levels, increasing poverty traps, particularly in regions characterised by a high level of human vulnerability (*high confidence*). {4.5.1, 4.6.1, 5.2.2, 5.4.3, 5.4.4, 5.5.3, 5.8.3, 5.9.3, 5.12.4, 7.3.1, 9.8.2, 9.8.5, 13.5.1, 14.5.4, 16.5.2, 16.6.3, CCB MOVING PLATE}

TS.C.3.4 Climate change is projected to increase malnutrition through reduced nutritional quality, access to balanced food and inequality (*high confidence*). Increased CO_2 concentrations promote crop growth and yield but reduce the density of important nutrients in some crops (*high confidence*) with projected increases in undernutrition and micronutrient deficiency, particularly in countries that currently have high levels of nutrient deficiency (*high confidence*) and regions with low access to diverse foods (*medium confidence*). Marine-dependent communities, including Indigenous Peoples and local peoples, will be at increased risk of malnutrition due to losses of seafood-sourced nutrients (*medium confidence*). {3.5.3, 5.2.2, 5.4.2, 5.4.3, 5.5.2, 5.12.1, 5.12.4, 7.3.1, 9.8.5, 16.5.2, CCP6.2.3, CCP6.2.4, CCP6.2.5, CCP6.2.6, CCP6.2.8, CCB MOVING PLATE}

TS.C.3.5 Climate change will further increase pressures on those terrestrial ecosystem services which support global food production systems (*high confidence*). Climate change will reduce the effectiveness of pollination as species are lost from certain areas, or the coordination of pollinator activity and flower receptiveness will be disrupted in some regions (*high confidence*). Greenhouse gas emissions will negatively impact air, soil and water quality, exacerbating direct climatic impacts on yields (*high confidence*). {5.4.3, 5.5.3, 5.7.1, 5.7.4, 5.9.4, 5.10.3, Box 5.3, Box 5.4, 13.10.2, 14.5.4, CCB MOVING PLATE, SRCCL}

TS.C.3.6 Climate change will compromise food safety through multiple pathways (*high confidence*). Higher temperatures and humidity will expand the risk of aflatoxin contamination into higher-latitude regions (*high confidence*). More frequent and intense flood events and increased melting of snow and ice will increase food contamination (*high confidence*). Aquatic food safety will decrease through increased detrimental impacts from harmful algal blooms (*high confidence*) and human exposure to elevated bioaccumulation of persistent organic pollutants and methylmercury (*low to medium confidence*). These negative food safety impacts will be greater without adaptation and fall disproportionately on low-income countries and communities with high consumption of seafood, including coastal Indigenous communities (*medium confidence*). {3.6.3, 5.4.3, 5.8.1, 5.8.3, 5.11.1, 5.12.4, Box 5.10, 7.3.1, 14.5.6, CCB ILLNESS}

Water systems and water security

TS.C.4 Water-related risks are projected to increase at all warming levels, with risks being proportionally lower at 1.5°C than at higher degrees of warming (*high confidence*). Regions and populations with higher exposure and vulnerability are projected to face greater risks than others (*medium confidence*). Projected changes in the water cycle, water quality, cryosphere changes, drought and flood will negatively impact natural and human systems (*high confidence*). {2.5.1, 2.5.2, 2.5.3, 2.5.4, 2.6.3, 3.5.5, 4.4.1, 4.4.2, 4.4.3, 4.4.4, 4.4.5, 4.4.6, 4.5.1, 4.5.2, 4.5.3, 4.5.4, 4.5.5, 4.5.6, 4.5.8, 4.6.1, Box 4.1, Box 4.3, 5.4.3, 5.5.2, 5.8.1, 5.8.2, 5.8.3, 5.9.1, 5.9.3, 5.11.1, 5.11.3, 5.12.3, 5.13, 6.1, 6.2, 6.3, 6.4, 7.3.1, 8.3, 8.4.4, 9.5.8, 9.5.3, 9.5.4, 9.5.5, 9.5.6, 9.5.7, 9.7.1, 9.7.2, 10.4.6, 10.4.7, Box 10.2, Box 10.5, 11.2.2, 11.3.3, 11.3.4, Box 11.3, Box 11.4, 12.3, 13.2.1, 13.2.2, 13.6.2, 13.10.2, 13.10.3, Box 13.1, 14.5.3, 14.5.5, 14.5.9, 16.5.2, 16.6.1, CCP1.2.1, CCP1.2.3.2, CCP2.2, CCP4.2, CCP4.3, CCP5.3.2}

TS.C.4.1 Water-related risks are projected to increase with every increment in warming level, and the impacts will be felt disproportionately by vulnerable people in regions with high exposure and vulnerability (*high confidence*). About 800 million to 3 billion people at 2°C and about 4 billion at 4°C warming are projected to experience different levels of water scarcity (*medium confidence*), leading to increased water insecurity. At 4°C global warming by the end of the century, approximately 10% of the global land area is projected to face simultaneously increasing high extreme streamflow and decreasing low extreme streamflow, affecting over 2.1 billion people (*medium confidence*). Globally, the greatest risks to attaining global sustainability goals come from risks to water security (*high confidence*). {4.4.1, 4.4.3, 4.4.5, 4.5.4, 4.6.1, Box 4.2, 5.8.3, 5.9.3, 5.13, 8.3, 8.4.4., 9.7.2, 12.3, Table 12.3, 13.2.1, 13.2.2, 13.6.1, 13.10.2, 15.3.3, 16.6.1, CCB SLR}

TS.C.4.2 Projected cryosphere changes will negatively impact water security and livelihoods, with higher severity of risks at higher levels of global warming (*high confidence*). Glacier mass loss, permafrost thaw and decline in snow cover are projected to continue beyond the 21st century (*high confidence*). Many low-elevation and small glaciers around the world will lose most of their total mass at 1.5°C warming (*high confidence*). Glaciers are likely to disappear by nearly 50% in High Mountain Asia and about 70% in Central and Western Asia by the end of the 21st century under the medium warming scenario. Glacier lake outburst flood will threaten the security of local and downstream communities in High Mountain Asia (*high confidence*). By 2100, annual runoff in one-third of the 56 large-scale glacierised catchments are projected to decline by over 10%, with the most significant reductions in Central Asia and the Andes (*medium confidence*). Cryosphere related changes in floods, landslides and water availability have the potential to lead to severe consequences for people, infrastructure and the economy in most mountain regions (*high confidence*). {4.4.2, 4.4.3, 4.5.8, 9.5.8, 10.4.4, Box 10.5, 11.2.2, Box 11.6, 14.2, 16.5.2, CCP1.2.3, CCP5.3.1, CCP5.3.2, SROCC}

TS.C.4.3 Projected changes in the water cycle will impact various ecosystem services (*medium confidence*). By 2050, environmentally critical streamflow is projected to be affected in 42% to 79% of the world's watersheds, causing negative impacts on freshwater ecosystems (*medium confidence*). Increased wildfire, combined with soil erosion due to deforestation, could degrade water supplies (*medium confidence*). Projected climate-driven water cycle changes, including increases in evapotranspiration, altered spatial patterns and amount of precipitation, and associated changes in groundwater recharge, runoff and streamflow, will impact terrestrial, freshwater, estuarine and coastal ecosystems and the transport of materials through the biogeochemical cycles, impacting humans and societal well-being (*medium confidence*). In Africa, 55–68% of commercially harvested inland fish species are vulnerable to extinction under 2.5°C global warming by 2071–2100. In Central and South America, disruption in water flows will significantly degrade ecosystems such as high-elevation wetlands (*high confidence*). {2.5.1, 2.5.2, 2.5.3, 2.5.4, 2.6.3, 3.5.5, 3.5.5, 4.4.1, 4.4.3, 4.4.5, 4.4.6, 4.5.4, 5.4.3, 9.8.5, 11.3.1, 12.3, 14.2.2, 14.5.3, 15.3.3, CCP1.2.1}

TS.C.4.4 Drought risks and related societal damage are projected to increase with every degree of warming (*medium confidence*). Under RCP6.0 and SSP2, the population that is projected to be exposed to extreme to exceptional low total water storage will reach up to 7% over the 21st century (*medium confidence*). Under RCP8.5, aridity zones could expand by one-quarter of the 1990 area by 2100. In southern Europe, more than a third of the population will be exposed to water scarcity at 2°C, and the risk doubles at 3°C, with significant economic losses (*medium confidence*). Over large

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areas of northern South America, the Mediterranean, western China and high latitudes in North America and Eurasia, the frequency of extreme agricultural droughts is projected to be 150% to 200% more likely at 2°C and over 200% more likely at 4°C (*medium confidence*). Above 2°C, the frequency and duration of meteorological drought are projected to double over North Africa, the western Sahel and southern Africa (*medium confidence*). More droughts and extreme fire weather are projected in southern and eastern Australia (*high confidence*) and over most of New Zealand (*medium confidence*). {4.5.1, 4.6.1, Box 4.1, 4.4.1, 4.4.1.1, 4.4.4, 4.4.5, 4.5.1, 4.5.4, 4.5.5, 4.6.1, 6.2.2, 6.2.3, 7.3.1, 9.5.2, 9.5.3, 9.5.6, 9.9.4, 10.4.6; 11.2.2, Box 11.6, 14.5.3, 14.5.5, CCP3.3.1, CCP3.3.2, CWGB URBAN}

TS.C.4.5 Flood risks and societal damages are projected to increase with every increment of global warming (*medium confidence*). The projected increase in precipitation intensity (*high confidence*) will increase rain-generated local flooding (*medium confidence*). Direct flood damage is projected to increase by four to five times at 4°C compared to 1.5°C (*medium confidence*). A higher sea level with storm surge further inland may create more severe coastal flooding (*high confidence*). Projected intensifications of the hydrological cycle pose increasing risks, including potential doubling of flood risk and 1.2- to 1.8-fold increase in GDP loss due to flooding between 1.5°C and 3°C (*medium confidence*). Projected increase in heavy rainfall events at all levels of warming in many regions in Africa will cause increasing exposure to pluvial and riverine flooding (*high confidence*), with expected human displacement increasing 200% for 1.6°C and 600% for 2.6°C. A 1.5°C increase would result in an increase of 100–200% in the population affected by floods in Colombia, Brazil and Argentina, 300% in Ecuador and 400% in Peru (*medium confidence*). In Europe, above 3°C global warming level, the costs of damage and people affected by precipitation and river flooding may double. {4.4.1, 4.4.4, 4.5.4, 4.5.5, 6.2.2, 7.3.1, Box 4.1, Box 4.3, 9.5.3, 9.5.4, 9.5.5, 9.5.6, 9.5.7, 9.7.2, 9.9.4, 10.4.6, Box 10.2, Box 11.4, 12.3, 13.2.1, 13.2.2, 13.6.2, 13.10.2, Box 13.1, 14.2.2, 14.5.3, CCP2.2, CWGB URBAN}

TS.C.4.6 Projected water cycle changes will impact agriculture, energy production and urban water uses (*medium confidence*). Agricultural water use will increase globally as a consequence of population increase and dietary changes, as well as increased water requirements due to climate change (*high confidence*). Groundwater recharge in some semiarid regions are projected to increase, but worldwide depletion of non-renewable groundwater storage will continue due to increased groundwater demand (*medium* to *high confidence*). Increased floods and droughts, together with heat stress, will have an adverse impact on food availability and prices, resulting in increased undernourishment in South and Southeast Asia (*high confidence*). In the Mediterranean and parts of Europe, potential reductions of hydropower of up to 40% are projected under 3°C warming, while declines below 10% and 5% are projected under 2°C and 1.5°C warming levels respectively. An additional 350 and 410 million people living in urban areas will be exposed to water scarcity from severe droughts at 1.5°C and 2°C respectively. {2.5.3, 4.4.1, 4.4.2, 4.5.6, 4.6.1, 5.4.3, 6.2.2, 6.2.4, Box 6.2, 6.3.5, 6.4, 9.7.2, 10.4.7, 12.3, 13.10.3, 4.5.2, 4.6.1, 11.3.3, 11.3.4, Box 11.3, 12.3, 14.5.3, 14.5.5, CCP4.2, CCP4.3, CWGB URBAN}

Risks from sea level rise

TS.C.5 Coastal risks will increase by at least one order of magnitude over the 21st century due to committed sea level rise impacting ecosystems, people, livelihoods, infrastructure, food security, cultural and natural heritage and climate mitigation at the coast. Concentrated in cities and settlements by the sea, these risks are already being faced and will accelerate beyond 2050 and continue to escalate beyond 2100, even if warming stops. Historically rare extreme sea level events will occur annually by 2100, compounding these risks (*high confidence*). {3.4.2, 3.5.5, 3.6.3, 9.9.4, Box 11.6, 13.2, Box 13.1, 14.5.2, Box 14.4, CCP2.2, CCB SLR}

TS.C.5.1 Under all emissions scenarios, coastal wetlands will *likely* face high risk from sea level rise in the mid-term (*medium confidence*), with substantial losses before 2100. These risks will be compounded where coastal development prevents upshore migration of habitats or where terrestrial sediment inputs are limited and tidal ranges are small (*high confidence*). Loss of these habitats disrupts associated ecosystem services, including wave-energy attenuation, habitat provision for biodiversity, climate mitigation and food and fuel resources (*high confidence*). Near- to mid-term sea level rise will also exacerbate coastal erosion and submersion and the salinisation of coastal groundwater, expanding the loss of many different coastal habitats, ecosystems and ecosystem services (*medium confidence*). {3.4.2, 3.5.2, 3.5.5, 3.6.3, 9.6.2, 11.3.1, 13.4.1, 13.4.2, 14.5.2, CCB NATURAL, CCB SLR}

TS.C.5.2 The exposure of many coastal populations and associated development to sea level rise is high, increasing risks, and is concentrated in and around coastal cities and settlements (*virtually certain*). High population growth and urbanisation in low-lying coastal zones will be the major driver of increasing exposure to sea level rise in the coming decades (*high confidence*). By 2030, 108–116 million people will be exposed to sea level rise in Africa (compared to 54 million in 2000), increasing to 190–245 million by 2060 (*medium confidence*). By 2050, more than a billion people located in low-lying cities and settlements will be at risk from coast-specific climate hazards, influenced by coastal geomorphology, geographical location and adaptation action (*high confidence*). {9.9.1, 9.9.4, Box 11.6, 14.5.2, Box 14.4, CCP2.2, CCB SLR}

TS.C.5.3 Under all climate and socioeconomic scenarios, low-lying cities and settlements, small islands, Arctic communities, remote Indigenous communities and deltaic communities will face severe disruption by 2100, and as early as 2050 in many cases (*very high confidence*). Large numbers of people are at risk in Asia, Africa and Europe, while a large relative increase in risk occurs in small island states and in parts of North and South America and Australasia. Risks to water security will occur as early as 2030 or earlier for the small island states and Torres Strait Islands in Australia and remote Maori communities in New Zealand. By 2100, compound and cascading risks will result in the submergence of some low-lying island states and damage to coastal heritage, livelihoods and infrastructure (*very high confidence*). Sea level rise, combined with altered rainfall patterns, will increase coastal inundation and

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water-use allocation issues between water-dependent sectors, such as agriculture, direct human consumption, sanitation and hydropower (*medium confidence*). {Box 4.2, 5.13, 9.12, 9.9.1, 9.9.4, 11.4.1, 11.4.2, Box 11.6, 14.5.2, Box 14.4, CCP2.2, CCB SLR}

TS.C.5.4 Risks to coastal cities and settlements are projected to increase by at least one order of magnitude by 2100 without significant adaptation and mitigation action (*high confidence*). The population at risk in coastal cities and settlements from a 100-year coastal flood increases by approx. 20% if the global mean sea level rises by 0.15 m relative to current levels, doubles at 0.75 m and triples at 1.4 m, assuming present-day population and protection height (*high confidence*). For example, in Europe, coastal flood damage is projected to increase at least 10-fold by the end of the 21st century, and even more or earlier with current adaptation and mitigation (*high confidence*). By 2100, 158–510 million people and USD7,919–12,739 billion in assets are projected to be exposed to the 1-in-100-year coastal floodplain under RCP4.5, and 176–880 million people and USD8,813–14,178 billion assets under RCP8.5 (*high confidence*). Projected impacts reach far beyond coastal cities and settlements, with damage to ports potentially severely compromising global supply chains and maritime trade, with local to global geopolitical and economic ramifications (*medium confidence*). Compounded and cascading climate risks, such as tropical cyclone storm surge damage to coastal infrastructure and supply chain networks, are expected to increase (*medium confidence*). (Figure TS.9 URBAN) {3.5.5, 3.6.2, 6.2.5, 6.2.7, 9.9.4, 9.12.2, 11.4, Box 11.4, Box 11.6, Table 11.14, 13.2.1, 13.2.2, 13.6.2, 13.10.2, Box 13.1, 14.5.5, Box 14.4, Box 14.5, CCP2.2.1, CCP2.2.2, CCP6.2.3, CCP6.2.7, CCP6.2.8, BoxCCP6.1, CCB SLR}

TS.C.5.5 Particularly exposed and vulnerable coastal communities, especially those relying on coastal ecosystems for protection or livelihoods, may face adaptation limits well before the end of this century, even at low warming levels (*high confidence*). Changes in wave climate superimposed on sea level rise will significantly increase coastal flooding (*high confidence*) and erosion of low-lying coastal and reef islands (*limited evidence, medium agreement*). The frequency, extent and duration of coastal flooding will significantly increase from 2050 (*high confidence*), unless coastal and marine ecosystems are able to naturally adapt to sea level rise through vertical growth and landward migration (*low confidence*). Permafrost thaw, sea level rise, and reduced sea ice protection is projected to damage or cause loss to many cultural heritage sites, settlements and livelihoods across the Arctic (*very high confidence*). Deltaic cities and settlements characterised by high inequality and informal settlements are especially vulnerable (*high confidence*). Although risks are distributed across cities and settlements at all levels of economic development, wealthier and more urbanised coastal cities and settlements are more likely to be able to limit impacts and risk in the near- to mid-term through infrastructure resilience and coastal protection interventions, with highly uncertain prospects in many of these locations beyond 2100 (*high confidence*). Prospects for enabling and contributing to climate resilient development thus vary markedly within and between coastal cities and settlements (*high confidence*). {9.9.4, 11.3.5, Table Box 11.6.1, 12.3, 12.4, Figure 12.7, Figure 12.9, Table 12.1, Table SM12.5, 13.2, 15.3.3, CCP2.2.1, CCP2.2.3, CCP2.2.5, Table SMCCP2.1}

Health and well-being

TS.C.6 Climate change will increase the number of deaths and the global burden of non-communicable and infectious diseases (*high confidence*). Over nine million climate-related deaths per year are projected by the end of the century, under a high emissions scenario and accounting for population growth, economic development and adaptation. Health risks will be differentiated by gender, age, income, social status and region (*high confidence*). {3.5.5, 3.6.2, 4.5.3, 5.12.4, Box 5.10, 6.2.2, 7.3.1, 8.4.5, 9.10.2, Figure 9.32, Figure 9.35, 10.4.7, Figure 10.11, 11.3.6, Table 11.14,12.3.2, 12.3.4, 12.3.5, 12.3.6, 12.3.8, Figure 12.5, Figure 12.6, 13.7.1, Figure 13.23, Figure 13.24, 14.5.4, 14.5.6, 15.3.4, 16.5.2, CCP Box 6.2, CCP6.2.6, CCB COVID, CCB ILLNESS, CCB MOVING PLATE}

TS.C.6.1 Future global burdens of climate-sensitive diseases and conditions will depend on emissions and adaptation pathways and the efficacy of public health systems, interventions and sanitation (*very high confidence*). Projections under mid-range emissions scenarios show an additional 250,000 deaths per year by 2050 (compared to 1961–1990) due to malaria, heat, childhood undernutrition and diarrhoea (*high confidence*). Overall, more than half of this excess mortality is projected for Africa. Mortality and morbidity will continue to escalate as exposures become more frequent and intense, putting additional strain on health and economic systems (*high confidence*), reducing capacity to respond, particularly in resource-poor regions. Vulnerable groups include young children (<5 years old), the elderly (>65 years old), pregnant women, Indigenous Peoples, those with pre-existing diseases, physical labourers and those in low socioeconomic conditions (*high confidence*). {4.5.3, 7.3.1, 9.10.2, 12.3.5, 16.5.2, CCB MOVING PLATE}

TS.C.6.2 Climate change is expected to have adverse impacts on well-being and to further threaten mental health (*very high confidence*). Children and adolescents, particularly girls, as well as people with existing mental, physical and medical challenges, are particularly at risk (*high confidence*). Mental health impacts are expected to arise from exposure to extreme weather events, displacement, migration, famine, malnutrition, degradation or destruction of health and social care systems, climate-related economic and social losses and anxiety and distress associated with worry about climate change (*very high confidence*). {7.3.1, 11.3.6, 14.5.6, CCP6.2.6, Box CCP6.2, CCB COVID}

TS.C.6.3 Increased heat-related mortality and morbidity are projected globally (*very high confidence*). Globally, temperature-related mortality is projected to increase under RCP4.5 to RCP8.5, even with adaptation (*very high confidence*). Tens of thousands of additional deaths are projected under moderate and high global warming scenarios, particularly in north, west and central Africa, with up to year-round exceedance of deadly heat thresholds by 2100 (RCP8.5) (*high agreement, robust evidence*). In Melbourne, Sydney and Brisbane, urban heat-related excess deaths are projected to increase by about 300 yr^{-1} (low emission pathway) to 600 yr^{-1} (high emission pathway) during 2031–2080 relative to 142 yr^{-1} during 1971–2020 (*high confidence*). In Europe the number of people at high risk of mortality

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will triple at 3°C compared to 1.5°C warming, in particular in central and southern Europe and urban areas (*high confidence*). {6.2.2, 7.3.1, 8.4.5, 9.10.2, Figure 9.32, Figure 9.35, 10.4.7, Figure 10.11, 11.3.6, 11.3.6, Table 11.14, 12.3.4, 12.3.8, Figure 12.6, 13.7.1, Figure 13.23, 14.5.6, 15.3.4, 16.5.2}

TS.C.6.4 Climate impacts on food systems are projected to increase undernutrition and diet-related mortality and risks globally (*high confidence*). Reduced marine and freshwater fisheries catch potential is projected to increase malnutrition in East, West and Central Africa (*medium to high confidence*) and in subsistence-dependent communities across North America (*high confidence*). By 2050, disability-adjusted life years due to undernutrition and micronutrient deficiencies are projected to increase by 10% under RCP8.5 (*medium evidence, high agreement*). These projected changes will increase diet-related risk factors and related non-communicable diseases globally and increase undernutrition, stunting and related childhood mortality, particularly in Africa and Asia (*high confidence*). Near-term projections (2030) of undernutrition are the highest for children (*confidence*), which can have lifelong adverse consequences for physiological and neurological development as well as for earnings capacity. Climate change is projected to put 8 million (SSP1-6.0) to 80 million people (SSP3-6.0) at risk of hunger in mid-century, concentrated in sub-Saharan Africa, South Asia and Central America (*high confidence*). These climate change impacts on nutrition could undermine progress towards the eradication of child undernutrition (*high confidence*). {4.5.3, 5.2.2, 5.12.4, Box 5.10, 7.3.1, 9.8.5, 9.10.2, 10.4.7, Figure 10.11, 13.7.1, 14.5.6, 15.3.4, CCP6.2, CCB MOVING PLATE}

TS.C.6.5 Vector-borne disease transmission is projected to expand to higher latitudes and altitudes, and the duration of seasonal transmission risk is projected to increase (*high confidence*), with the greatest risk under high emissions scenarios. Dengue vector ranges will increase in North America, Asia, Europe and sub-Saharan Africa under RCP6 and RCP8.5, potentially putting another 2.25 billion people at risk (*high confidence*). Higher incidence rates of Lyme disease are projected for the Northern Hemisphere (*high confidence*). Climate change is projected to increase malaria's geographic distribution in endemic areas of sub-Saharan and southern Africa, Asia and South America (*high confidence*), exposing tens of millions more people to malaria, predominately in east and southern Africa, and up to hundreds of millions more exposed under RCP8.5 (*high confidence*). {7.3.1, 9.10.2, Figure 9.32, 10.4.7, Figure 10.11, 11.3.6, 12.3.2, 12.3.5, 12.3.6, Figure 12.5, 13.7.1, Figure 13.24, 14.5.6, 15.3.4, CCB ILLNESS}

TS.C.6.6 Higher temperatures and heavy rainfall events are projected to increase rates of water-borne and food-borne diseases in many regions (*high confidence*). At 2.1°C, thousands to tens of thousands of additional cases of diarrhoeal disease are projected, mainly in central and east Africa (*medium confidence*). Morbidity from cholera will increase in central and east Africa (*medium confidence*), and increased schistosomiasis risk is projected for eastern Africa (*high confidence*). In Asia and Africa, 1°C warming can cause a 7% increase in diarrhoea, an 8% increase in *E. coli* and a 3% to 11% increase in deaths (*medium confidence*). Warming increases the risk of food-borne disease outbreaks, including *Salmonella* and *Campylobacter* infections (*medium confidence*). Warming supports the growth and geographical expansion of toxigenic fungi in crops (*medium confidence*) and potentially toxic marine and freshwater algae (*medium confidence*). Food safety risks in fisheries and aquaculture are projected through harmful algal blooms (*high confidence*), pathogens (e.g., *Vibrio*) (*high confidence*), and human exposure to elevated bioaccumulation of persistent organic pollutants and mercury (*medium confidence*). {3.5.5, 3.6.2, 4.5.3, 5.12.4, Box 5.10, 7.3.1, 9.10.2, Figure 9.32, 10.4.7, Figure 10.11, 11.3.6, 13.7.1, Figure 13.24, 14.5.4, 14.5.6, 15.3.4, CCP6.2.6, CCB MOVING PLATE}

TS.C.6.7 The burden of several non-communicable diseases is projected to increase under climate change (*high confidence*). Cardiovascular disease mortality could increase by 18.4%, 47.8% and 69.0% in the 2020s, 2050s and 2080s respectively under RCP4.5, and by 16.6%, 73.8% and 134% under RCP8.5 compared to the 1980s (*high confidence*). Future risks of respiratory disease associated with aeroallergens and ozone exposure are expected to increase (*high confidence*). {7.3.1, 10.4.7, 11.3.6, 12.3.4, 13.7.1}

Migration and displacement

TS.C.7 Migration patterns due to climate change are difficult to project as they depend on patterns of population growth, adaptive capacity of exposed populations and socioeconomic development and migration policies (*high confidence*). In many regions, the frequency and/or severity of floods, extreme storms and droughts is projected to increase in coming decades, especially under high emissions scenarios, raising future risk of displacement in the most exposed areas (*high confidence*). Under all global warming levels, some regions that are presently densely populated will become unsafe or uninhabitable, with movement from these regions occurring autonomously or through planned relocation (*high confidence*). {4.5.7, 7.3.2, Box 9.8, 15.3.4, CCB MIGRATE}

TS.C.7.1 Future climate-related migration is expected to vary by region and over time, according to future climatic drivers, patterns of population growth, adaptive capacity of exposed populations and international development and migration policies (*high confidence*). Future migration and displacement patterns in a changing climate will depend not only on the physical impacts of climate change, but also on future policies and planning at all scales of governance (*high confidence*). Projecting the number of people migrating due to slow onset events is difficult due to the multi-causal nature of migration and the dominant role that socioeconomic factors have in determining migration responses (*high confidence*). Increased frequency of extreme heat events and long-term increases in average temperatures pose future risks to the habitability of settlements in low latitudes; this, combined with the urban heat island effect, may in the long term affect migration patterns in exposed areas, especially under high emissions scenarios, but more evidence is needed. High emissions/low development scenarios raise the potential for both increased rates of migration and displacement and larger involuntary immobile populations that are highly exposed to climatic risks but lack the means of moving to other locations (*medium confidence*). {4.5.7,

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7.2.6, 7.3.2, 15.3.4, 4.6.9, 5.14.1, 5.14.2, 7.3.2, 7.4.5, 8.2.1, Box 8.1, Box 9.8, CCP 6.3.2, CCB MIGRATE}

TS.C.7.2 Estimates of displacement from rapid-onset extreme events exist; however, the range of estimates is large as they largely depend on assumptions made about future emissions and socioeconomic development trajectories (*high confidence*). Uncertainties about socioeconomic development are reflected in the wide range of projected population displacements by 2050 in Central and South America, sub-Saharan Africa and South Asia due to climate change, ranging from 31 million to 143 million people (*high confidence*). Projections of the number of people at risk of future displacement by sea level rise range from tens of millions to hundreds of millions by the end of this century, depending on the level of warmings and assumptions about exposure (*high confidence*). (Figure TS.9 URBAN) {4.5.7, 7.3.2, 7.3.2, 7.3.2, 9.9.4, CCP2.2.1, CCP2.2.2, CCB MIGRATE, CCB SLR, Figure AI.42}

TS.C.7.3 As climate risk intensifies, the need for planned relocations will increase to support those who are unable to move voluntarily (*medium confidence*). Planned relocation will be increasingly required as climate change undermines livelihoods, safety and overall habitability, especially for coastal areas and small islands (*medium confidence*). This will have implications for traditional livelihood practices, social cohesion and knowledge systems that have inherent value as intangible culture as well as introduce new risks for communities by amplifying existing and generating new vulnerabilities (*high confidence*). {4.6.8, 15.3.4, 14.4, CCP2.3.5, CCB FEASIB, CCB MIGRATE}

Human vulnerability

TS.C.8 Under an inequality scenario (SSP4) by 2030, the number of people living in extreme poverty will increase by 122 million from currently around 700 million (*medium confidence*). Future climate change may increase involuntary displacement, but severe impacts also undermine the capacity of households to use mobility as a coping strategy, causing high exposure to climate risks, with consequences for basic survival, health and well-being (*high confidence*). The COVID-19 pandemic is expected to increase the adverse consequences of climate change since the financial consequences have led to a shift in priorities and constrain vulnerability reduction (*medium confidence*). {7.3.2, 8.1.1, 8.3.2, 8.4.4, 8.4.5, 9.11.4, Box 9.8, 16, Table 16.9, CCB COVID, CCB ILLNESS, CCB MOVING SPECIES}

TS.C.8.1 Even with current, moderate climate change, vulnerable people will experience a further erosion of livelihood security that can interact with humanitarian crises, such as displacement and involuntary migration (*high confidence*) and violence and armed conflict, and lead to social tipping points (*medium confidence*). Under higher emissions scenarios and increasing climate hazards, the potential for societal risks also increases (*medium confidence*). Lessons from COVID-19 risk management have implications for managing urban climate change risk (*limited evidence, high agreement*). {4.5.1, 4.5.3, 4.5.4, 4.5.7, 4.5.8, 6.1.1, 6.3, 6.4, 8.2.1, 8.3, 8.4.4, 9.11.4}

TS.C.8.2 Indigenous Peoples and local communities will experience changes in cultural opportunities (*low* to *medium confidence*). Cultural heritage is already being impacted by climate change and variability, for example in Africa, Small Island Developing States and the Arctic, where heritage sites are exposed to future climate change risk (*high confidence*). Coastal erosion and sea level rise are projected to affect natural and cultural coastal heritage sites spread across 36 African countries and all Arctic nations. Frequent drought episodes will lower groundwater tables and gradually expose highly valued archaeological sites to salt weathering and degradation. Coastal inundation and ocean acidification will intensify impacts on sacred sites, including burial grounds, and the corrosion of shipwrecks and underwater ruins. {3.5.3, 3.5.4, 3.5.5, 3.5.6, 4.5.8, 9.12., 2.1.2, 11.4.1, 11.4.2, 13.8.1.3, 13.8.2, Box 13.2, 14.4, CCP6.2.7, CCP2.2}

TS.C.8.3 Climate change increases risks of violent conflict, primarily intrastate conflicts, by strengthening climate-sensitive drivers (*medium confidence*). Climate change may produce severe risks to peace within this century through climate variability and extremes, especially in contexts marked by low economic development, high economic dependence on climate-sensitive activities, high or increasing social marginalisation and fragile governance (*medium confidence*). The largest impacts are expected in weather-sensitive communities with low resilience to climate extremes and high prevalence of underlying risk factors (*medium confidence*). Trajectories that prioritise economic growth, political rights and sustainability are associated with lower conflict risk (*medium confidence*). {4.5.6, 7.3.3, 16.5.2}

Cities, settlements and infrastructure

TS.C.9 Climate change increases risks for a larger number of growing cities and settlements across wider areas, especially in coastal and mountain regions, affecting an additional 2.5 billion people residing in cities mainly in Africa and Asia by 2050 (*high confidence*). In all cities and urban areas, projected risks faced by people from climate-driven impacts has increased (*high confidence*). Many risks will not be felt evenly across cities and settlements or within cities. Communities in informal settlements will have higher exposure and lower capacity to adapt (*high confidence*). Most at risk are women and children who make up the majority populations of these settlements (*high confidence*). Risks to critical physical infrastructure in cities can be severe and pervasive under higher warming levels, potentially resulting in compound and cascading risks, and can disrupt livelihoods both within and across cities (*high confidence*). In coastal cities and settlements, risks to people and infrastructure will get progressively worse in a changing climate, sea level rise and with ongoing coastal development (*very high confidence*). {2.6.5, 6.1, 6.1.4, 6.2, 9.9.4, 16.5, 14.5.5, Box 14.4, CCP2.2}

TS.C.9.1 An additional 2.5 billion people are projected to live in urban areas by 2050, with up to 90% of this increase concentrated in the regions of Asia and Africa (*high confidence*). By 2050, 64% and 60% of Asia's and Africa's population respectively will be urban. Growth is most pronounced in smaller and medium-sized urban settlements of up to one million people (*high confidence*). {4.5.4, 6.1, 6.1.4, 6.2, 9.9.1, 10.4.6}

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TS.C.9.2 Asian and African urban areas are considered high-risk locations from projected climate, extreme events, unplanned urbanisation and rapid land use change (*high confidence*). These could amplify pre-existing stresses related to poverty, informality, exclusion and governance, such as in African cities (*high confidence*). Climate change increases heat stress risks in cities (*high confidence*) and amplifies the urban heat island across Asian cities at 1.5°C and 2°C warming levels, both substantially larger than under present climates (*medium confidence*). Urban population exposure to extreme heat in Africa is projected to increase from 2 billion person-days per year in 1985–2005 to 45 billion person-days by the 2060s (1.7°C global warming with low population growth) and to 95 billion person-days (2.8°C global warming with medium-high population growth) (*medium confidence*). Risks driven by flooding and droughts will also increase in cities (*high confidence*). Urban populations exposed to severe droughts in West Africa will increase (65.3±34.1 million) at 1.5°C warming and increase further at 2°C (*medium confidence*). Urban land in flood zones and drylands exposed to high-frequency floods is expected to increase by as much as 2600% and 627% respectively across East, West and Central Africa by 2030. Higher risks from temperature and precipitation extremes are projected for almost all Asian cities under RCP8.5 (*medium confidence*), impacting on freshwater availability, regional food security, human health and industrial outputs. {4.3.4, 4.3.5, 4.5.4, 6.1, 6.2, Table 6.3, Table 6.4, 9.9.4, 10.3.7, 10.4.6, 15.3.3, 15.3.4, 15.4.3, CCP2.2, CCP6.2.7, CWGB URBAN}

TS.C.9.3 Globally, urban key infrastructure systems are increasingly sites of risk creation that potentially drive compounding and cascading risks (*high confidence*). Unplanned rapid urbanisation is a major driver of risk, particularly where increasing climate-driven risks affect key infrastructure and potentially result in compounding and cascading risks as cities expand into coastal and mountain regions prone to flooding or landslides that disrupt transportation networks, or where water and energy resources are inadequate to meet the needs of growing settlements (*high confidence*). These infrastructure risks expand beyond city boundaries; climate-related transport and energy infrastructure damage is projected to be a significant financial burden for African countries, reaching tens to hundreds of billions of US dollars under moderate and high emissions scenarios (*high confidence*). Projected changes in both the hydrological cycle and the cryosphere will threaten urban water infrastructure and resource management in most regions (*very high confidence*). South and Southeast Asian coastal cities can experience significant increases in average annual economic losses between 2005 and 2050 due to flooding, with very high losses in east Asian cities under RCP8.5 (*high confidence*). By 2050, permafrost thaw in the pan-Arctic is projected to impact 69% of infrastructure, more than 1200 settlements, 36,000 buildings, and 4 million people in Europe under RCP4.5. In small islands, degraded terrestrial ecosystems decrease resource provision (e.g., potable water) and amplify the vulnerability of island inhabitants (*high confidence*). Projections suggest that 350 million (± 158.8 million) more people in urban areas will be exposed to water scarcity from severe droughts at 1.5°C warming and 410.7 million (± 213.5) at 2°C warming (*low confidence*). {6.2.2, 9.9.4, 10.4.6, 13.6.1, 13.6.2, 13.11.3, 14.5.5, CCP2.2, SMCCP2.1}

TS.C.9.4 The characteristics of coastal cities and settlements means that climate-driven risks to people and infrastructure in many of them are already high and will get progressively worse over the 21st century and beyond (*high confidence*). These risks are driven by disproportionately high exposure of multiple assets, economic activities and large coastal populations concentrated in narrow coastal zones. Climate change risks, including sea level rise, interact in intricate ways with non-climatic drivers of coastal change, such as land subsidence, continued infrastructure development in coastal floodplains, the rise of asset values and landward development adversely impacting coastal ecosystems, to shape future risk in coastal settlements (*high confidence*). (Figure TS.9 URBAN) {3.4.2, 6.2, 6.3, 7.4, 9.9.4, 10, 11.3.5, Box 11.4, 13.6.1, 14.5.5, Box 14.4, 15.3.4, 15.3.4, CCP7.1, CCP2.2, CCP2.3, CCB SLR}

Economic sectors

TS.C.10 Across sectors and regions, market and non-market damage and adaptation costs will be lower at 1.5°C compared to 3°C or higher global warming levels (*high confidence*). Some recent estimates of projected global economic damage from climate impacts are higher than previous estimates and generally increase with global average temperature (*high confidence*). However, the spread in the estimates of the magnitude of this damage is substantial and does not allow for robust range to be established (*high confidence*). Non-market, non-economic damage and adverse impacts on livelihoods will be concentrated in regions and populations that are already more vulnerable (*high confidence*). Socioeconomic drivers and more inclusive development will largely determine the extent of this damage (*high confidence*). {4.4.4, 4.7.5, 9.11.2, 10.4.6, 11.5.2, 13.10.2, 13.10.3, 14.5.8, Box 14.6, 16.5.2, 16.5.3}

TS.C.10.1 Without limiting warming to 1.5°C global warming level, many key risks are projected to intensify rapidly in almost all regions of the world, causing damage to assets and infrastructure and losses to economic sectors and entailing high recovery and adaptation costs (*high confidence*). Severe risks are more likely in developing regions that are already hotter and in regions and communities with a large portion of the workforce employed in highly exposed industries (e.g., agriculture, fisheries, forestry, tourism, outdoor labour). In addition to market damage and disaster management costs, substantial costs of climate inaction are projected for human health (*high confidence*). At higher levels of warming, climate impacts will pose risks to financial and insurance markets, especially if climate risks are incompletely internalised (*medium confidence*), with adverse implications for the stability of markets (*low confidence*). While the overall economic consequences are clearly negative, opportunities may arise for a few economic sectors and regions, such as from longer growing seasons or reduced sea ice, primarily in northern latitudes (*medium* to *high confidence*). {4.4.4, 4.7.5, 9.11.2, 10.4.6, 11.6, 13.9.2, 13.10.3, 14.5.4, 14.5.5, 14.5.7, 14.5.8, 14.5.9, Box 14.5, Box 14.6, 16.5.2, 16.5.3, CCP4.2, CCP6.2, CCB INTEREG}

TS.C.10.2 Estimates of global economic damage generally increase non-linearity with warming and some are larger than previous estimates (*high confidence*). Some recent estimates have

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increased relative to the range reported in AR5, though there is low agreement and significant spread within and across methodology types (e.g., statistical, structural, meta-analysis), resulting in an inability to identify a best estimate or robust range (*high confidence*). Under high warming (>4°C) and limited adaptation, the magnitude of decline in annual global GDP in 2100 relative to a non-global-warming scenario could exceed economic losses during the Great Recession in 2008–2009 and the COVID-19 pandemic in 2020. Much smaller effects are estimated for less warming, lower vulnerability and more adaptation (*medium confidence*). Regional estimates of GDP damage vary (*high confidence*). Severe risks are more likely in (typically hotter) developing countries (*medium confidence*). For Africa, GDP damage is projected to be negative across models and approaches (*high confidence*). {4.4.4, 4.7.5, 9.11.2, 10.4.6, 13.10.2, 13.10.3, 14.5.8, Box 14.6, 16.5.2, 16.6.3, CWGB ECONOMIC}

TS.C.10.3 Even at low levels of warming, climate change will disrupt the livelihoods of tens to hundreds of millions of additional people in regions with high exposure and vulnerability and low adaptation in climate-sensitive regions, ecosystems and economic sectors (*high confidence*). If future climate change under high emissions scenarios continues and increases risks, without strong adaptation measures, losses and damage will likely be concentrated among the poorest vulnerable populations (*high confidence*). {8.4.5, 9.11.4, Box 15.2, 16.5.3}

TS.C.10.4 Potential socioeconomic futures, in terms of population, economic development and orientation towards growth, vary widely and these drivers have a large influence on the economic costs of climate change (*high confidence*). Higher growth scenarios along higher warming levels increase exposure to hazards and assets at risk, such as sea level rise for coastal regions, which will have large implications for economic activities, including shipping and ports (*high confidence*). The high sensitivity of developing economies to climate impacts will pose increasing challenges to economic growth and performance, although projections depend as much or more on future socioeconomic development pathways and mitigation policies as on warming levels (*medium confidence*). {9.11.2, 11.4, 13.2.1, 16.5.3, CCB SLR, CWGB ECONOMIC}

TS.C.10.5 Large non-market and non-economic losses are projected, especially at higher warming levels (*high confidence*). This wide range of effects underscore the impact of climate change on welfare and the adverse effects on vulnerable populations (*medium confidence*). Including as many of these impacts in decision-making as possible, and as part of the social cost of carbon, will improve evaluation of the overall and distributional effects of climate mitigation and adaptation actions as well as in more comprehensively internalising climate impacts. {1.5.1, 4.5.8, 4.7.5, 8.4.1, 8.4.5, Map 8.8, 16.5.2, Box 14.6, CWGB ECONOMIC}

Compound, cascading and transboundary risks

TS.C.11 Compound, cascading risks and transboundary risks give rise to new and unexpected types of risks (*high confidence*). They exacerbate existing stressors and constrain adaptation options (*medium confidence*). They are projected to become major threats for many areas, such as coastal cities (*medium* to *high confidence*). Some compound and cascading impacts occur locally, some spread across sectors and socioeconomic and natural systems, while others can be driven by events in other regions, for instance through trade and flows of commodities and goods through supply chain linkages (*high confidence*). (Figure TS.10 COMPLEX RISK) {1.3.1, 2.3, 2.5.5, 6.2, 4.4, 4.5.1, 11.5.1, Box 11.1, 13.10.3, Figure 14.10, 14.5.4, 11.5.1, 11.6, Box 11.7, Figure Box 11.1.2, Table 11.14, Box 14.5, CCP2.2.5, CCP6.2.3, CCB EXTREMES, CCB INTEREG}

TS.C.11.1 Escalating impacts of climate change on terrestrial, freshwater and marine life will further alter the biomass of animals (*medium confidence*), the timing of seasonal ecological events (*high confidence*) and the geographic ranges of terrestrial, coastal and ocean taxa (*high confidence*), disrupting life cycles (*medium confidence*), food webs (*medium confidence*) and ecological connectivity throughout the water column (*medium confidence*). For example, cascading effects on food webs have been reported in the Baltic due to detrimental oxygen levels (*high confidence*). (Figure TS.5 ECOSYSTEMS, Figure TS.10 COMPLEX RISK) {2.4.3, 2.4.5, 2.5.4, 3.4.2, 3.4.3, 13.3.1, 13.4.1, 14.5.2, CCP2.2, CCP5.3.2, WGI AR6 2.3.4}

TS.C.11.2 Climate hazards cause multiple impacts, interacting to compound risks to food security, nutrition and human health (*high confidence*). Compound risks to health and food systems (especially in tropical regions) are projected from simultaneous reductions in food production across crops, livestock and fisheries (*high confidence*), heat-related loss of labour productivity in agriculture (*high confidence*), increased heat-related mortality (*high confidence*), contamination of seafood (*high confidence*), malnutrition (*high confidence*) and flooding from sea level rise (*high confidence*). Malnourished populations will increase through direct impacts on food production with cascading impacts on food prices and household incomes, reducing access to safe and nutritious food (*high confidence*). Food safety will be undermined from increased food contamination for seafood with marine toxins from harmful algal blooms and chemical contaminants, worsening health risks (*high confidence*). (Figure TS.10 COMPLEX RISK) {4.5.1, 5.2.2, 5.4.3, 5.8.1, 5.8.3, 5.11.1, 5.12, Figure 5.2, 5.12.4, Box 5.10, 7.3.1, 9.10.2, 9.8.2, 9.8.3, 14.5.6, CCP5.2.3, CCP6.2.3, CCB ILLNESS}

TS.C.11.3 Compound hazards increasing with global warming include increased frequency of concurrent heatwaves and droughts (*high confidence*), dangerous fire weather (*medium confidence*) and floods (*medium confidence*), resulting in increased and more complex risks to agriculture, water resources, human health, mortality, livelihoods, settlements and infrastructure. Extreme weather events result in cascading and compounding risks that affect health and are expected to increase with warming (*very high confidence*). Compound climate hazards can overwhelm adaptive capacity and substantially increase damage (*high confidence*); for example, heat and drought are projected to substantially reduce agricultural production, and although irrigation can reduce this risk, its feasibility is limited by drought. (Figure TS.10 COMPLEX RISK) {4.2.5, 6.2.5, 7.1.3, 7.1.4,7.2.2, 7.2.1, 7.2.2, 7.2.3,

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7.2.4, 7.3.1, 7.3.2, 7.3.3, 7.4.1, 7.4.5, 11.5.1, 11.8.1, Box 11.1, 12.4, 13.3.1, 13.10.2, CCP5.4.6, CCP5.4.3, CCP 6, CCB COVID, CCB EXTREMES, CCB HEALTH, WGI AR6 11.8}

TS.C.11.4 Interacting climatic and non-climatic drivers when coupled with coastal development and urbanisation are projected to lead to losses for coastal ecosystems and their services under all scenarios in the near to mid-term (*medium to high confidence*). The compound impacts of warming, acidification and sea level rise are projected to lead to losses for coastal ecosystems (*medium to high confidence*). Fewer habitats, less biodiversity, lower coastal protection (*medium confidence*) and decreased food and water security will result (*medium confidence*), reducing the habitability of some small islands (*high confidence*). (Figure TS.10 COMPLEX RISK) {2.3, 2.5.5, 3.4.2, 3.5.2, 3.5.3, 3.5.5, 3.5.6, 3.6.3, 4.5.1, 5.13.6, 6.2, 6.2.6, 6.4.3, 11.3.2, 11.5.1, Box 11.6, 12.4, 12.5.2, 13.5.2, 13.10.2, Table 13.12, 15.3.3, 15.3.4, Box 15.5, 16.5.2, CCP1.2.1, CCP1.2.4, Box CCP1.1, Table CCP1.1, Figure CCP1.1, Figure CCP1.2, CCP2.2, CCP 2.2.5, CCB EXTREMES, CCB SLR}

TS.C.11.5 Observed human and economic losses have increased since AR5 for urban areas and human settlements arising from compound, cascading and systemic events (*medium evidence, high agreement*). Urban areas and their infrastructure are susceptible to both compounding and cascading risks arising from interactions between severe weather from climate change and increasing urbanisation (*medium evidence, high agreement*). Compound risks to key infrastructure in cities have increased from extreme weather (*medium evidence, high agreement*). Losses become systemic when they affect entire systems and can even jump from one system to another (e.g., drought impacting rural food production contributing to urban food insecurity) (*medium confidence*). (Figure TS.10 COMPLEX RISK) {6.2.6, 6.2.7, 6.4.3, Figure 6.2, 11.5.1, Box 11.1, 13.9.2, 13.5.2, 13.10.2, 13.10.3, 14.6.3, CCP2, CCP5.3.2, CWGB URBAN}

TS.C.11.6 Interconnectedness and globalisation establish pathways for the transmission of climate-related risks across sectors and borders, through trade, finance, food and ecosystems (*high confidence*). Flows of commodities and goods, as well as people, finance and innovation, can be driven or disrupted by distant climate change impacts on rural populations, transport networks and commodity speculation (*high confidence*). For example, Europe faces climate risks from outside the area due to global supply chain positioning and shared resources (*high confidence*). Climate risks in Europe also impact finance, food production and marine resources beyond Europe (*medium confidence*). (Figure TS.10 COMPLEX RISK) {1.3.1, 5.13.3, 5.13.5, 6.2.4, 9.9, 13.9.2, 13.5.2, 13.9.2, 13.9.3, Box 14.5, CCB INTEREG, Figure CCB INTEREG.1}

TS.C.11.7 Arctic communities and Indigenous Peoples face risks to economic activities (*very high confidence*) as direct and cascading impacts of climate change continue to occur at a magnitude and pace unprecedented in recent history and much faster than projected for other regions (*very high confidence*). Impacts and risks include reduced access to and productivity of future fisheries, regional and global food and nutritional security (*high confidence*), local livelihoods, health and well-being (*high confidence*) and loss to sociocultural assets, including heritage sites in all Arctic regions (*very high confidence*). (Figure TS.10 COMPLEX RISK) {Box 7.1, 13.8.1, Box 13.2, Figure 13.14, CCP6.2.1, CCP6.2.2, CCP6.2.3, CCP.6.2.4, CCP6.2.5, CCP6.3.1, Table CCP6.1, Table CCP6.2, Table CCP6.6}

TS.C.11.8 Indigenous Peoples, traditional communities, small-holder farmers, urban poor, children and elderly in Amazonia are burdened by cascading impacts and risks from the compound effects of climate and land use change on forest fires in the region (*high confidence*). Deforestation, fires and urbanisation have increased the exposure of Indigenous Peoples to respiratory problems, air pollution and diseases (*high confidence*). Amazonian forest fires are transboundary and increase systemic losses of wild crops, infrastructure and livelihoods, requiring a landscape governance approach (*medium evidence, high agreement*). (Figure TS.10 COMPLEX RISK) {2.4.3, 2.4.4, 2.5.3, 8.2.1, 8.4.5, Box 8.6, CCP7.2.3, CCP7.3}

TS.C.11.9 Population groups in most vulnerable and exposed regions to compound and cascading risks have the most urgent need for improved adaptive capacity (*high confidence*). Regions characterised by compound challenges of high levels of poverty, a significant number of people without access to basic services, such as water and sanitation and wealth and gender inequalities, and governance challenges are among the most vulnerable regions and are particularly located in East, Central and West Africa, South Asia, Micronesia and Melanesia and in Central America (*high confidence*). {8.3, 8.4, Box 8.6, CCP5.3.2}

TS.C.11.10 Emergent risks arise from responses to climate change, including maladaptation and unintended side effects of mitigation, including in the case of afforestation and hydropower (*very high confidence*). Solar radiation modification (SRM) approaches attempt to offset warming and ameliorate some climate risks but introduce a range of new risks to people and ecosystems, which are not well understood (*high confidence*). {1.3.1, 3.6.3, 5.13.6, CWGB SRM}

Reasons for concern (RFC)

TS.C.12 More evidence now supports the five major RFCs about climate change, describing risks associated with unique and threatened systems (RFC1), extreme weather events (RFC2), distribution of impacts (RFC3), global aggregate impacts (RFC4) and large-scale singular events (RFC5) (*high confidence*). (Figure TS.4, Table TS.1) {16.6.3, Figure 16.15}

TS.C.12.1 Compared to AR5 and SR15, risks increase to high and very high levels at lower global warming levels for all five RFCs (*high confidence*), and transition ranges are assigned with greater confidence. Transitions from high to very high risk emerge in all five RFCs, compared to just two RFCs in AR5 (*high confidence*). As in previous assessments, levels of concern at a given level of warming remain higher for RFC1 than for other RFCs. (Table TS.1, TS.AII) {16.6.3, Figure 16.15}

TS.C.12.2 Limiting global warming to 1.5°C would ensure risk levels remain moderate for RFC3, RFC4 and RFC5 (*medium*

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***confidence*), but risk for RFC2 would have transitioned to a high risk at 1.5°C and RFC1 would be well into the transition to very high risk (*high confidence*).** Remaining below 2°C warming (but above 1.5°C) would imply that risk for RFC3 through RFC5 would be transitioning to high, and risk for RFC1 and RFC2 would be transitioning to very high (*high confidence*). By 2.5°C warming, RFC1 will be at very high risk (*high confidence*), and all other RFCs will have begun their transitions to very high risk, with *medium confidence* for RFC2, RFC3 and RFC4, and *low confidence* for RFC5. (Table TS.1) {16.6.3, Figure 16.15}

TS.C.12.3 While the RFCs represent global risk levels for aggregated concerns about 'dangerous anthropogenic interference with the climate system', they represent a great diversity of risks, and in reality, there is not one single dangerous climate threshold across sectors and regions. RFC1, RFC2 and RFC5 include risks that are irreversible, such as species extinction, coral reef degradation, loss of cultural heritage or loss of a small island due to sea level rise. Once such risks materialise, the impacts would persist even if global temperatures subsequently declined to levels associated with lower levels of risk in an 'overshooting' scenario, for example where temperatures increase over 'well below 2°C above pre-industrial' for multi-decadal time spans before decreasing (*high confidence*). (Figure TS.4, see also TS.C.13) {16.6.3, Figure 16.15}

Temporary overshoot

TS.C.13 Warming pathways that imply a temporary temperature increase over 'well below 2°C above pre-industrial' for multi-decadal time spans imply severe risks and irreversible impacts in many natural and human systems (e.g., glacier melt, loss of coral reefs, loss of human lives due to heat) even if the temperature goals are reached later (*high confidence*). {2.5.2, 2.5.3, 4.6.1}

TS.C.13.1 Projected warming pathways may entail exceeding 1.5°C or 2°C around mid-century. Even if the Paris temperature goal is still reached by 2100, this 'overshoot' entails severe risks and irreversible impacts on many natural and human systems (e.g., glacier melt, loss of coral reefs, loss of human life due to heat) (*high confidence*). {2.5, 3.4, 16.6, WGI AR6 SPM}

TS.C.13.2 Overshoot substantially increases risk of carbon stored in the biosphere being released into the atmosphere due to increases in processes such as wildfires, tree mortality, insect pest outbreaks, peatland drying and permafrost thaw (*high confidence*). These phenomena exacerbate self-reinforcing feedbacks between emissions from high-carbon ecosystems (which currently store around 3030–4090 GtC) and increasing global temperatures. Complex interactions of climate change, land use change, carbon dioxide fluxes and vegetation changes, combined with insect outbreaks and other disturbances, will regulate the future carbon balance of the biosphere, processes incompletely represented in current Earth system models. The exact timing and magnitude of climate–biosphere feedbacks and potential tipping points of carbon loss are characterised by large uncertainty, but studies of feedbacks indicate increased ecosystem carbon losses can cause large future temperature increases (*medium confidence*). {2.5.2, 2.5.2, 2.5.3, Figure 2.10, Figure 2.11, Table 2.4, Table 2.5, Table 2.S. 2, Table 2.S. 4, Table 5.4, Figure 5.29, WGI AR6 5.4}

TS.C.13.3 Extinction of species is an irreversible impact of climate change whose risk increases sharply with rises in global temperature (*high confidence*). Even the lowest estimates of species extinctions (9% lost) are 1000 times the natural background rates (*medium confidence*). Projected species extinctions at future global warming levels are consistent with projections from AR4, but assessed on many more species with much greater geographic coverage and a broader range of climate models, giving higher confidence. (see also TS.C.1) {2.5.1, Figure 2.6, Figure 2.7, Figure 2.8, CCP1, CCB DEEP}

TS.C.13.4 Solar radiation modification (SRM) approaches have the potential to offset warming and ameliorate other climate hazards, but their potential to reduce risk or introduce novel risks to people and ecosystems is not well understood (*high confidence*). SRM effects on climate hazards are highly dependent on deployment scenarios, and substantial residual climate change or overcompensating change would occur at regional scales and seasonal time scales (*high confidence*). Due in part to limited research, there is low confidence in projected benefits or risks to crop yields, economies, human health or ecosystems. Large negative impacts are projected from rapid warming for a sudden and sustained termination of SRM in a high-CO_2 scenario. SRM would not stop CO_2 from increasing in the atmosphere or reduce resulting ocean acidification under continued anthropogenic emissions (*high confidence*). There is high agreement in the literature that for addressing climate change risks SRM is, at best, a supplement to achieving sustained net zero or net negative CO_2 emission levels globally. Co-evolution of SRM governance and research provides a chance for responsibly developing SRM technologies with broader public participation and political legitimacy, guarding against potential risks and harms relevant across a full range of scenarios. {CWGB SRM}

TS

Table TS.1 | Updated assessment of risk level transitions for the five reasons for concern (RFC) {16.6.3}

RFC	Example of impacts (not comprehensive)	Updated risk level based on observed and modelled impacts	Warming level
RFC1 Unique and threatened systems: ecological and human systems that have restricted geographic ranges constrained by climate-related conditions and have high endemism or other distinctive properties. Examples include coral reefs, the Arctic and its Indigenous Peoples, mountain glaciers and biodiversity hotspots.	Coral bleaching, mass tree and animal mortalities, species extinction; decline in sea-ice dependent species, range shifts in multiple ecosystems	In transition from moderate to high	1.1°C (*very high confidence*)
	Further decline of coral reef (by 70–90% at 1.5°C) and Arctic sea-ice dependent ecosystems; insects projected to lose >50% climatically determined geographic range 2°C; reduced habitability of small islands; increased endemic species extinction in biodiversity hotspots	Projected to transition from high to very high risk	1.2°C–2.0°C (*high confidence*)

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RFC	Example of impacts (not comprehensive)	Updated risk level based on observed and modelled impacts	Warming level
RFC2 Extreme weather events: risks/impacts to human health, livelihoods, assets and ecosystems from extreme weather events such as heatwaves, heavy rain, drought and associated wildfires and coastal flooding.	Increased heat-related human mortality, wildfires, agricultural and ecological droughts, water scarcity; short-term food shortages; impacts on food security and safety, price spikes; marine heatwaves estimated to double in frequency.	In transition to high risk at present	1.0°C–1.5°C (*high confidence*)
	Significant projected increases in fluvial flood frequency and resultant risks associated with higher populations; at least 1 d yr^{-1} with a heat index above 40.6°C for about 65% of megacities at 2.7°C and close to 80% at 4°C; soil moisture droughts 2–3 times longer; agricultural and ecological droughts more widespread; simultaneous crop failure across worldwide breadbasket regions; malnutrition and increasing risk of disease.	Projected to transition to very high risk (new in AR6)	1.8°C–2.5°C (*medium confidence*)
RFC3 Distribution of impacts: risks/impacts that disproportionately affect particular groups, such as vulnerable societies and socio-ecological systems, including disadvantaged people and communities in countries at all levels of development, due to uneven distribution of physical climate change hazards, exposure or vulnerability.	Increasing undernutrition, stunting and related childhood mortality, particularly in Africa and Asia and disproportionately affecting children and pregnant women; distributional impacts on crop production and water resources	Current risk level is moderate	1.1°C (*high confidence*)
	Risk of simultaneous crop failure in maize estimated to increase from 6% to 40%; increasing flood risk in Asia, Africa, China, India and Bangladesh; high risks of mortality and morbidity due to heat extremes and infectious disease with regional disparities	Projected to transition to high risk	1.5°C–2.0°C (*medium confidence*)
	Much more negative impacts on food security in low to mid-latitudes; substantial regional disparity in risks to food production; food-related health projected to be negatively impacted by 2°C–3°C warming; heat-related morbidity and mortality, ozone-related mortality, malaria, dengue, Lyme disease and West Nile fever projected to increase regionally and globally	Projected to transition to very high risk	2.0°C–3.5°C (*medium confidence*)
RFC4 Global aggregate impacts: impacts to socio-ecological systems that can be aggregated globally into a single metric, such as monetary damages, lives affected, species lost or ecosystem degradation at a global scale.	Aggregate impacts on biodiversity with damages of global significance (e.g., drought, pine bark beetles, coral reef ecosystems); climate-sensitive livelihoods like agriculture, fisheries and forestry would be severely impacted	In transition to moderate risk	1.1°C (*medium confidence*)
	Estimated 10% relative decrease in effective labour at 2°C; global exposure to multi-sector risks approximately doubles between 1.5°C and 2°C; global population exposed to flooding projected to rise by 24% at 1.5°C and by 30% at 2°C warming; reduced marine food provisioning, fishery distribution and revenue value with projected approximate 13% decline in ocean animal biomass.	Projected to transition to high risk	1.5°C–2.5°C (*medium confidence*)
	Widespread death of trees, damage to ecosystems and reduced provision of ecosystem services over temperature range 2.5°C–4.5°C; projected global annual damages associated with sea level rise of USD31,000 billion yr^{-1} in 2100 for 4°C warming scenario.	Projected to transition to very high risk (new in AR6)	2.5°C–4.5°C (*low confidence*)
RFC5 Large-scale singular events: relatively large, abrupt and sometimes irreversible changes in systems caused by global warming, such as ice sheet disintegration or thermohaline circulation slowing, sometimes called tipping points or critical thresholds.	Mass loss from both Antarctic (whether associated with marine ice sheet instability or not) and Greenland ice sheets is more than seven times higher over the period 2010–2016 than over the period 1992–1999 for Greenland and four times higher for the same time intervals for Antarctica; in Amazon forest, increases in tree mortality and a decline in carbon sink are reported	Current risk level is moderate	1.1°C (*high confidence*)
	Implications for 2000-year commitments to sea level rise from sustained mass loss from both ice sheets as projected by various ice sheet models, reaching 2.3–3.1 m at 1.5°C peak warming and 2–6 m at 2°C peak warming; risk of savannisation for Amazon alone was assessed to lie between 1.5°C and 3°C, with a median value at 2°C	Projected to transition to high risk	1.5°C–2.5°C (*medium confidence*)
	Uncertainties in projections of sea level rise at higher levels of warming, long-term equilibrium sea level rise of 5–25 m at mid-Pliocene temperatures of 2.5°C; potential for Amazon forest dieback between 4°C and 5°C; risk of ecosystem carbon loss from tipping points in tropical forest and loss of Arctic permafrost.	Projected to transition to very high risk (new in AR6)	2.5°C–4°C (*low confidence*)

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TS.D Contribution of Adaptation to Solutions

This section covers climate change adaptation and explains how our knowledge of it has progressed since AR5. The section begins with an explanation of overall progress on adaptation and the adaptation gaps and then discusses limits to adaptation. Maladaptation and the underlying evidence base are explained together with the strategies available to strengthen the biosphere that can help ecosystems function in a changing climate. Different adaptation options across water, food, nutrition and ecosystem-based adaptation and other nature-based solutions are also discussed and, in particular, the ways in which urban systems and infrastructure are coping with adaptation. Adaptation to sea level rise is specifically discussed given its global impact on coastal areas, while health, well-being, migration and conflict are also explained as these warrant additional important considerations. Justice and equity have a significant impact as well on how effective adaptation can be and are discussed as key issues that relate to decision-making processes on adaptation and the range of enablers that can support adaptation. Lastly, the focus shifts to system transitions and transformational adaptation that are needed to move climate change adaptation forward in a rapidly warming world.

Adaptation progress and gaps

TS.D.1 Increasing adaptation is being observed in natural and human systems (*very high confidence*), yet the majority of climate risk management and adaptation currently being planned and implemented are incremental (*high confidence*). There are gaps between current adaptation and the adaptation needed to avoid the increase of climate impacts that can be observed across sectors and regions, especially under medium and high warming levels (*high confidence*). {4.6.1, 4.6.2, 4.6.3, 4.6.4, 4.6.5, 4.6.6, 4.6.7, 4.6.8, 4.6.9, Box 4.3, Box 4.5, Box 4.6, 7.4.1, Table 4.8, Figure 4.24, Figure 6.4.3, Figure 6.5, 9.3.1, 9.6.4, 9.8.3, 9.11.4, 13.2, 13.11, 14.7.1, 16.3, 16.4, 17.2.2, CCP5.2.4, CCP5.2.7, CCP7.5.1, CCP7.5.2}

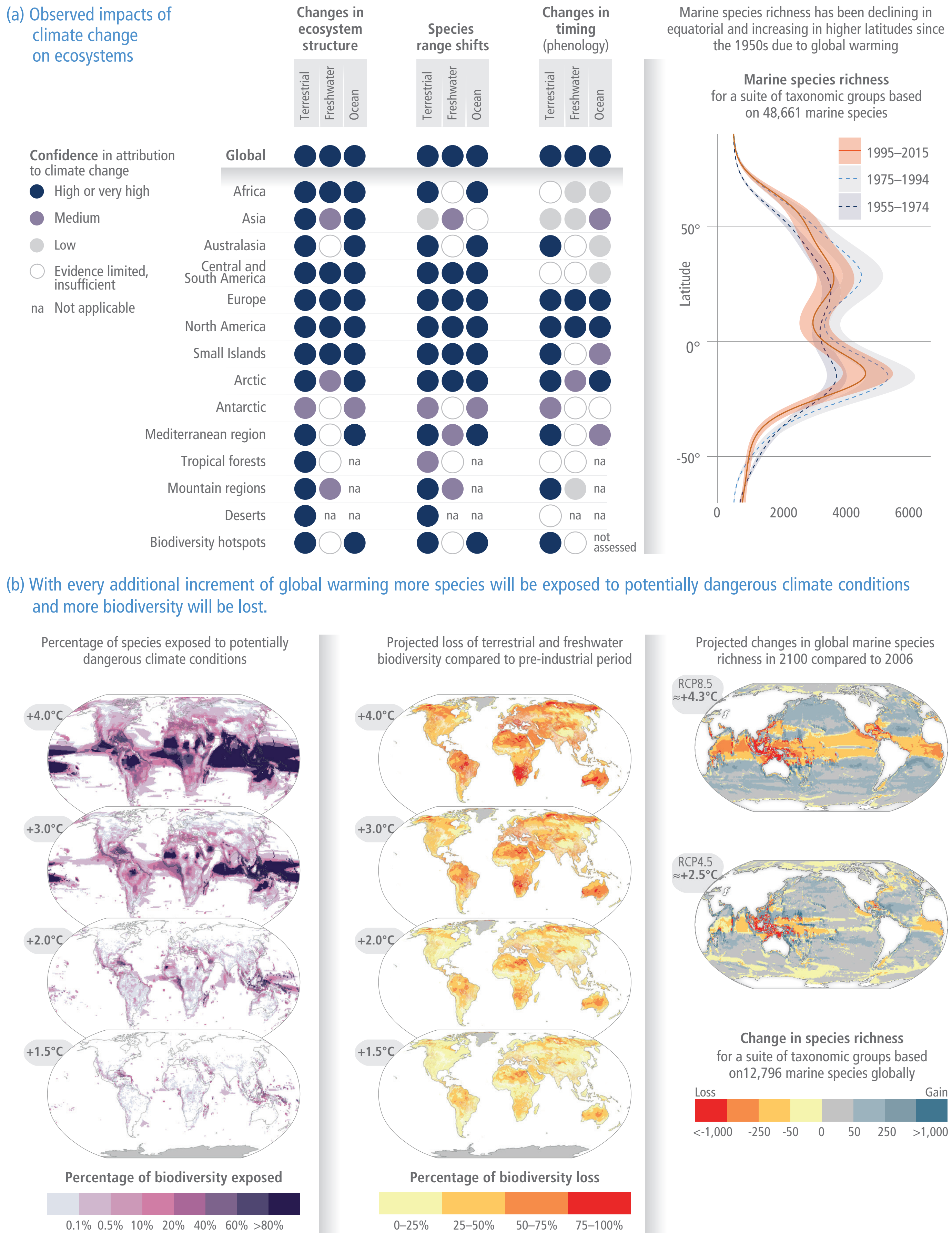
TS.D.1.1 Responses have accelerated in both developed and developing regions since AR5, with some examples of regression (*high confidence*). Growing adaptation knowledge in public and private sectors, increasing numbers of policy and legal frameworks and dedicated spending on adaptation are all clear indications that the availability of response options has expanded (*high confidence*). However, observed adaptation in human systems across all sectors and regions is dominated by small incremental, reactive changes to usual practices often after extreme weather events, while evidence of transformative adaptation in human systems is limited (*high confidence*). Droughts, pluvial, fluvial and coastal flooding are the most common hazards for which adaptation is being implemented, and many of these have physical, affordability and social limits (*high confidence*). There is some evidence of global vulnerability reduction, particularly for flood risk and extreme heat. {1.4.5, 2.4.2, 2.4.5, 2.5.4, 2.6.1, 2.6.6, 3.4.2, 3.4.3, 3.6.3, 4.6.1, 4.6.2, 4.6.3, 4.6.4, 4.6.5, 4.6.6, 4.6.7, 4.6.8, 4.6.9, Box 4.3, Box 4.5, Box 4.6, 7.4.1, Table 4.8, Figure 4.24, 11.6, Table 11.14, Box 11.2, 12.12.5, 13.2.2, 13.10, 13.11, 14.7.1, 15.5.4, 16.3.2, 16.4.2, 12.3, CCB EXTREMES}

TS.D.1.2 Current adaptation in natural and managed ecosystems includes earlier planting and changes in crop varieties, soil improvement and water management for livestock and crops, aquaculture, restoration of coastal and hydrological processes, introduction of heat- and drought-adapted genotypes into high-risk populations, increasing the size and connectivity of habitat patches, agroecological farming, agroforestry and managed relocations of high-risk species (*medium confidence*). These measures can increase the resilience, productivity and sustainability of both natural and food systems under climate change (*high confidence*). Financial barriers limit the implementation of adaptation options in natural ecosystems, agriculture, fisheries, aquaculture and forestry as financial strategies are stochastically deployed. Investment in climate service provision has benefited the agricultural sector in many regions, with limited uptake of climate service information into decision-making frameworks (*medium confidence*). {2.6.2, 2.6.3, 2.6.4, 2.6.5, 2.6.8, 3.6.3, 4.6.2, 4.7.1, Figure 4.23, 5.4.3, 5.5.3, 5.9.4, 5.10.3, 5.14.3, 9.4, 9.4.4, 9.4.1, 12.5.4, 12.8, 13.5.2, 13.10.2, 14.5.4, 15.5.7, 17.2.1, 17.5.1, CCP5.2.5, CCP 7.5, CCB NATURAL}

TS.D.1.3 The ambition, scope and progress on adaptation have risen among governments at the local, national and international levels, along with businesses, communities and civil society, but many funding, knowledge and practice gaps remain for effective implementation, monitoring and evaluation (*high confidence*). There are large gaps in risk management and risk transfer in low-income contexts, and even larger gaps in conflict-affected contexts (*high confidence*). Adaptive capacity is highly uneven across and within regions (*high confidence*). Current adaptation efforts are not expected to meet existing goals (*high confidence*). {1.1.3, 1.2.1, 1.3.1, 1.3.2, 1.4.5, 2.6.2, 2.6.3, 2.6.6, 2.6.8, 3.6.3, 4.7.1, 6.1, 6.4.3, Figure 6.5, 9.1.5, 9.4.1, 9.4.5, 11.7.1, 11.7.2, 13.11.1, 14.7.1, 15.6, 17.2, 17.4.2, 17.5.1, 17.5.2, CCP7.5, CCB DEEP, CCB NATURAL}

TS.D.1.4 Many cities and settlements have developed adaptation plans since AR5, but a limited number of these have been implemented so that urban adaptation gaps exist in all world regions and for all hazard types (*high confidence*). Many plans focus on climate risk reduction, missing opportunities to advance co-benefits of climate mitigation and sustainable development and risking compounding inequality and reduced well-being (*medium confidence*). The largest adaptation gaps exist in projects that manage complex risks, for example in the food–energy–water–health nexus or the inter-relationships of air quality and climate risk (*high confidence*). Most innovation in adaptation has occurred through advances in social and ecological infrastructures, including disaster risk management, social safety nets and green/blue infrastructure (*medium confidence*). However, most financial investment continues to be directed narrowly at large-scale hard engineering projects after climate events have caused harm (*medium confidence*). {4.6.5, 6.3.1, 6.3.2, Figure 6.4, 6.4.3, 6.4.5, 10.3.7, Table 10.2, 11.3.5, 12.5.5, 13.11, 14.5.5, 14.7.1, 15.3.4, 17.4.2, CCP2.3, CCP2.4, CCP5.2.7, CCB FINANCE}

Species and ecosystems around the world are at increasing risk due to climate change



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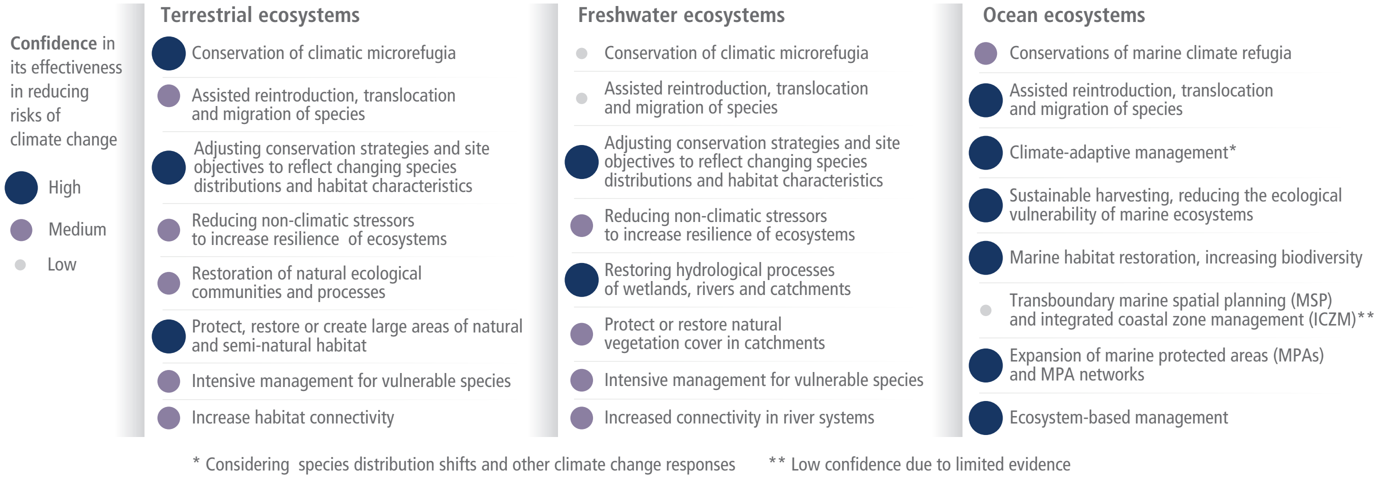
(c) Example of adaptation actions for ecosystems and biodiversity.



(d) Adaptation pathways for ecosystems.

Adaptation options can be facilitated by actions which increase the solution space such as consideration of local knowledge, new regulations and incentives but also decrease due to climatic and non-climatic stressors and maladaptation.

Strategies
- Protect
- Restore/migrate
- Sustainable use
- Uncertainty in effectiveness with increasing pressures

Examples for actions
i. Networks of Protected Areas combined with zoning increase resilience.
ii. Assisted migration and evolution might reduce extirpation and extinction.
iii. Adaptation and mitigation increase space for nature and benefit society.
iv. Ecosystem-based Adaptation (EbA) and Nature-based Solutions (NbS).

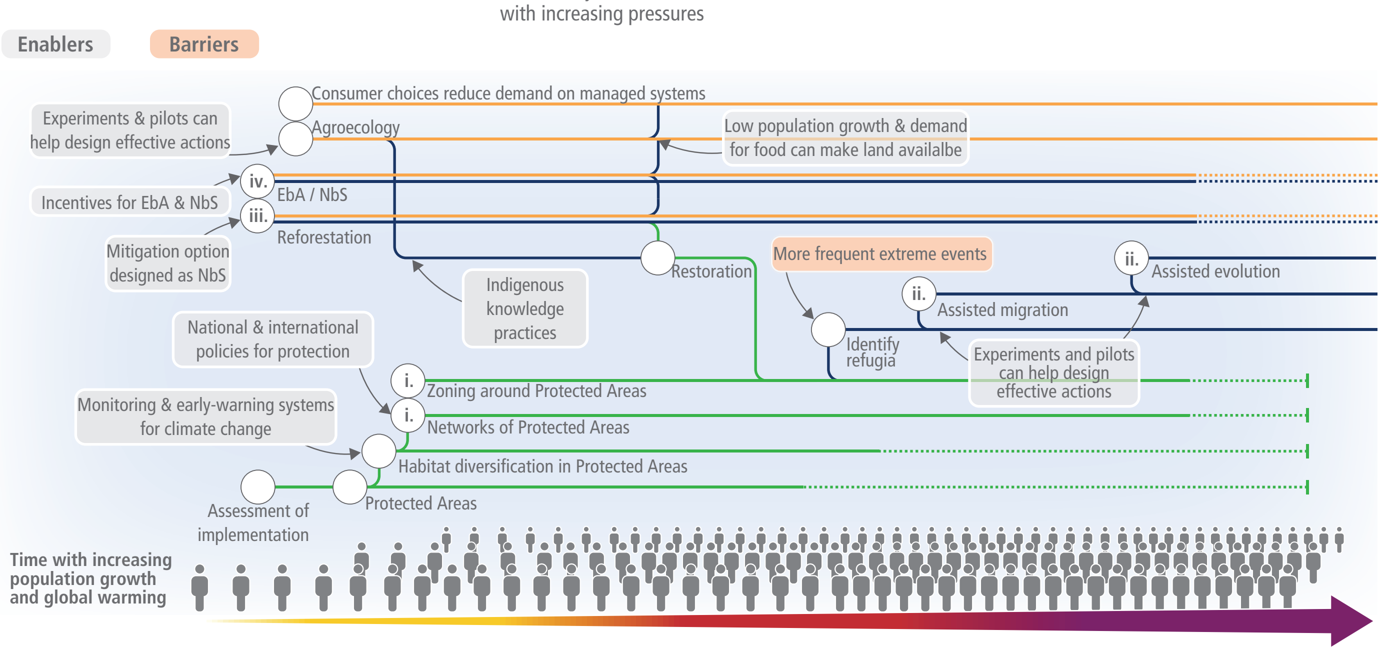


Figure TS.5 ECOSYSTEMS | (a) Left: Observed global and regional impacts on ecosystems and human systems attributed to climate change. Confidence levels reflect uncertainty in attribution of the observed impact to climate change. For more details and line of sight to chapters and cross-chapter papers see Figure TS.3a, SMTS.1 and Table SMTS.1. **Right:** Observed species richness across latitude for three historical periods. {3.4.3, Figure 3.18}. **(b) Left:** Global warming levels (GMST) modelled across the ranges of more than 30,000 marine and terrestrial species. **Middle:** Global warming levels (GSAT); change indicated by the proportion of species (modelled n=119,813 species globally) for which the climate is projected to become unsuitable across their current distributions. **Right:** Modelled 12,796 marine species globally. {2.5.1, Figure 2.6, 3.4.3, Figure 3.18, Figure 3.20a, CCP1.2.4, Figures AI.6, AI.15, AI.16}. **(c)** {2.6.2, Table 2.6, 3.6.2, Figure 3.24}. **(d)** Some actions facilitate sustainable use but also increase space for nature. {2.4 2, 2.6.2, 2.6.3, 2.6.5, 2.6.7, 2.6.8, 3.6.2, 3.6.5, Table 3.30, 5.6.3, Box 5.11, 9.3.1, 9.3.2, 9.6.3, 9.6.4, 9.12 .3, 10.4.2, 10.4.3, 11.3.1, 11 .3.2, 11 .7.3, 12.5. 1, 12. 5.2, 12.5.9, 12.6.1, 13.3.2, 13.4.2, 13.5 .2, 13.10.2, 14.5.1, 14.5.2, Box 14.2, Box 14.7, 15.5.4, 15.3.3, Table 15 .6, 16.5.2, 16.6.3, CCP1.3, CCP3. 2.2, CCP4.4.1, CCP5 .2.5, CCP5.4.1, CCP6.3.2, CCP7.5, CCP7 .5. 1, CCPBox7.1, Table CCP7 .3, CCB EXTREMES, CCB NATURAL}

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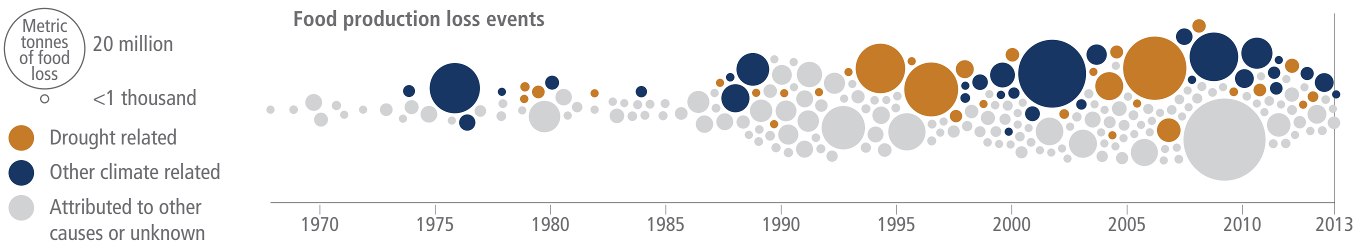
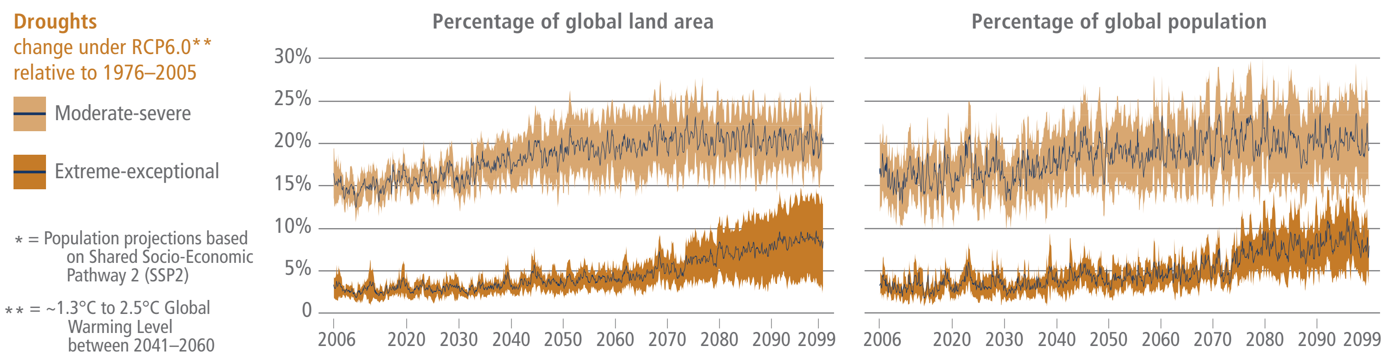
Climate change is affecting food security through pervasive water impacts

Its impacts are being felt in every water use sector, more so in agriculture which globally consumes over 80% of the total water.

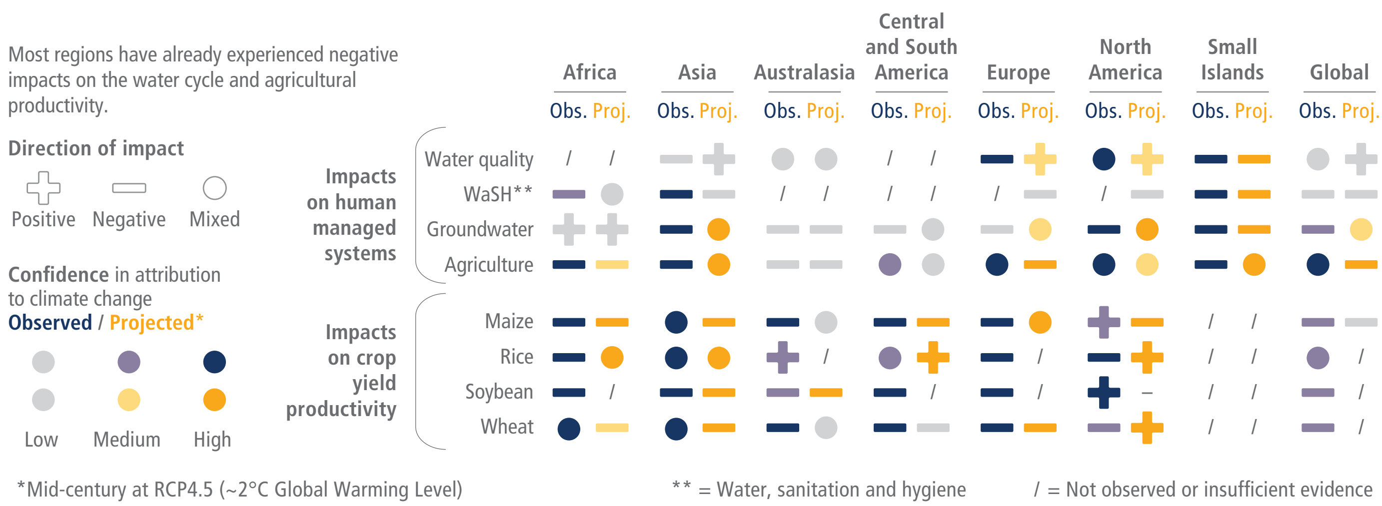
(a) The frequency of climated-related food production losses in crops, livestocks, fisheries and aquacultures has been increasing over the last decades.



(b) By the late 21st century the share of the global land area and population* affected by combinations of agricultural, ecological and hydrological droughts is projected to increase substantially.



(c) Observed and projected impacts from climate change in the water cycle for human managed systems and crop yield productivity.



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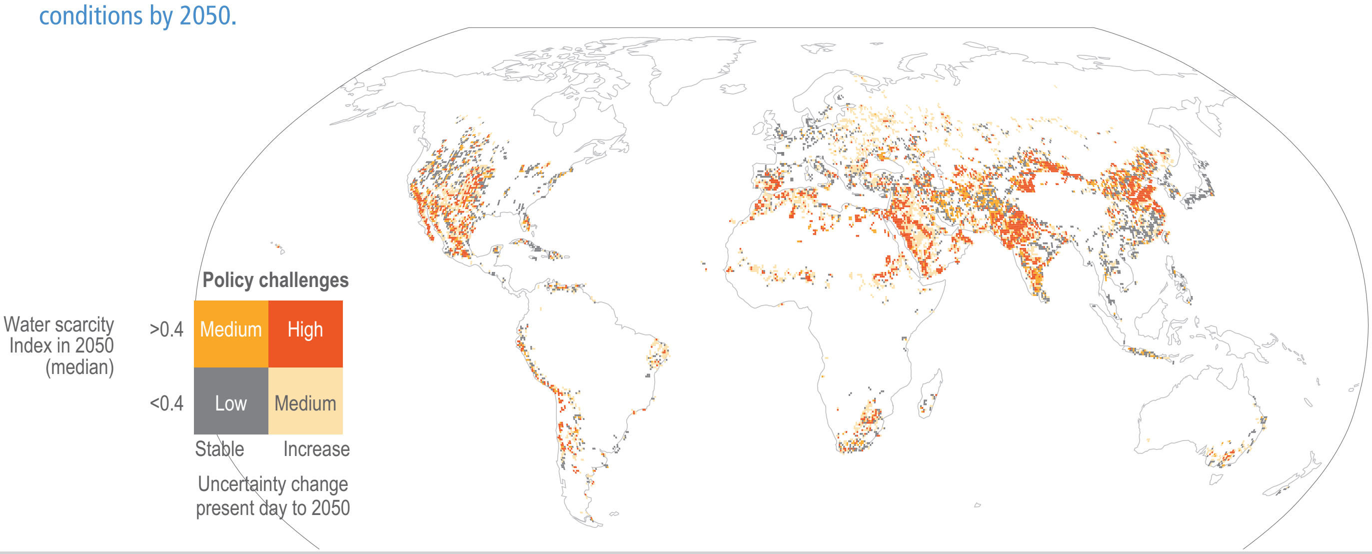
(d) Drought is exacerbating water management challenges which vary across regions with respect to anticipated water scarcity conditions by 2050.



(e) Water-related adaptation responses.

Current beneficial outcomes, co-benefits with mitigation, and maladaptive outcomes of responses and future effectiveness of adaptation and residual risk under different levels of global warming.

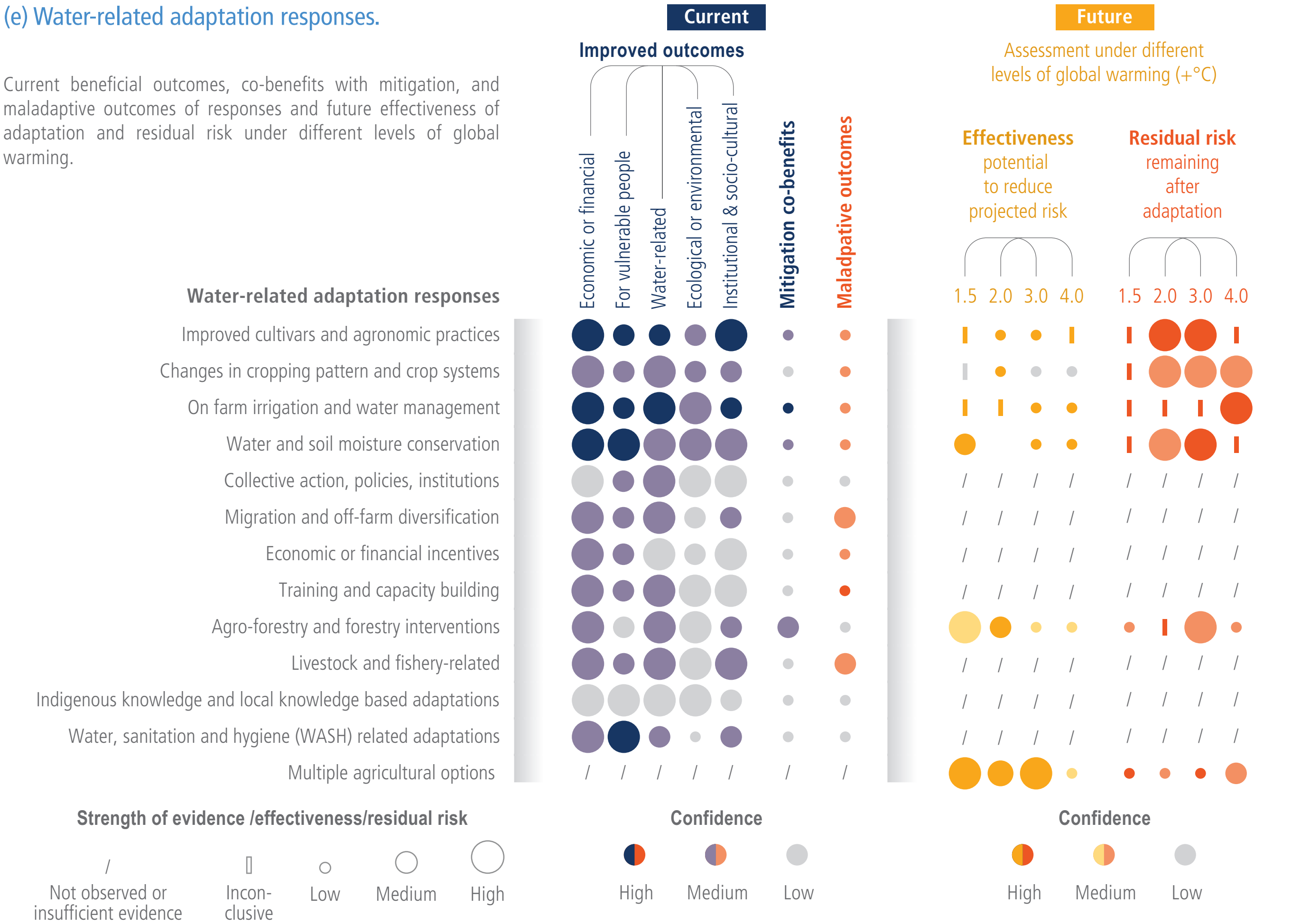


Figure TS.6 FOOD-WATER | (a) {5.4.1.1, Box 5.1, FAQ 5.1, SM5.1, Figure AI.20}. **(b)** Projected increase in the global share of area and population impacted from droughts. Changes are calculated based on the RCP6.0 concentration pathway for Terrestrial Water Storage (TWS) droughts, which can be considered to be a combination of agricultural, ecological and hydrological droughts. TWS is the sum of continental water stored in canopies, snow and ice, rivers, lakes and reservoirs, wetlands, soil and groundwater. {Figure 4.19; 4.4.5}. **(c)** Projected impacts are for RCP4.5 mid 21st century, taking into account adaptation and CO_2 fertilisation for the crop yield productivity {4.3.1, 4.2.7, 4.5.1, Figure 4.2, 5.5.3, 5.4.1, Figure 5.3, Figure 9.22, 15.3.3, 15.3.4}. **(d)** Projections used five CMIP5 climate models, three global hydrological models from ISIMIP, and three Shared Socioeconomic Pathways (SSPs).{Box 4.1, Figure Box 4.1.1, Figure AI.48}. **(e)** {4.6.2, Figure 4.29, Figure 4.28, SM4.7, SM4.8, 5.5.4, 5.6.3}.

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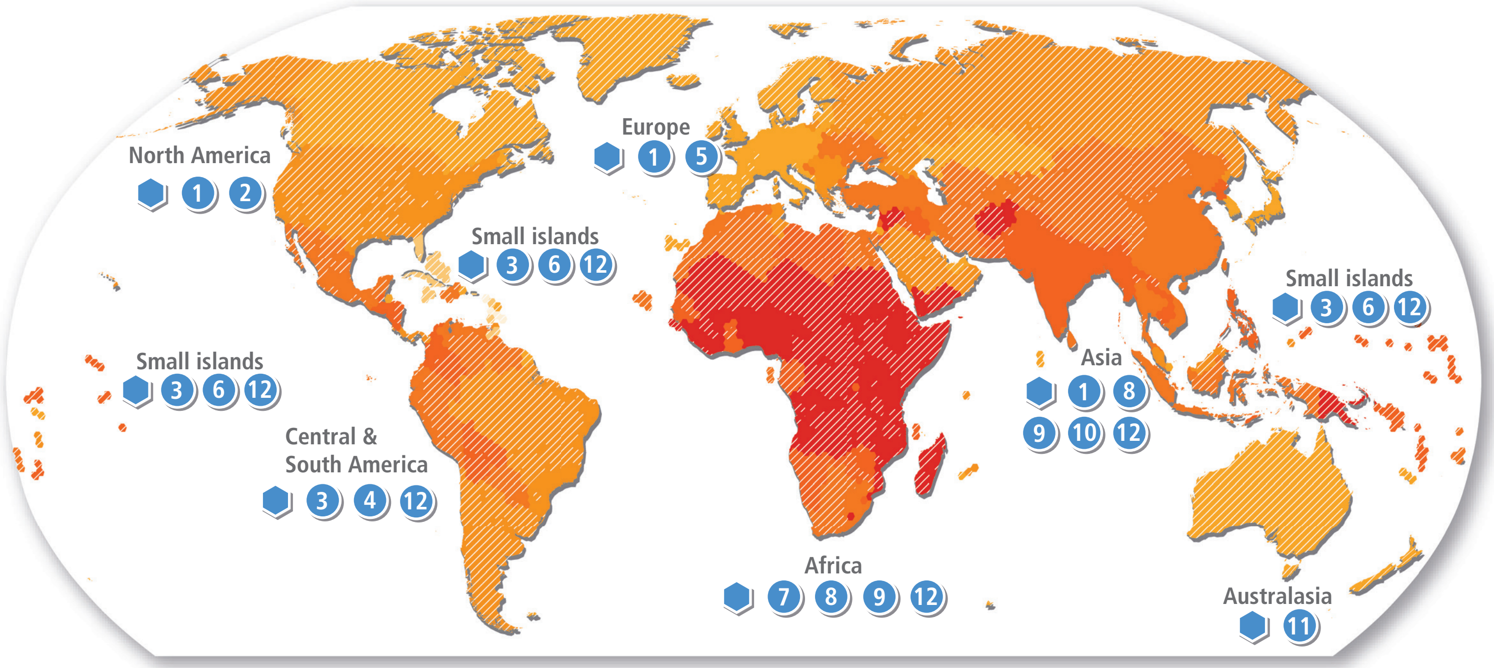
Observed human vulnerability differs between and within countries and strongly determines how climate hazards impact people and society

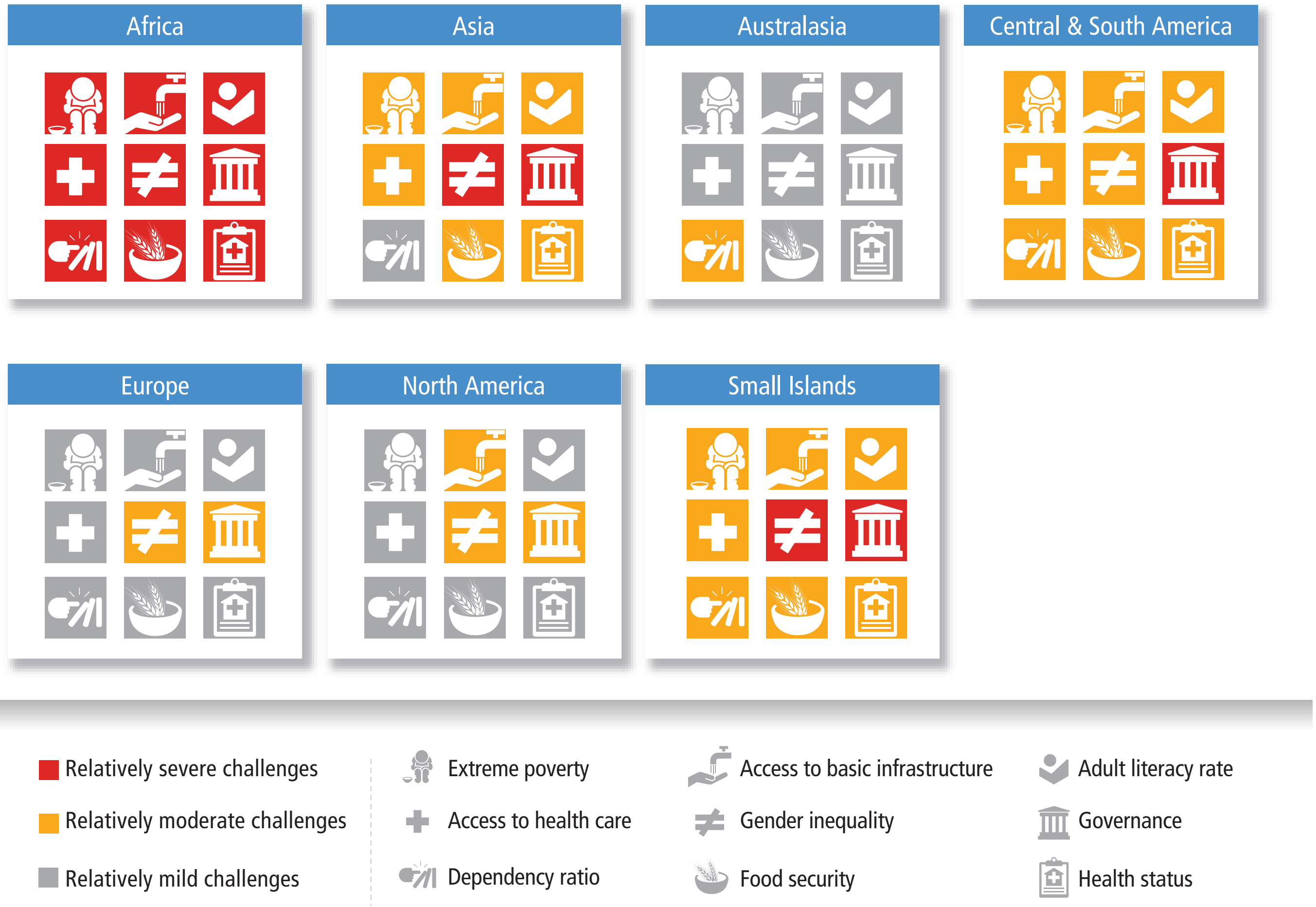
(a) Map of observed human vulnerability based on two comprehensive global indicator-systems using national data, plus examples of selected local vulnerable populations and Indigenous Peoples



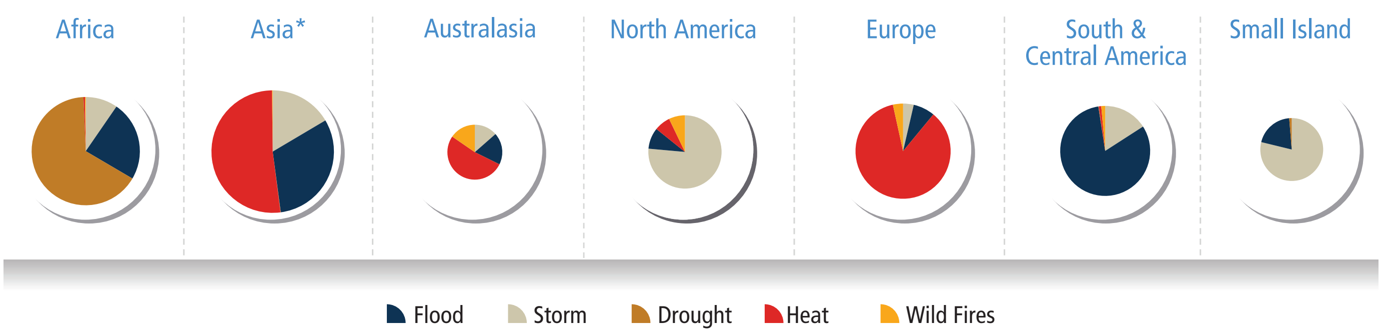
Examples of local vulnerable populations | Examples of some aspects of vulnerability | Chapter references

1. **Indigenous Peoples of the Arctic** | health inequality, limited access to subsistence resources and culture | CCP 6.2.3, CCP 6.3.1
2. **Urban ethnic minorities** | structural inequality, marginalisation, exclusion from planning processes | 14.5.9, 14.5.5, 6.3.6
3. **Smallholder coffee producers** | limited market access & stability, single crop dependency, limited institutional support | 5.4.2
4. **Indigenous Peoples in the Amazon** | land degradation, deforestation, poverty, lack of support | 8.2.1, Box 8.6
5. **Older people, especially those poor & socially isolated** | health issues, disability, limited access to support | 8.2.1, 13.7.1, 6.2.3, 7.1.7
6. **Island communities** | limited land, population growth and coastal ecosystem degradation | 15.3.2
7. **Children in rural low-income communities** | food insecurity, sensitivity to undernutrition and disease | 5.12.3
8. **People uprooted by conflict in the Near East and Sahel** | prolonged temporary status, limited mobility | Box 8.1, Box 8.4
9. **Women & non-binary** | limited access to & control over resources, e.g. water, land, credit | Box 9.1, CCB-GENDER, 4.8.3, 5.4.2, 10.3.3
10. **Migrants** | informal status, limited access to health services & shelter, exclusion from decision-making processes | 6.3.6, Box 10.2
11. **Aboriginal and Torres Strait Islander Peoples** | poverty, food & housing insecurity, dislocation from community | 11.4.1
12. **People living in informal settlements** | poverty, limited basic services & often located in areas with high exposure to climate hazards | 6.2.3, Box 9.1, 9.9, 10.4.6, 12.3.2, 12.3.5, 15.3.4

(b) Different aspects and dimensions of vulnerability (regional averages of selected vulnerability indicators)



(c) Average mortality per hazard event per region between 2010 and 2020:



Average mortality per hazard event is indicated by size of pie charts. The slice of pie chart shows absolute number of deaths from a particular hazard

* The large size of the pie chart and the strong representation of heat waves is caused by the significant number of deaths from a single event in a single country. This single extreme outlier affected the overall average mortality per event in Asia.

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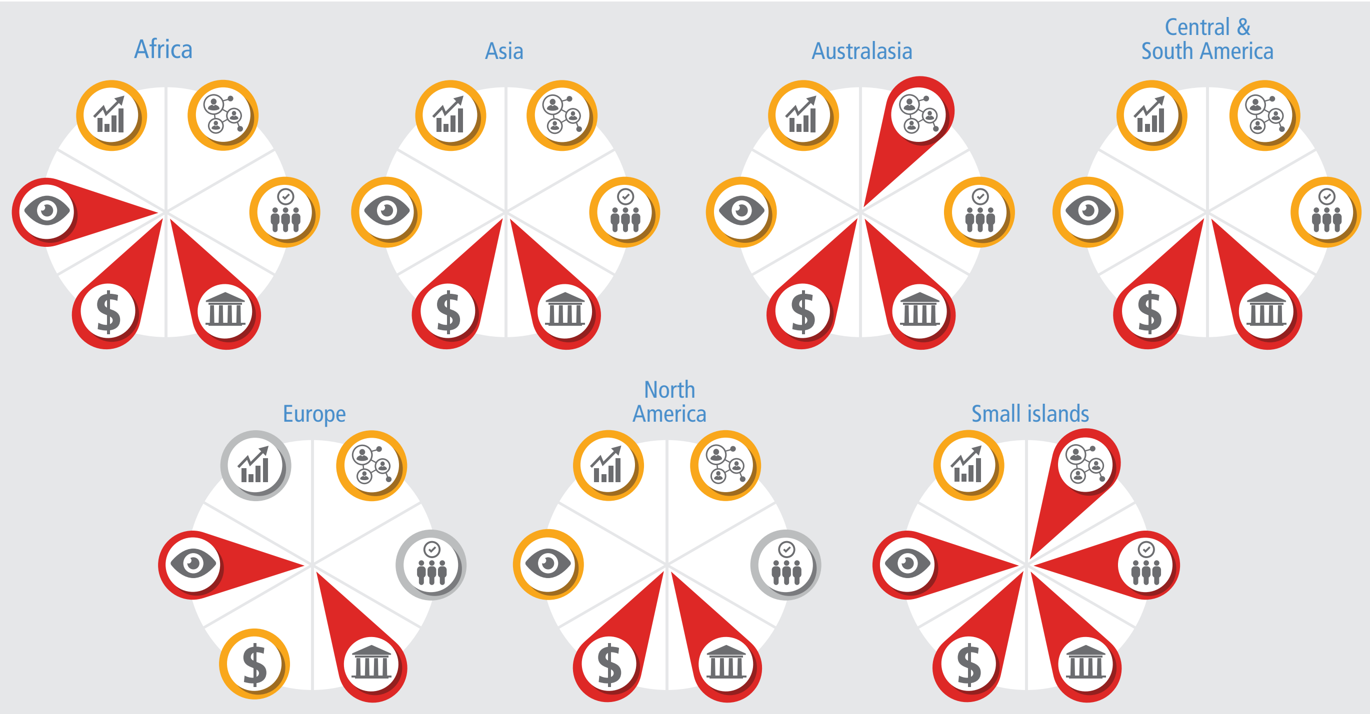
(d) Constraints that make it harder to plan and implement human adaptation



Constraints associated with limits to adaptation for regions across all sectors:

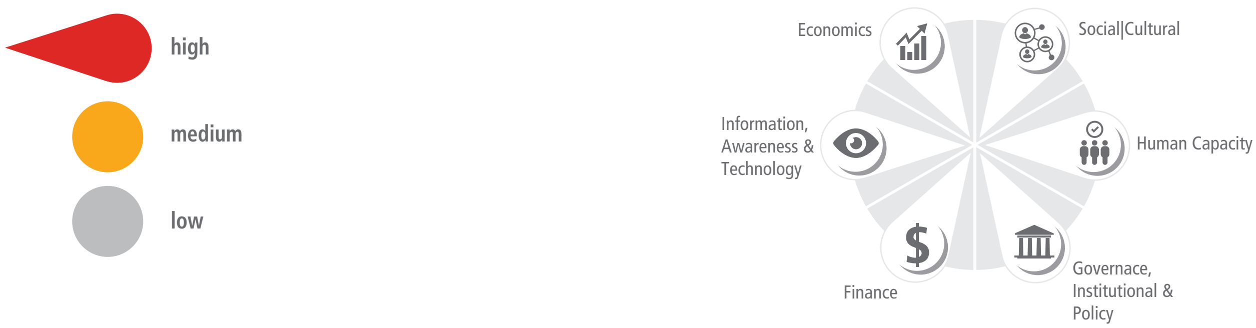


Figure TS.7 VULNERABILITY | (a) The global map of vulnerability is based on two comprehensive global indicator systems, namely INFORM Risk Index and WorldRiskIndex (2019). Climate change hazards and exposure levels are not included in this figure. The relative level of average national vulnerability is shown by the colours. Vulnerability values are based on the average of the two indices, classified into 5 classes using the quantile method. A hexagon binning method was used to simplify the global map and enlarge small states. The map combines information about the level of vulnerability (independent of the population size) with two classes of population density (high density ≥ 20 people/km2 and low density < 20 people/km^2). The selected examples of local vulnerable populations underscore that there are also highly vulnerable populations in countries with overall low relative vulnerability {8.3.2, Figure 8.6} **(b)** This figure shows regional averages for selected aspects of human vulnerability. The indicators are a selection of the indicator systems used within the global vulnerability map (panel a). The colours represent the average value of the respective indicator for the regional level; classified into three classes using natural breaks. This regional information reveals that within all regions challenges exist in terms of different aspects of vulnerability, however, in some regions these challenges are more severe and accumulate in multiple-dimensions. For example, the indicator "dependency ratio" measures the ratio of the number of children (0–14 years old) and older persons (65 years or over) to the working-age population (15–64 years old). {8.3.2, Figure 8.7} **(c)** The pie charts show the number of deaths (mortality) per hazard (storm, flood, drought, heatwaves and wildfires) event per continental region based on Emergency Events Database (EM-DAT) (Centre for Research on the Epidemiology of Disasters, 2020). The size of the pie chart represents the average mortality per hazard event while slices of each pie chart show the absolute number of deaths from each hazard. This reveals that significantly more fatalities per hazard (storms, floods, droughts, heatwaves and wildfires) did occur in the past decade in more vulnerable regions, e.g. Africa and Asia. {Figure 8.6} **(d)** The figure shows constraints that make it harder to plan and implement human adaptation. Across regions and sectors, the most significant challenges to human adaptation are financial, governance, institutional and policy constraints. The ability of actors to overcome these socio-economic constraints largely influences whether additional adaptation is able to be implemented and prevent limits to adaptation from being reached. Low: <20% of assessed literature identifies this constraint; Medium: 20–40% of assessed literature identifies this constraint; High: >40% of assessed literature identifies this constraint. {9.3, 16.4.3, Figure 16.8}

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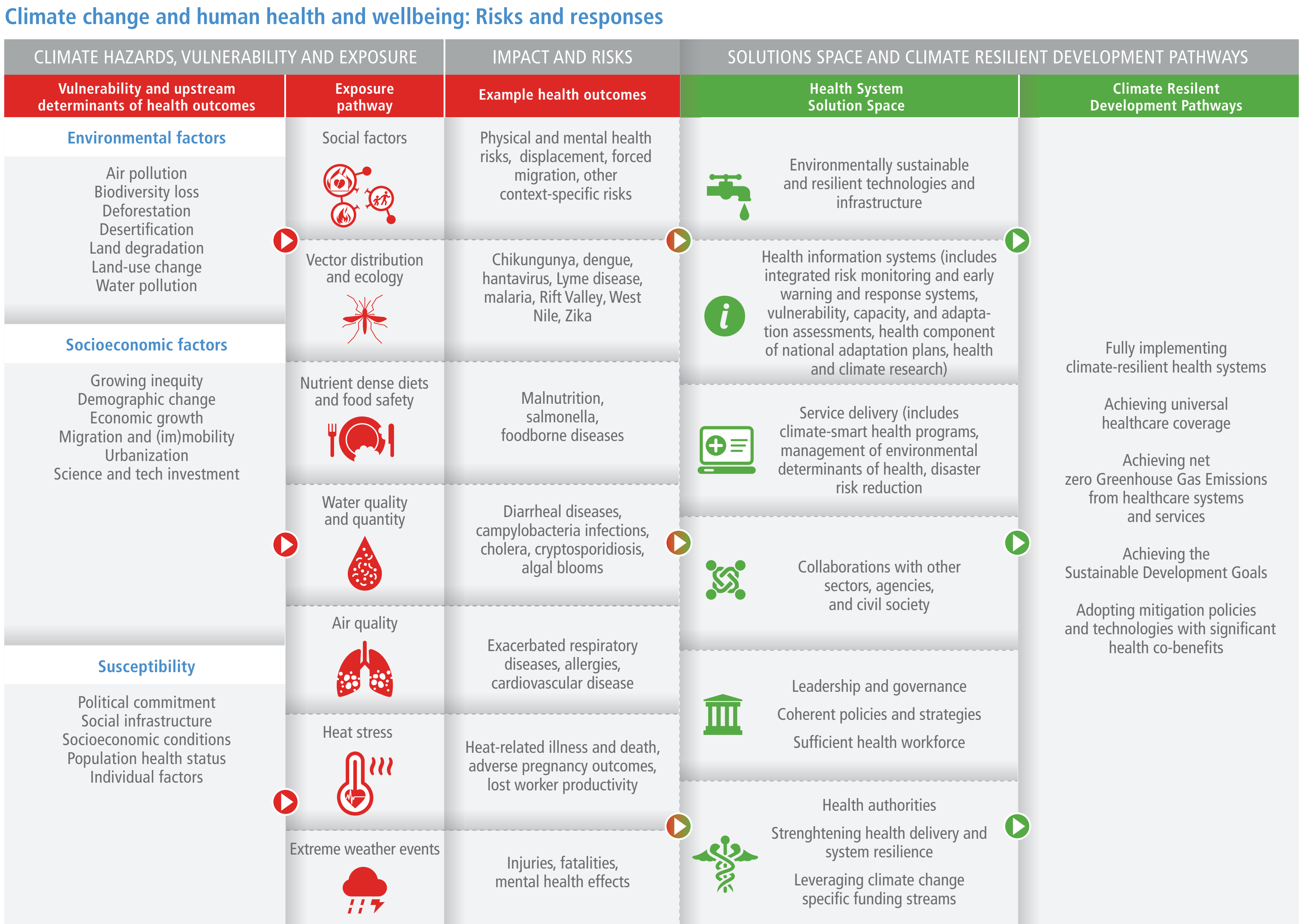
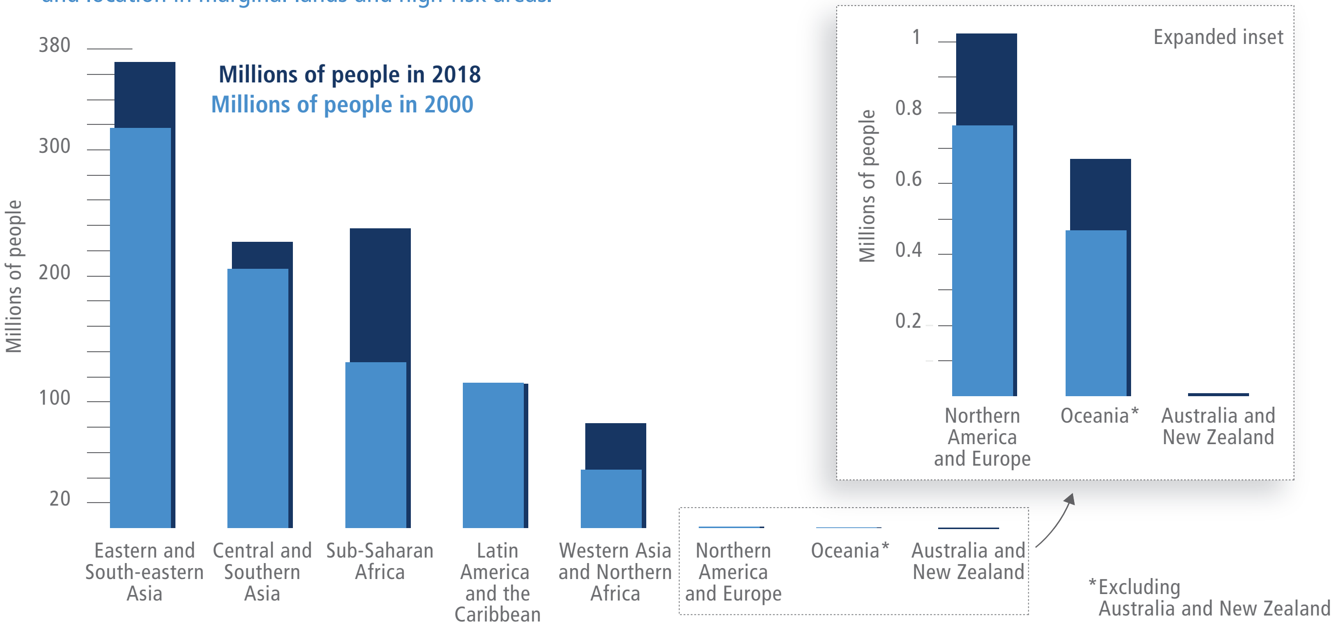


Figure TS.8 HEALTH | Multiple socio-economic and environmental factors interact with climate risks to shape human health and well-being. Achieving climate resilient development requires leveraging opportunities in the solution space within health systems and across other sectors. {7.1.4, 7.1.6, 7.1.7, 7.2.1, 7.2.2, 7.2.3, 7.2.4, 7.2.5, 7.2.6, 7.2.7, 7.3.1, 7.3.3, 7.4.1, 7.4.2, 7.4.3, 7.4.6, 7.4.7, Box 7.1, Box 7.2, Figure 7.6, Figure 7.7, Figure 7.16, Table 7.1,Table 7.3, Table 7.6, Table 7.7, Table 7.8, Table 7.10, Table 7.11, CCB COVID, CCB HEALTH, CCB MIGRATE}

Climate change in cities and settlements

(a) Urban poor populations residing in informal settlements are highly vulnerable to climate hazards given their housing characteristics and location in marginal lands and high-risk areas.



(b) Global distribution of population exposed to potentially deadly conditions from extreme temperatures and relative humidity.

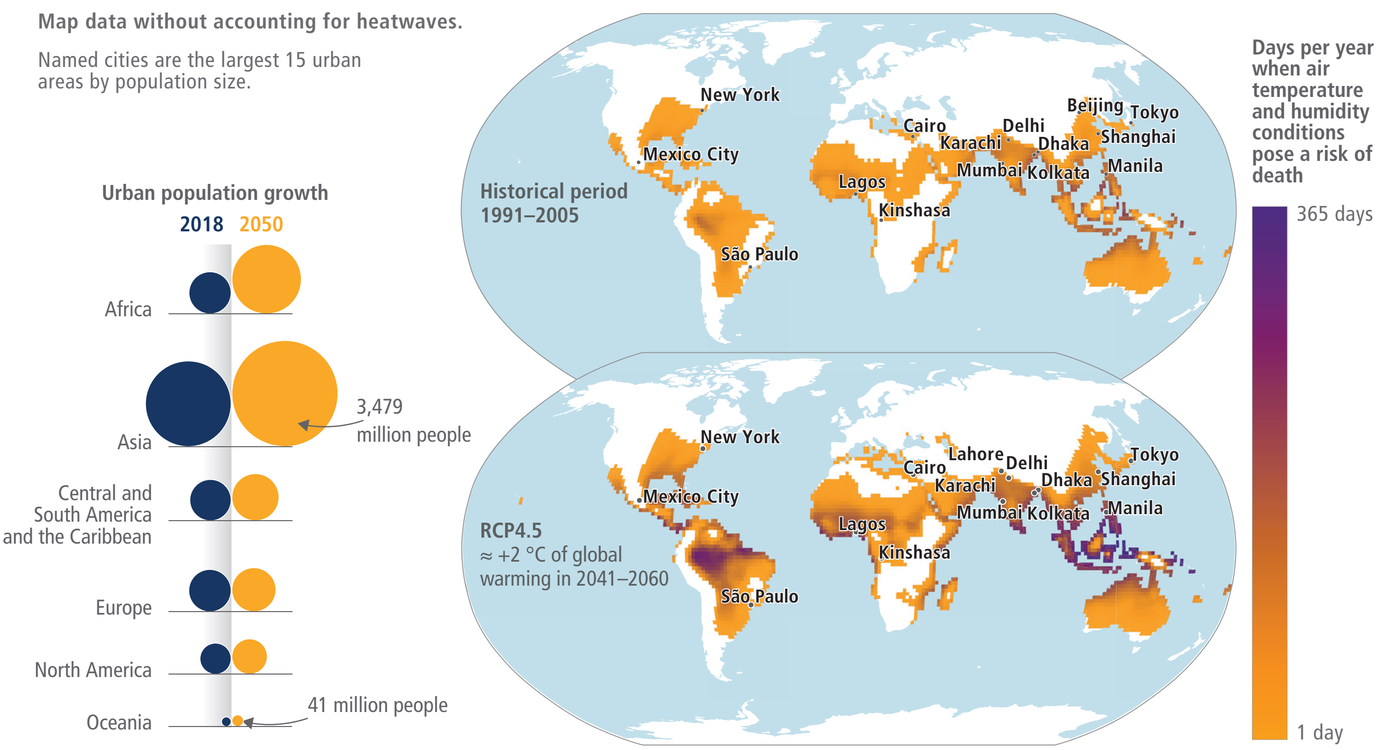


Figure TS.9 URBAN | (a) The regions shown are reflecting the original dataset from UN Habitat and vary from IPCC regions. {6.1.4, 9.9.3, 10.4.6, 12.5.5} **(b)** Heat is a growing health risk due to increasing urbanization and rising temperature extremes. Within cities the urban heat island effect elevates temperatures further, with some populations in cities being disproportionately at risk including low income communities in informal settlements, children, the elderly, disabled, people who work outdoors and ethnic minorities. The data does not consider heatwaves which are also projected to increase and can cause thousands of deaths in higher latitudes. {6.1.4, 7.2.4, 7.3.1, 10.4.6, 13.6.1, Annex I: Global to Regional Atlas}

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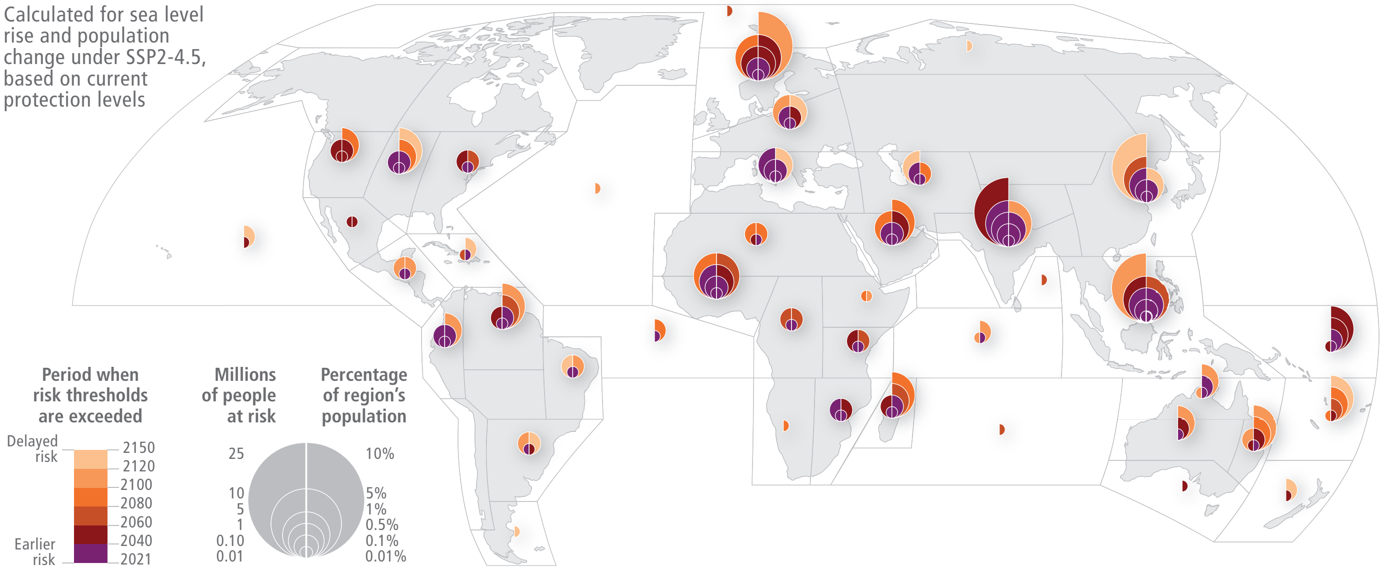
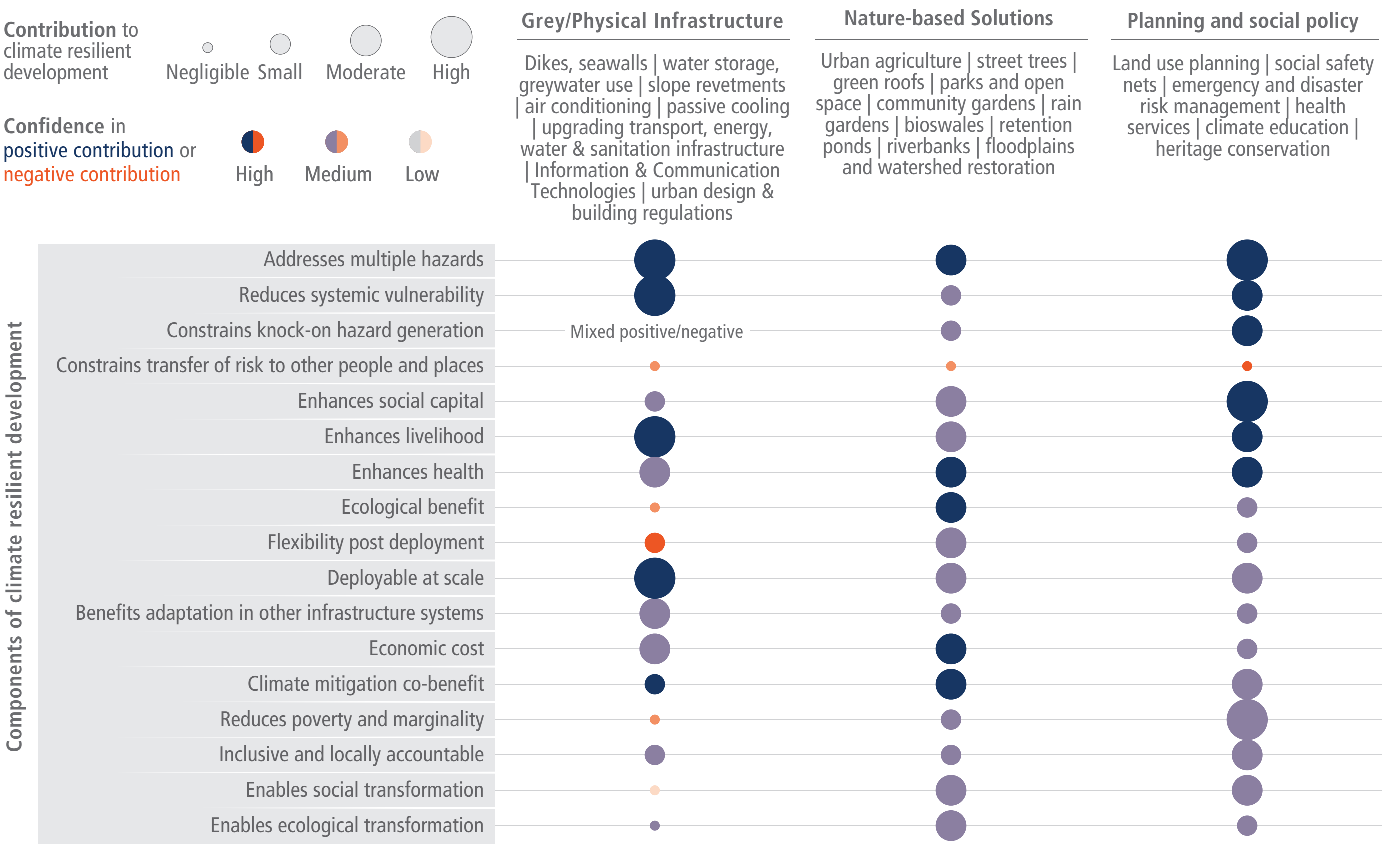
(c) Projected number of people at risk of a 100-year coastal flood.



(d) Contributions of urban adaptation options to climate resilient development.

Nature-based solutions and social policy as innovative domains of adaptation show how some of the limitations of grey infrastructure can be mediated. A mixture of the three categories has considerable future scope in adaptation strategies and building climate resilience in cities and settlements.



(c) The size of the circle represents the number of people at risk per IPCC region and the colours show the timing of risk based on projected population change and sea level rise under SSP2-4.5. Darker colours indicate earlier in setting risks. The left side of the circles shows absolute projected population at risk and the right side the share of the population in percentage. {Figure 13.6, Figure 15.3, Figure CCP2.4, Annex I: Global to Regional Atlas}. **(d)** The figure is based on Table 6.6 which is an assessment of 21 urban adaptation mechanisms. Supplementary Material 6.3 provides a detailed analysis including definitions for each component of climate resilient development and the evidences. {6.3.1, 6.3.2, 6.3.3, Table 6.6, SM6.3}

TS

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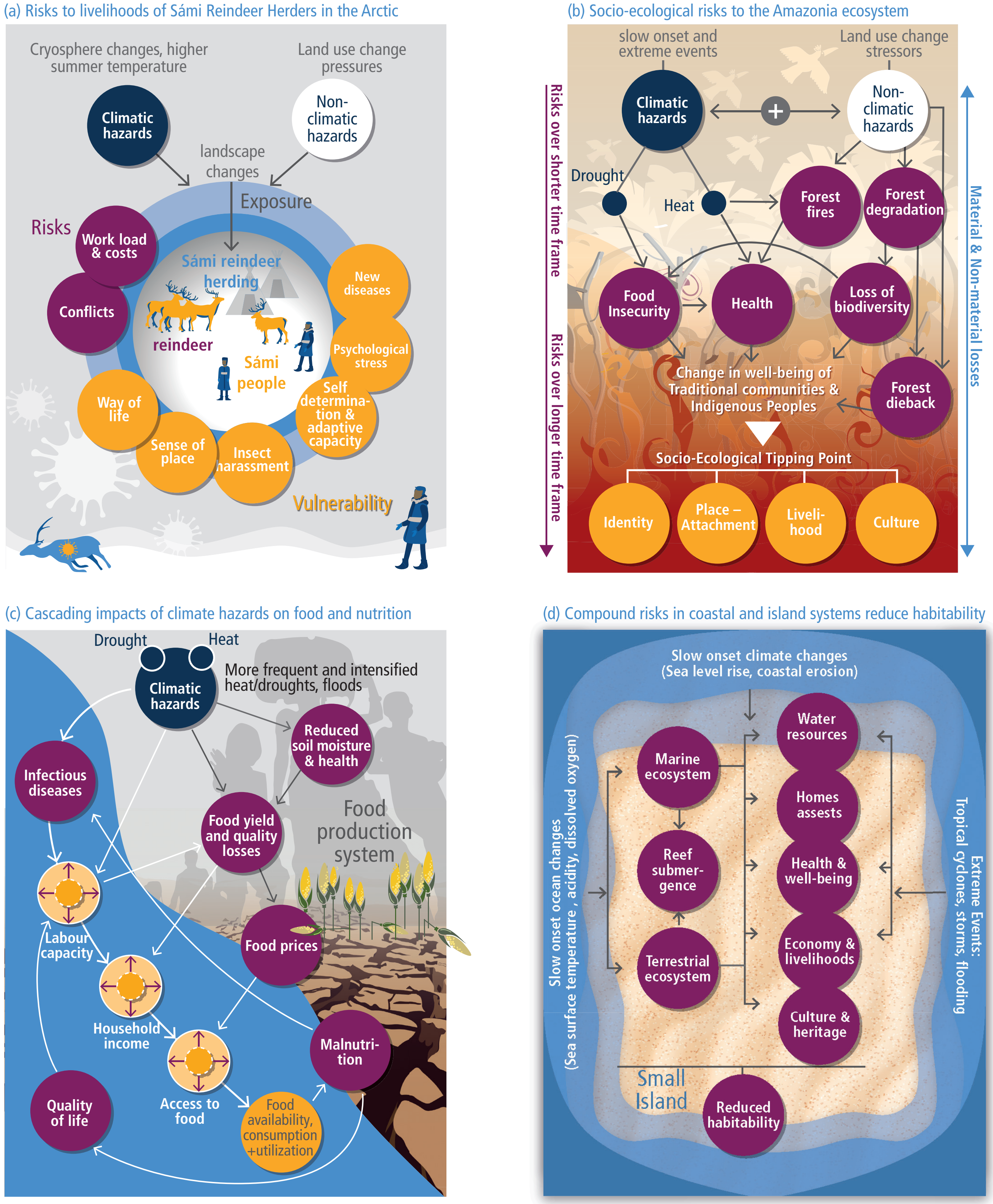
Compound, cascading and transboundary impacts for humans and ecosystems result from the complex interaction of multiple climate hazards, exposures and vulnerabilities



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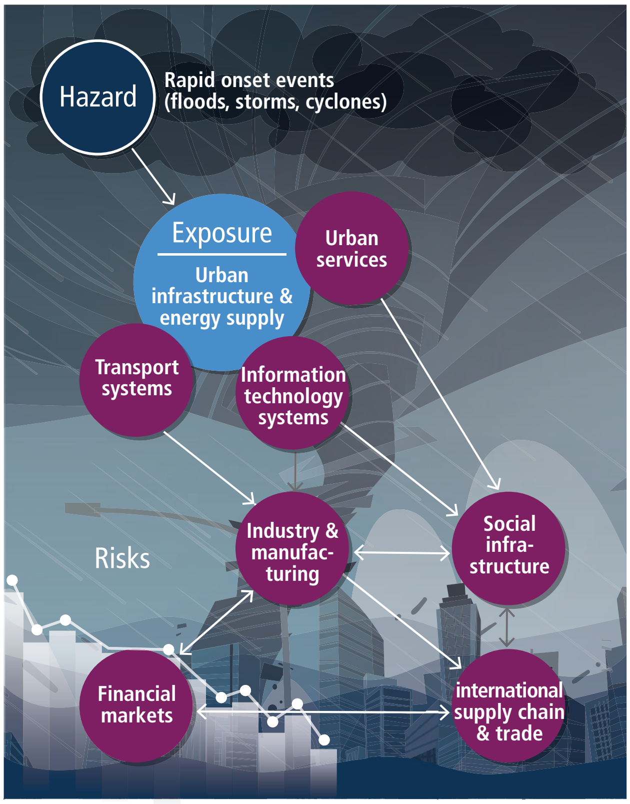
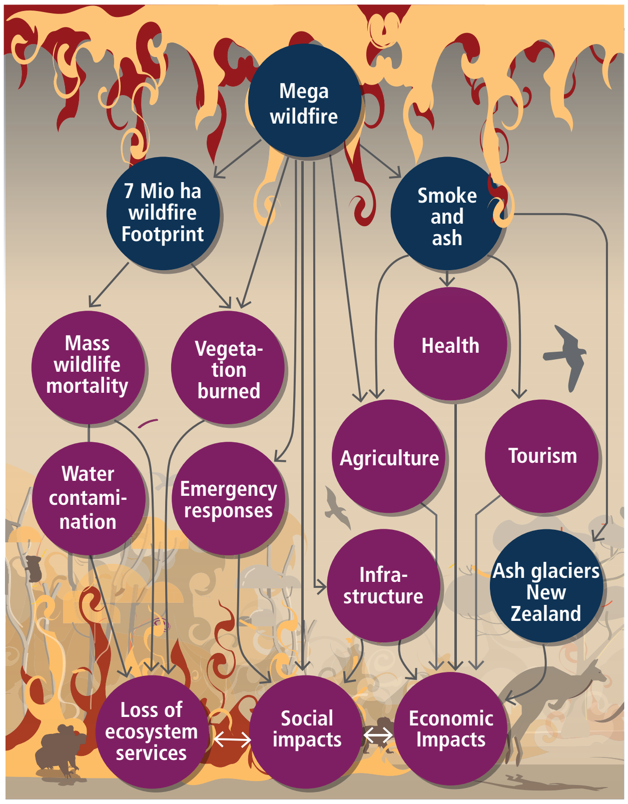
(e) Urban infrastructure failures cascade risk and loss across and beyond the city



(f) Cross-sectoral and transboundary impacts of Australian megafires, 2019–2020



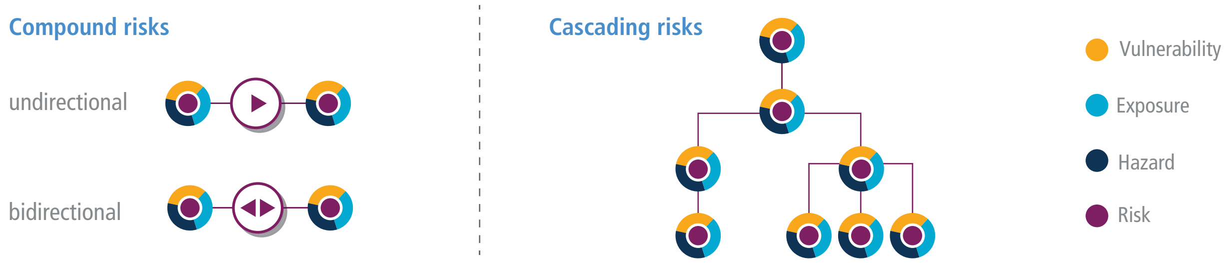


Figure TS.10 COMPLEX RISK | Compound, cascading and transboundary impacts for humans and ecosystems result from exposure to the complex interactions of (1) multiple climatic hazards, including with non-climatic stressors (as seen in panels a, b, c, d), (2) multiple vulnerabilities compounding the effect of risks (as seen in panel a, b, c), and (3) multiple impacts/risks that compound and cascade to spread across sectors and boundaries (panels b, c, d, e, f)

(a) Climate and land use change result in cumulative impacts on traditional, semi-nomadic Sámi reindeer herding. Impacts cascade due to a lack of access to key ecosystems, lakes and rivers, thereby increasing costs and threatening traditional livelihoods, food security, cultural heritage, and mental health. {Box 7.1, Figure Box 9.7.1, 13.8.1.2, Box 13.2, Figure 13.14. Table SM13.7, Figure 16.2, Figure CCP6.7}

(b) Risks compound from deforestation, wildfires, urbanization, and climate change in Amazonia impacts biodiversity, livelihoods, medicinal, spiritual, and cultural sites; increasing migration patterns, loss of place-based attachments, and culture, causing health problems and mental and emotional distress of vulnerable traditional communities and Indigenous People dependent on the forest ecosystem. {Box 8.7, Figure Box 9.7.1, 12.4, Figure 12.11, Table 12.6, Figure 16.2}

(c) Complex pathways from climate hazards to malnutrition in subsistence farming households. The factors involved in and the probable impacts of weather variables on food yields and of production on malnutrition. {Figure 1.3, Figure 1.4, 5.2.1, 5.2.2, 5.12.3, 5.12.4, Box 5.10, Figure 5.2, 7.2.2, 7.3.1, Figure Box 9.7.1, 13.5.1, 13.5.2, 13.10.2, 16.5.2, 16.5.3, Figure 16.2}

(d) Risk compounds and amplifies through cascading effects due to interconnectedness of island systems. Loss of marine, coastal, terrestrial biodiversity and ecosystem services can cause submergence of reef islands, increase water insecurity, destroy settlements and infrastructure, degrade health and well-being, reduce economy and livelihoods, and result in loss of cultural resources and heritage. {15.3.4.9, Figure Box 15.1, Figure 15.5, Figure 16.2}

(e) Climate impacts can cascade through interconnected infrastructure in cities and settlements impacting on social well-being and economic activities, spreading loss and risk through lost economic productivity disrupting the distribution of goods and provision of basic services, spreading widely, into rural places and across international borders as supply chains, financial investment and remittance flows are disrupted. {6.1.3, 6.2.2, 6.2.4, Figure 6.2, Figure 16.2, Figure CCB INTEREG.1}

(f) Cascading, compounding and transboundary impacts on people's mortality and physical and mental health, economic activity, built assets, ecosystems and mass species mortality and with smoke and ash transported to New Zealand affecting air quality and glaciers, arising from the "Black Summer" fires of 2019–2020 which burned over a five-month period in eastern and southern Australia. Fire weather is projected to worsen across Australasia. {Figure 1.3, Figure 1.4, 11.3.1.3, Box 11.1, Figure Box 11.1.2, Figure 16.2, WGI AR6 Figure SPM.9}

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TS.D.1.5 Systemic barriers constrain the implementation of adaptation options in vulnerable sectors, regions and social groups (*high confidence*). Key barriers are limited resources, lack of private-sector and citizen engagement, insufficient mobilisation of finance (including for research), lack of political leadership, limited research and/or slow and low uptake of adaptation science and a low sense of urgency. Most of the adaptation options to the key risks depend on limited water and land resources (*high confidence*). Governance capacity, financial support and the legacy of past urban infrastructure investment constrain how cities and settlements are able to adapt (*high confidence*). Critical urban capacity gaps include limited ability to identify social vulnerability and community strengths, the absence of integrated planning to protect communities, the lack of access to innovative funding arrangements and a limited capability to manage finance and commercial insurance (*medium confidence*). Prioritisation of options and transitions from incremental to transformational adaptation are limited due to vested interests, economic lock-ins, institutional path dependencies and prevalent practices, cultures, norms and belief systems. For example, Africa faces severe climate data constraints and inequities in research funding and leadership that reduce adaptive capacity (*very high confidence*)—from 1990 to 2019 research on Africa received just 3.8% of climate-related research funding globally, and 78% of this funding for Africa went to European Union- and North America–based institutions and only 14.5% to African institutions. {3.6.3, 9.1.5, 9.5.1, 9.8.4, 12.5.1, 12.5.5, 12.5.7, 12.8, 13.11, 14.7.2, 15.6.1, 15.7, CCP7.6, CCB FEASIB}

TS.D.1.6 Insufficient financing is a key driver of adaptation gaps (*high confidence*). Annual finance flows targeting adaptation for Africa, for example, are billions of US dollars less than the lowest adaptation cost estimates for near-term climate change (*high confidence*). Finance has not targeted more vulnerable countries and communities. From 2014 to 2018 a greater amount of financial commitments to developing countries was in the form of debt rather than grants, and—excluding multilateral development banks—only 51% of commitments targeting adaptation were dispersed (compared to 85% for other development projects). Tracked private-sector finance for climate change action has grown substantially since 2015, but the proportion directed towards adaptation has remained small (*high confidence*); in 2018 contributions were 0.05% of total climate finance and 1% of adaptation finance. Globally, private-sector financing of adaptation has been limited, especially in developing countries (*high confidence*). {3.6.3, 4.7,4, 4.7.5, 4.8.2, 6.4.5, Table 6.10, 9.4.1, 12.5.4, 12.5.8, 15.6.3, 17.4.3, CCB FINANCE}

TS.D.1.7 Closing the adaptation gap requires moving beyond short-term planning to develop long-term, concerted pathways and enabling conditions for ongoing adaptation to ensure timely and effective implementation (*high confidence*). Inclusive, equitable and just adaptation pathways are critical for climate resilient development. Such pathways require consideration of SDGs, gender and Indigenous knowledge and local knowledge and practices. The success of adaptation will depend on our understanding of which adaptation options are feasible and effective in their local context (*high confidence*). Long lead times for nature-based and infrastructure solutions or planned relocation will require implementation in the coming decade to reduce risks in time. To close the adaptation gap, political commitment, persistent and consistent action across scales of government and upfront mobilisation of human and financial capital are key (*high confidence*), even when the benefits are not immediately visible. {3.6.5, 4.8, 6.3.5, 11.7, 12.5.7, 13.2.2, 13.8, 13.11, 14.7.2, 15.7, CCP2.3, CCP2.4, CCP7.5, CCB DEEP, CCB FEASIB, CCB GENDER}

Limits to adaptation

TS.D.2 There is increasing evidence on limits to adaptation which result from the interaction of adaptation constraints and the speed of change (*high confidence*). In some natural systems, hard limits have been reached (*high confidence*) and more will be reached beyond 1.5°C (*medium confidence*). Surpassing such hard, evolutionary limits causes local species extinctions and displacements if suitable habitats exist (*high confidence*). Otherwise, species' existence is at very high risk (*high confidence*). In human, managed and natural systems, soft limits are already being experienced (*high confidence*). Financial constraints are key determinants of adaptation limits in human and managed systems, particularly in low-income settings (*high confidence*), while in natural systems key determinants for limits are inherent traits of the species or ecosystem (*very high confidence*). (Figure TS.7 VULNERABILITY) {2.4.2, 2.6.1, 3.3, 3.4.2, 3.4.3, 15.5.4, CCP5.3.2, CCP7.5.2, CCB EXTREMES}

TS.D.2.1 Adaptation limits can be differentiated into hard and soft limits. Soft limits are those for which no further adaptation options are feasible currently but might become available in the future. Hard limits are those for which existing adaptation options will cease to be effective and additional options are not possible. Hard limits will increasingly emerge at higher levels of warming (*high confidence*). Adaptation limits are shaped by constraints that can or cannot be overcome by adaptation actions and by the speed with which climate impacts unfold. Evidence and signals of the thresholds at which constraints result in limits is still sparse and, in human systems, are expected to remain contested even with increasing knowledge (*high confidence*). {2.4.2, 2.6.1, 4.7.4, Box 4.2, Box 4.3, 15.3.4, 15.5.4, 16.4.1, 16.4.2, 16.4.3, CCB EXTREMES}

TS.D.2.2 Limits to adaptation have been observed for terrestrial and aquatic species and ecosystems and for some human and managed systems in specific geographies such as small island states and mountain regions (*high confidence*). Beginning at below 1.5°C, autonomous and evolutionary adaptation responses by more terrestrial and aquatic species and ecosystems will face hard limits, resulting in species extinctions, loss of ecosystem integrity and a resulting loss of livelihoods (*high confidence*). Examples of hard limits being exceeded include observed population losses and species extinctions and loss of whole ecosystems from certain locations (e.g., irrecoverable loss of tropical coral reefs locally). Large local population declines of wild species have already impacted human food sources and livelihoods (e.g., for Indigenous Arctic communities). Soft limits are currently being experienced in particular by individuals, households, cities and settlements along the coast and by small-scale farmers (*medium confidence*). As sea levels rise and extreme events intensify, coastal communities face limits due to financial, institutional and socioeconomic constraints and a short timeline for adaptation implementation, reducing

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the efficacy of coastal protection and accommodation approaches and resulting in loss of life and economic damages (*medium confidence*). {2.4.2, 2.5.4, 2.6.1, 3.4.2, 3.4.3, CCP1, CCP2, CCP6, 4.7.4, Box 4.2, 6.4.4, 11.3.1, 11.3.2, 11.3.4, 11.3.5, 12.5.1, 13.3.1, 13.4.1, 13.10.2, 15.5.4, 15.5.6, 16.4.2, 16.4.3, CCP5.2.7, CCP5.3.2}

TS.D.2.3 Limits to adaptation will be reached in more systems, including, for example, coastal communities, water security, agricultural production and human health, as global warming increases (*medium confidence*). Hard limits beginning at 1.5°C are also projected for coastal communities reliant on nature-based coastal protection (*medium confidence*). Adaptation to address the risks of heat stress, heat mortality and reduced capacities for outdoor work for humans face soft and hard limits across regions that become significantly more severe at 1.5°C and are particularly relevant for regions with warm climates (*high confidence*). Beginning at 3°C, hard limits are projected for water management measures, leading to decreased water quality and availability, negative impacts on health and well-being, economic losses in water and energy-dependent sectors and potential migration of communities (*medium confidence*). Soft and hard limits for agricultural production are related to water availability and the uptake and effectiveness of climate resilient crops, which are constrained by socioeconomic and political challenges (*medium confidence*). In terms of settlements, limits to adaptation are often most pronounced in smaller and rapidly growing towns and cities, including those without dedicated local government (*medium confidence*). At the same time, legacy infrastructure in large and mega cities, designed without taking climate change risk into account, constrains innovation, leading to stranded assets and with increasing numbers of people unable to avoid harm, including heat stress and flooding, without transformative adaptation (*medium confidence*). {2.4.2, 3.4.2, 3.5.5, 3.6.3, 4.7.4, Box 4.2, Box 4.3, 4.7.2, 4.7.3, 6.4.3, 6.4.5, 6.4.5, 6.4.5, Figure 6.4, 16.4.2, 16.4.3, 3.4.3, 11.3.1, 11.3.2 11.3.4, 11.3.5, 11.3.6, 12.5.1, 12.5.2, 12.5.3, 13.10.2, Box 11.6, Table 14.6, 15.3.3, 15.3.4, 15.5.4, 16.4.2, 16.4.3, CCP2, CCB ILLNESS, CCB SLR}

TS.D.2.4 Across regions and sectors, the most significant determinants of soft limits are financial, governance, institutional and policy constraints (*high confidence*). The ability of actors to address these socioeconomic constraints largely influences whether additional adaptation can be implemented and prevent soft limits from becoming hard limits. Global and regional evidence shows that climate impacts may limit the availability of financial resources, stunt national economic growth, result in higher levels of losses and damage and thereby increase financial constraints (*medium evidence*). Information, awareness and technological constraints are also high in multiple regions (*high confidence*). For example, awareness of anthropogenic climate change ranges between 23% and 66% of people across 33 African countries, with low climate literacy limiting potential for transformative adaptation (*medium confidence*). (Figure TS.7 VULNERABILITY) {2.3.1, 2.3.2, 2.5.1, 2.6.8, 3.6.3, 4.7.4, 6.4.4, 9.3.1, 9.4.1, 9.4.5, 12.8, 13.11.1, 14.7.2, 15.6.1, 15.6.3, 16.4.2, 16.4.3, CCP2, CCP5.4.1, CCP7.5, CCP7.6, CCB EXTREMES}

TS.D.2.5 The potential for reaching adaptation limits fundamentally depends on emissions reductions and mitigating global warming (*high confidence*). Under all emissions scenarios, climate change reduces capacity for adaptive responses and limits choices and opportunities for sustainable development. The ability of actors to overcome socioeconomic constraints determines whether additional adaptation can be implemented and prevent soft limits from becoming hard limits (*medium confidence*). Above 1.5°C of warming, limits to adaptation are reported for human and natural systems, including coral reefs (*high confidence*), regional water availability (*medium evidence, high agreement*) and outdoor labour and existing tourism-related activities. {1.1.3, 1.5.1, 2.6.0, 2.6.1, 2.6.2, 2.6.3, 2.6.4, 2.6.5, 2.6.8, 3.6.3, 3.6.5, 4.7.1, 4.7.2, Box 4.3, 3.5.2, 3.6.2, 3.6.2, 13.10.2, 14.5.7, 14.5.8, 15.3.3, 15.3.4, Box 15.1, 16.4, 16.5, 16.6, CCP5.3.2}

Maladaptation

TS.D.3 Evidence of maladaptation is increasing in some sectors and systems, highlighting how inappropriate responses to climate change create long-term lock-in of vulnerability, exposure and risks that are difficult and costly to change (*very high confidence*) and exacerbate existing inequalities for Indigenous Peoples and vulnerable groups, impeding achievement of SDGs, increasing adaptation needs and shrinking the solution space (*high confidence*). Decreasing maladaptation requires attention to justice and a shift in enabling conditions towards those that enable timely adjustments for avoiding or minimising damage and for seizing opportunities (*high confidence*). (Figure TS.11a) {1.2.1, 1.3.1, 1.4.2, 2.6, Box 2.2, 3.6.3, Box 4.3, Box 4.5, 4.6.8, 4.7.1, Figure 4.29, 5.6.3, 5.13.4, 8.4.5, 8.2.1, 8.3.3, 8.4.5, 8.6.1, 9.7, 9.8, 9.9, 9.10, 9.11, Box 9.8, Box 9.9, Box 11.6, 12.5.3, 12.5.7, 13.3, 13.4, 13.5, 13.11.3, 14.5.9, 15.5.1, 15.6.5, 16.3.2, 17.5.1, CCP2.3.2, CCP2.3.6, CCB DEEP, CCB NATURAL, CCB SLR, CWGB BIOECONOMY}

TS.D.3.1 Maladaptation has been observed across many regions and systems and occurs for many reasons, including inadequate knowledge and short-term, fragmented, single-sector and/or non-inclusive governance planning and implementation (*high confidence*). Policy decisions that ignore the risks of adverse effects can be maladaptive by worsening the impacts of and vulnerabilities to climate change (*high confidence*). Examples include in coastal systems (e.g., sea walls that enable further exposure through intensification of developments in low-lying coastal areas), urban areas (e.g., inflexible infrastructure in cities and settlements that cannot be adjusted easily or affordably for increased heavy rainfall), agriculture (e.g., the use of high cost irrigation in areas that are projected to have more intense drought conditions), forestry (e.g., planting of unsuitable trees species which displace Indigenous Peoples and other forest-dependent communities) and human settlements (e.g., stranded assets and stranded vulnerable communities that cannot afford to shift away or adapt and require an increase in social safety nets) (*high confidence*). {Box 2.2, 2.6.6, 2.6.5, 3.6.3, Box 4.3, Box 4.5, 4.7.1, Figure 4.29, 4.6.8, 5, 5.13.4, 9.7, 9.8, 9.9, 9.10, 9.11, Box 9.8, Box 9.9, Box 11.5, Box 11.6, 13.2, 13.3, 13.3.1, 13.4, 13.4.2, 13.5.1, 14.5.9, 15.5.1, 15.5.4, 15.5.5, 16.3.2, CCP2.4, CCB DEEP, CCB FEASIB, CCB SLR}

TS.D.3.2 Indigenous Peoples and disadvantaged groups, such as low-income households and ethnic minorities, are especially adversely affected by maladaptation, which often deprives

them of food and livelihoods and reinforces and entrenches existing inequalities (*high confidence*). Rights-based approaches to adaptation, participatory methodologies and inclusion of local and Indigenous knowledge, combined with informed consent, deliver mechanisms to avoid these pitfalls (*medium confidence*). Adaptation solutions benefit from engagement with Indigenous and marginalised groups, solve past equity and justice issues and offer novel approaches (*medium confidence*). Indigenous knowledge is a powerful tool to assess interlinked ecosystem functions across terrestrial, marine and freshwater systems, bypassing siloed approaches and sectoral problems (*high confidence*). Lastly, engagement with Indigenous knowledge and marginalised groups often offers an intergenerational context for adaptation solutions needed to avoid maladaptation (*high confidence*). {2.6.5, 4.6.9, 8.4, 8.4.5, 5.12.8, 5.13.4, 11.4.1, 11.4.2, 12.5.8, 13.8.1, Box 13.2, 14.4, 14.5.9, 5.13.5, 15.6.5, 18.2.4, CCP5.4.2, Box CCP7.1}

TS.D.3.3 Reliance on hard protection against sea level rise can lead to development intensification, which compounds risk and locks in exposure of people and assets as socioeconomic and governance barriers and technical limits are reached. Avoiding maladaptive responses to sea level rise depends on immediate mitigation and application of adaptive planning that sets out near-term, low-regret actions while keeping open options to account for ongoing committed sea level rise (*very high confidence*). Such forward-looking adaptive pathway planning and iterative risk management can address the current path dependencies that lead to maladaptation and can enable timely adaptation alignment with long implementation lead times, as well as addressing uncertainty about rate and magnitude of local sea level rise, and ensuring that adaptation will be more effective (*medium confidence*). As sea level rise advances, only avoidance and relocation will eliminate coastal risks (*high confidence*). Other measures only delay impacts for a time, increasing residual risk, perpetuating risk and creating ongoing legacy effects and inevitable property and ecosystem losses (*high confidence*). While relocation may in the near term appear socially unacceptable, economically inefficient or technically infeasible, it may become the only feasible option as protection costs become unaffordable and technical limits are reached (*medium confidence*). {3.4.2, 3.5.5, 3.6.3, 11.7.3, Box 11.6, 12.5.7, 12.5.8, 13.10, 15.3.4, 15.5.1, 15.5.2, 15.5.3, CCP2.2.3, CCP4, CCB DEEP, CCB SLR}

TS.D.3.4 Maladaptation can be reduced using the principles of recognitional, procedural and distributional justice in decision-making, responsibly evaluating who is regarded as vulnerable and at risk, who is part of decision-making, who is the beneficiary of adaptation measures and integrated and flexible governance mechanisms that account for long-term goals (*high confidence*). Examples include selecting native and appropriate species in habitat restoration, monitoring key social and environmental indicators for adaptation progress, embedding strong monitoring and evaluation processes, considering measures of efficiency and social welfare, and social and political drivers and power relationships. Integrated approaches, such as the water–energy–food nexus and inter-regional considerations of risks can reduce the risk of maladaptation, building on existing adaptation strategies, increasing community participation and consultation, integration of Indigenous knowledge and local knowledge, focusing on the most vulnerable small-scale producers, anticipating risks of maladaptation in decision-making for long-lived activities, including infrastructure decisions, and the impact of trade-offs and co-benefits (*high confidence*). (Figure TS.11a) {2.6.5, 2.6.6, 2.6.7, 4.7.6, 4.8, Box 4.8, 5.9.2, Table 5.21, 5.9.2, 5.9.4, 5.13.3, 5.14.2, 5.13.3, 6.2.7, 7.4.2, 8.2.2, 8.3.3, 8.10, 10.6.3, 11.4, 11.5, 11.7.12, 15.5.4, Figure 15.7, 17.5.1, 17.5.2, 17.6, CCP1.3, CCP5.4.2, CCP5.4.2, CCB INTEREG, CCB NATURAL}

Strengthening the biosphere

TS.D.4 Diverse, self-sustaining ecosystems with healthy biodiversity provide multiple contributions to people that are essential for climate change adaptation and mitigation, thereby reducing risk and increasing societal resilience to future climate change (*high confidence*). Better ecosystem protection and management is key to reduce the risks that climate change poses to biodiversity and ecosystem services and build resilience; it is also essential that climate change adaptation be integrated into the planning and implementation of conservation and environmental management if it is to be fully effective in future (*high confidence*). Risks to ecosystems from climate change can be reduced by protection and restoration and also by a range of targeted actions to adapt conservation practice to climate change (*high confidence*). Protected areas are key elements of adaptation but need to be planned and managed in ways that take account of climate change, including shifting species distributions and changes in biological communities and ecosystem structure. Adaptation to protect ecosystem health and integrity is essential to maintain ecosystem services, including for climate change mitigation and the prevention of greenhouse gas emissions. (Figure TS.12, Figure TS.5 ECOSYSTEMS) {2.5.4, 2.6.2, 2.6.3, 2.6.6, 2.6.7, 3.6.2, 3.6.3, 3.6.5, 4.6.6, Box 4.6, 5.14.1, 12.5.1, 13.3.2, 13.4.2, Box 14.7, 15.5.4, 15.5.6, CCP1, CCP5.4.1, CCP5.4.2, CCB NATURAL}

TS.D.4.1 Ecosystem protection and restoration can build resilience of ecosystems and generate opportunities to restore ecosystem services with substantial co-benefits (*high confidence*) and provision of ecosystem-based adaptation.[7] Ecosystem-based adaptation includes protection and restoration of forests, grasslands, peatlands and other wetlands, blue carbon systems (mangroves, salt marshes and seagrass meadows), and agroecological farming practices. In coastal systems, nature-based solutions, including ecosystem-based adaptation, can reduce impacts for human settlements until sea level rise results in habitat loss. High rates of warming and drought may severely threaten the success of nature-based solutions such as forest expansion or peatland restoration. Ecosystem-based adaptation is being increasingly advocated in coastal defence against storm surges, terrestrial flood regulation, reducing urban heat and restoring natural fire regimes. Nature-based solutions, including ecosystem-based adaptation, can therefore reduce risks for ecosystems and benefit people, provided they are planned and implemented in the right way and in the right place. For example, coastal wetlands and ecosystems can also be seriously damaged by coastal defences designed to protect

7 Ecosystem-based adaptation is defined as the use of ecosystem management activities to increase the *resilience* and reduce the *vulnerability* of people and *ecosystems* to *climate change*.

infrastructure. {2.6.2, 2.6.3, 2.6.5, 2.6.7, Table 2.7, 3.4.2, 3.5.5, 3.6.2, 3.6.3, 9.6.3, 9.6.4, 13.2.2, 13.3.2, 13.4.2, 13.5.2, 13.6.1, Box 14.7, CCB NATURAL, CCB SLR}

TS.D.4.2 Increasing the resilience of biodiversity and ecosystem services to climate change includes minimising additional stresses or disturbances, reducing fragmentation, increasing natural habitat extent, connectivity and heterogeneity, maintaining taxonomic, phylogenetic and functional diversity and redundancy and protecting small-scale refugia where microclimate conditions can allow species to persist (*high confidence*). In some cases, specific management interventions may be possible to reduce risks to individual species or biological communities, including translocation or manipulating microclimate or site hydrology. Adaptation also includes actions to prevent the impacts of extreme events or aid the recovery of ecosystems following extreme events, such as wildfire, drought or marine heatwaves. In some cases, recovery of ecosystems from extreme events can be facilitated by removing other human pressures. Understanding the characteristics of vulnerable species can assist in early warning systems to minimise negative impacts and inform management intervention. (Figure TS.5 ECOSYSTEMS) {2.3, 2.3.1, 2.3.2, 2.5.3, 2.5.4, 2.6.2, 2.6.5, 2.6.7, 2.6.8, Figure 2.1, Table 2.6, Table 2.8, 3.6.3, 3.6.5, 4.6.6, Box 4.6, 12.5.1, 13.3.2, 13.4.2, 13.10.2, Box 14.7, 15.5.4, CCB EXTREMES, CCB FEASIB}

TS.D.4.4 Available adaptation options can reduce risks to ecosystems and the services they provide, but they cannot prevent all changes and should not be regarded as a substitute for reductions in greenhouse gas emissions (*high confidence*). Ambitious and swift global mitigation offers more adaptation options and pathways to sustain ecosystems and their services (*high confidence*). Even under current climate change, it is necessary to take account of climate change impacts, which are already occurring or are inevitable, in environmental management to maintain biodiversity and ecosystem services (*high confidence*), and this will become increasingly important at higher levels of warming. (Figure TS.5 ECOSYSTEMS) {2.2, 2.3, 2.4.5, 2.5.1, 2.5.2, 2.5.3, 2.5.4, 2.6.1, 2.6.2, 2.6.3, 2.6.4, 2.6.5, 2.6.6, 2.6.7, 2.6.8, 3.4.2, 3.4.3, 3.5.2, 3.5.3, 3.5.5, 3.6.2, 3.6.3, 3.6.5, Figure 3.24, Figure 3.25, 4.6.6, Box 4.6, Box 4.7, 13.4.2, Box 14.7, 15.5.4, CCP5.4.2, CCB FEASIB, CCB NATURAL}

TS.D.4.5 Ecosystem-based adaptation measures can reduce climatic risks to people, including from flood, drought, fire and overheating (*high confidence*). Ecosystem-based adaptation approaches are increasingly being used as part of strategies to manage flood risk, at the coast in the face of rising sea levels and inland in the context of more extreme rainfall events (*high confidence*). Flood-risk measures that work with nature by allowing flooding within coastal and wetland ecosystems and support sediment accretion can reduce costs and bring substantial co-benefits to ecosystems, liveability and livelihoods (*high confidence*). In urban areas, trees and natural areas can lower temperatures by providing shade and cooling from evapotranspiration (*high confidence*). Restoration of ecosystems in catchments can also support water supplies during periods of variable rainfall and maintain water quality and, combined with inclusive water regimes that overcome social inequalities, provide disaster risk reduction and sustainable development (*high confidence*). Restoring natural vegetation cover and wildfire regimes can reduce risks to people from catastrophic fires. Restoration of wetlands could support livelihoods and help sequester carbon (*medium confidence*), provided they are allowed accommodation space. Ecosystem-based adaptation approaches can be cost effective and provide a wide range of additional co-benefits in terms of ecosystem services and biodiversity protection and enhancement. (Figure TS.9 URBAN, Figure TS.11a) {2.6.3, 2.6.5, 2.6.7, Table 2.7, 3.6.2, 3.6.3, 3.6.5, Box 4.6, Box 4.7, 12.5.1, 12.5.3, 12.5.5, 13.2.2, 13.3.2, 13.6.2, Box 14.7, 15.5.4, Figure 15.7, CCP2, CCP5.4.2, CCB NATURAL, CCB SLR}

TS.D.4.6 Ecosystem-based adaptation and other nature-based solutions[8] are themselves vulnerable to climate change impacts (*very high confidence*). Under higher emissions scenarios they will increasingly be under threat. Nature-based solutions cannot deliver the full range of benefits, unless they are based on functioning, resilient ecosystems and developed taking account of adaptation principles. There is a serious risk that high-carbon ecosystems will become sources of greenhouse gas emissions, which makes it increasingly difficult to halt anthropogenic climate change without prompt protection, restoration, adaptation and mitigation at a global scale. {2.5.2, 2.5.3, 2.5.4, 2.6.3, 2.6.5, 2.6.6, 2.6.7, 3.6.2, 3.6.3, 3.6.5, Box 4.6, 13.4.2, 15.3.3, 15.5.4, CCB NATURAL, CCB SLR}

TS.D.4.7 Potential benefits and avoidance of harm are maximised when nature-based solutions are deployed in the right places and with the right approaches for those areas, with inclusive governance (*high confidence*). Taking account of interdisciplinary scientific information, Indigenous knowledge and local knowledge and practical expertise is essential to effective ecosystem-based adaptation (*high confidence*). There is a large risk of maladaptation where this does not happen (*medium confidence*). For example, naturally treeless peatlands can be afforested if they are drained, but this leads to the loss of distinctive peatland species as well as high greenhouse gas emissions. It is important that nature-based solution approaches to climate change mitigation also take account of climate change adaptation if they are to remain effective. {1.4.2, 2.2, 2.4.3, 2.4.4, 2.5.2, 2.5.3, 2.6.2, 2.6.3, 2.6.5, 2.6.6, 2.6.7, Box 2.2, Table 2.6, Table 2.7, 3.6.3, 3.6.5, 4.7.2, Box 4.6, 5.14.2, 13.4.2, Box 14.7, 15.5.4, CCP1, CCB NATURAL}

Water and food sectors

TS.D.5 Various adaptation options in the water, agriculture and food sectors are feasible with several co-benefits (*high confidence*), some of which are effective at reducing climate impacts (*medium confidence*). Adaptation responses reduce future climate risks at 1.5°C warming, but effectiveness decreases above 2°C (*high confidence*). Resilience is strengthened by ecosystem-based adaptation (*high confidence*) and sustainable resource management of terrestrial and aquatic species (*medium confidence*). Agricultural intensification strategies produce

8 Actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits.

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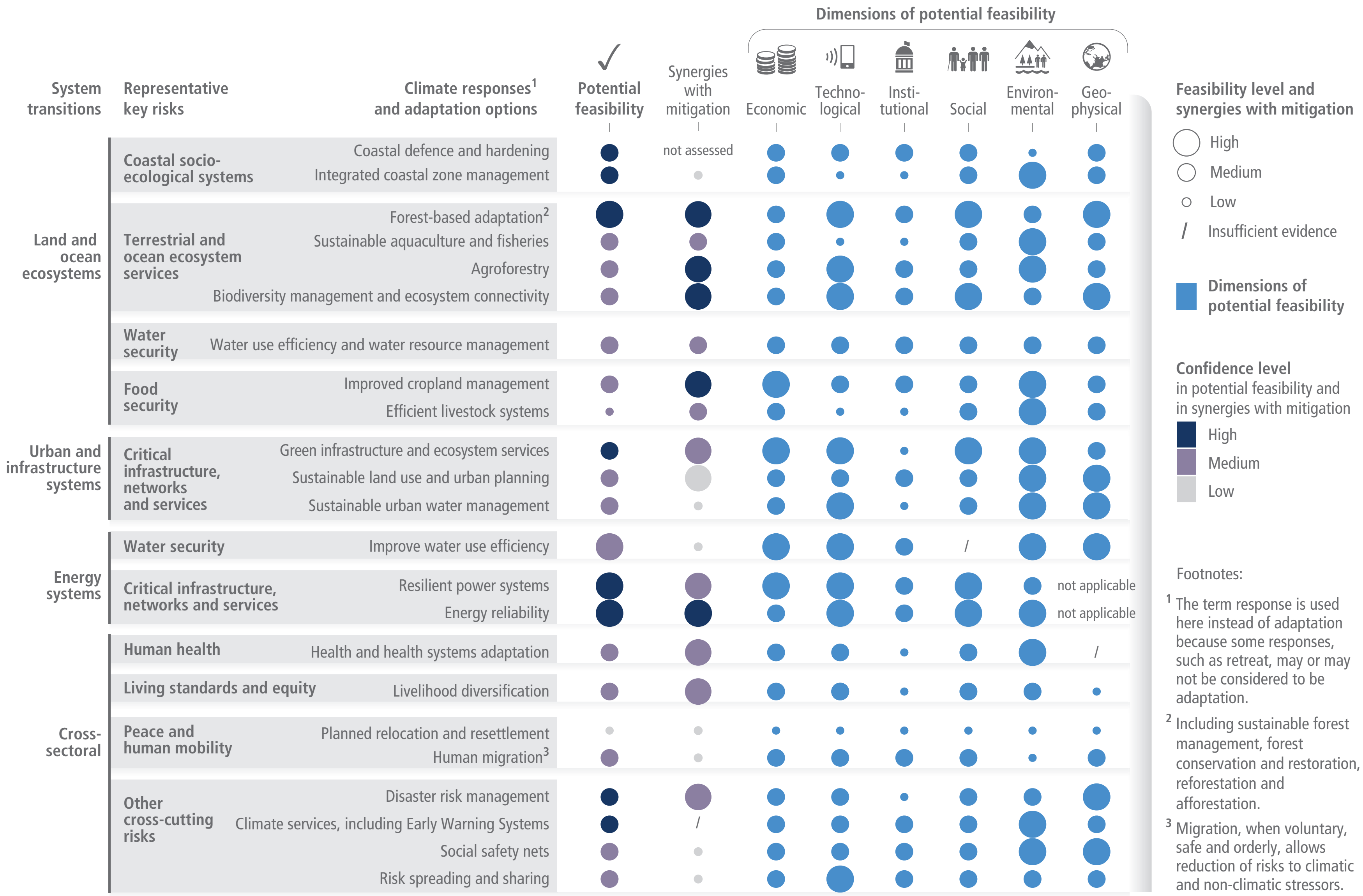
(a) Diverse feasible climate responses and adaptation options exist to respond to Representative Key Risks of climate change, with varying synergies with mitigation

Multidimensional feasibility and synergies with mitigation of climate responses and adaptation options relevant in the near-term, at global scale and up to 1.5°C of global warming



Footnotes:

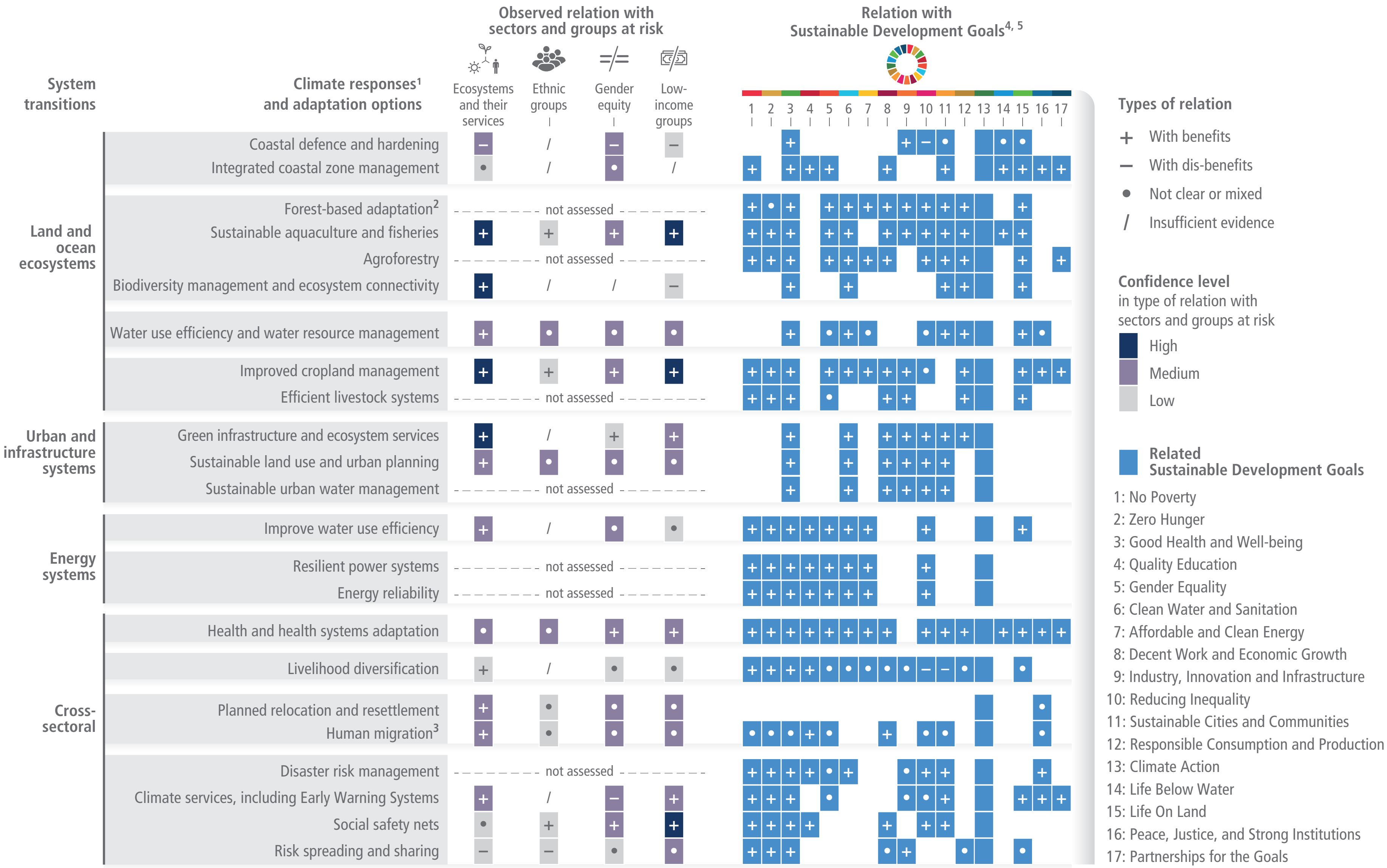
[1] The term response is used here instead of adaptation because some responses, such as retreat, may or may not be considered to be adaptation.

[2] Including sustainable forest management, forest conservation and restoration, reforestation and afforestation.

[3] Migration, when voluntary, safe and orderly, allows reduction of risks to climatic and non-climatic stressors.

(b) Climate responses and adaptation options have benefits for ecosystems, ethnic groups, gender equity, low-income groups and the Sustainable Development Goals

Relations of sectors and groups at risk (as observed) and the SDGs (relevant in the near-term, at global scale and up to 1.5°C of global warming) with climate responses and adaptation options



Footnotes: [1] The term response is used here instead of adaptation because some responses, such as retreat, may or may not be considered to be adaptation. [2] Including sustainable forest management, forest conservation and restoration, reforestation and afforestation. [3] Migration, when voluntary, safe and orderly, allows reduction of risks to climatic and non-climatic stressors. [4] The Sustainable Development Goals (SDGs) are integrated and indivisible, and efforts to achieve any goal in isolation may trigger synergies or trade-offs with other SDGs. [5] Relevant in the near-term, at global scale and up to 1.5°C of global warming.

Figure TS.11 | (a) Climate responses and adaptation options, organized by System Transitions and Representative Key Risks (RKRs), are assessed for their multidimensional feasibility at global scale, in the near term and up to 1.5°C global warming. As literature above 1.5°C is limited, feasibility at higher levels of warming may change, which is currently not possible to assess robustly. Climate responses and adaptation options at global scale are drawn from a set of options assessed in AR6 that have robust evidence across the feasibility dimensions. This figure shows the six feasibility dimensions (economic, technological, institutional, social, environmental and geophysical) that are used to calculate the potential feasibility of climate responses and adaptation options, along with their synergies with mitigation. For potential feasibility and feasibility dimensions, the figure shows high, medium, or low feasibility. Synergies with mitigation are identified as high, medium, and low. Insufficient evidence is denoted by a dash. {CCB FEASIB, Table SMCCB FEASIB.1.1, SR1.5 4.SM.4.3} **(b)** Climate responses and adaptation options, organized by System Transitions and Representative Key Risks, are assessed at global scale for their likely ability to reduce risks for ecosystems and social groups at risk, as well as their relation with the 17 Sustainable Development Goals (SDGs). Climate responses and adaptation options are assessed for observed benefits (+) to ecosystems and their services, ethnic groups, gender equity, and low-income groups, or observed dis-benefits (-) for these systems and groups. Where there is highly diverging evidence of benefits/ dis-benefits across the scientific literature, e.g., based on differences between regions, it is shown as not clear or mixed (•). Insufficient evidence is shown by a dash. The relation with the SDGs is assessed as having benefits (+), dis-benefits (-) or not clear or mixed (•) based on the impacts of the climate response and adaptation option on each SDG. Areas not coloured indicate there is no evidence of a relation or no interaction with the respective SDG. The climate responses and adaptation options are drawn from two assessments. For comparability of climate responses and adaptation options see Table SM17.5. {17.2, 17.5, CCB FEASIB}

benefits but with trade-offs and negative socioeconomic and environmental effects (*high confidence*). Competition, trade-offs and conflict between mitigation and adaptation priorities will increase with climate change impacts (*high confidence*). Integrated, multi-sectoral, inclusive and systems-oriented solutions reinforce long-term resilience (*high confidence*), along with supportive public policies (*medium confidence*). (Figure TS.6 FOOD-WATER, Figure TS.11a) {2.6, 4.6.2, 4.7.1, 4.7.4, 4.8, Box 4.3, Figure 4.27, Figure 4.29, 5.4.3, 5.4.4, 7.4.2, 1.1, 9.12.4, 12.5.3, 12.5.4, 13.2.2, 14.4.3, 14.4.4, CCP5.4.2, CCB FEASIB, CCB NATURAL}

TS.D.5.1 There are a range of options for water- and food-related adaptation in different sociocultural, economic and geographical contexts, with benefits across several dimensions across regions (*high confidence*), including climate risk reduction (*medium confidence*). Frequently documented options include rainwater harvesting, soil moisture conservation, cultivar improvements, community-based adaptation, agricultural diversification, climate services and adaptive eco-management in fisheries (*high confidence*). Roughly 25% of assessed water-related adaptations have co-benefits, while 33% of the assessed reported current or future maladaptive outcomes (*high confidence*). There is *limited evidence, medium agreement* on the institutional feasibility or cost effectiveness of adaptation activities or their limits. Integration of Indigenous knowledge and local knowledge increase their effectiveness (*high confidence*). (Figure TS.6 FOOD-WATER) {4.6, 4.7.1, 5.4.4, 5.5.4, 5.6.3, 5.8.4, 5.9.4, 5.10.4, 5.11.4, 5.12.4, 5.14.1, 12.5.3, 12.5.4, 13.2.2, 13.5.2, 13.10.2, Figure 13.7, Figure 13.15, 15.5.4, 15.5.6, CCB FEASIB}

TS.D.5.2 The projected future effectiveness of available adaptation for agriculture and food systems decreases with increasing warming (*high confidence*). Currently known adaptation responses generally perform more effectively at 1.5°C than at 2°C or more, with increasing risks remaining after adaptation at higher warming levels (*high confidence*). Irrigation expansion will face increasing limits due to water availability beyond 1.5°C (*medium confidence*), with a potential doubling of regional risks to irrigation water availability between 2°C and 4°C (*medium confidence*). Negative risks even with adaptation will become greater beyond 2°C warming in an increasing number of regions (*high confidence*). (Figure TS.6 FOOD-WATER) {4.6.2, 4.7.1, 4.7.2, 4.7.3, 5.4.3, 5.4.4, 13.5.1, 13.10.2, 14.5.4, 15.3.4}

TS.D.5.3 Ecosystem-based approaches, agroecology and other nature-based solutions in agriculture and fisheries have the potential to strengthen resilience to climate change with multiple co-benefits (*high confidence*); trade-offs and benefits vary with socioecological context. Options such as ecosystem approaches to fisheries, agricultural diversification, agroforestry and other ecological practices support long-term productivity and ecosystem services such as pest control, soil health, pollination and buffering of temperature extremes (*high confidence*), but potential and trade-offs vary by socioeconomic context, ecosystem zone, species combinations and institutional support (*medium confidence*). Ecosystem-based approaches support food security, nutrition and livelihoods when inclusive equitable governance processes are used (*high confidence*). {2.6.3, 3.4.2, 3.5.2, 3.5.3, 3.5.5, 3.6.2, 3.6.3, 3.6.5, Figure 3.26, Table SM3.6, 4.6.6, Box 4.6, 5.4.4, 5.6.3, 5.8.4, 5.9.3, 5.10.4, 5.14.1, 8.5.2, 8.6.3, 9.6.4, 12.5.1, 12.5.4, 13.3.2, 13.5.2, 14.5.1, 14.5.2, 14.5.3, 14.5.4, Box 14.7, 16.3.2, CCB FEASIB, CCB MOVING PLATE, CCB NATURAL, CWGB BIOECONOMY}

TS.D.5.4 Sustainable resource management in response to distribution shifts of terrestrial and aquatic species under climate change is an effective adaptation option to reduce food and nutritional risk, conflict and loss of livelihood (*medium confidence*). Adaptation options exist to reduce the vulnerability of fisheries through better management, governance and socioeconomic dimensions (*medium confidence*) to eliminate overexploitation and pollution (*high confidence*). Indigenous knowledge and local knowledge can facilitate adaptation in small-scale fisheries, especially when combined with scientific knowledge and utilised in management regimes (*medium confidence*). Adaptive transboundary governance and ecosystem-based management, livelihood diversification, capacity development and improved knowledge-sharing will reduce conflict and promote the fair distribution of sustainably harvested wild products and revenues (*medium confidence*). {5.8.4, 5.14.3, CCP5.4.2, CCB MOVING PLATE}

TS.D.5.5 Adaptation options that promote intensification of production have been widely adopted in agriculture for climate change adaptation, but with potential negative effects (*high confidence*). Agricultural intensification addresses short-term food security and livelihood goals but has trade-offs in equity, biodiversity and ecosystem services (*high confidence*). Irrigation is widely used and effective for yield stability, but with several negative outcomes, including water demand (*high confidence*), groundwater depletion (*high confidence*), alteration of local to regional climates (*high confidence*), increasing soil salinity (*medium confidence*), widening inequalities and loss of rural smallholder livelihoods with weak governance (*medium confidence*). Conventional breeding assisted by genomics introduces traits that adapt crops to climate change (*high confidence*). Genetic improvements through modern biotechnology have the potential to increase climate resilience in food production systems (*high confidence*), but with biophysical ceilings, and technical, agroecosystem, socioeconomic and political variables strongly influence and limit the uptake of climate resilient crops, particularly for smallholders (*medium confidence*).{4.6.2, 4.7.1, Box 4.3, 5.4.4, 5.12.5, 5.13.4, 5.14.1, 10.2.2, 12.5.4, 13.5.1, 13.5.2, 13.5.14, 14.5.4, 15.3.4, 17.5.1}

TS.D.5.6 Integrated and systems-oriented solutions to alleviate competition and trade-offs between mitigation and adaptation will reinforce long-term resilience and equity in water and food systems (*high confidence*). Large-scale land deals for climate mitigation have trade-offs with livelihoods, water and food security (*high confidence*). Afforestation programmes without adequate safeguards adversely affect Indigenous Peoples' rights, land tenure and adaptive capacity (*high confidence*). Some mitigation measures, such as carbon capture and storage, bio-energy and afforestation, have a high water footprint (*high confidence*). Increased demand for aquaculture, animal and marine foods and energy products will intensify competition and potential conflict over land and water resources, particularly in low- and medium-income countries (*high confidence*), with negative impacts on food security and deforestation (*medium confidence*). Integrated, systems-oriented solutions reduce competition and trade-offs and include inclusive governance, behavioural (e.g., healthier diets with lower carbon and water footprints) and technical (e.g., novel feeds) responses (*high confidence*).{1.4.2, 2.2, 2.3, 2.5. 2.6, 3.6.3, 4.7.1, 4.7.6, Box 4.5, Box 4.8, 5.13.1, 5.13.2, 5.13.3, 5.13.5, 5.13.7, 9.4.3, 12.5.8, 12.6.2, 14.5.4, 15.5.6, 17.5.1, CCP5.4.2, CWGB BIOECONOMY}

TS.D.5.7 Integrated multi-sectoral strategies that address social inequities (e.g., gender, ethnicity) and social protection of low-income groups will increase the effectiveness of adaptation responses for water and food security (*high confidence*). Multiple interacting factors help to ensure that adaptive communities have water and food security, including addressing poverty, social inequities, violent conflict, provision of social services such as water and sanitation, social safety nets and vital ecosystem services. Differentiated responses based on water and food security level and climate risk increase effectiveness, such as social protection programmes for extreme events, medium-term responses such as local food procurement for school meals, community seed banks or well construction to build adaptive capacity (*medium confidence*). Longer-term responses include strengthening ecosystem services, local and regional markets, enhanced capacity and reducing systemic gender, land tenure and other social inequalities as part of a rights-based approach (*medium confidence*). In the urban context, policies that account for social inclusion in governance and rights to green urban spaces will enhance urban agriculture's potential for food and water security and other ecosystem services. (Figure TS.6 FOOD-WATER) {4.7.1, 4.8.3, Figure 4.27, Figure 4.29, 5.12.5, 5.12.7, 12.5.3, 12.5.4, 12.5.5, 15.6.5, 17.5.1}

TS.D.5.8 Supportive public policies for transitions to resilient water and food systems enhance effectiveness and feasibility in ecosystem provisioning services, livelihoods and water and food security (*medium confidence*). Collective efforts across sectors, with the involvement of food producers and water users and including Indigenous knowledge and local knowledge, are a pre-condition to reaching sustainable water and food systems (*high confidence*). Policies that support system transitions include shifting subsidies, certification, green public procurement, capacity building, payments for ecosystem services and social protection (*medium confidence*). (Figure TS.6 FOOD-WATER) {4.7.1, 4.8.4, 5.4.4, 5.4.4, 5.10.4, 5.12.6, 5.13.4, 5.14.1, 5.14.2, Box 5.13, 12.5.4, CWGB BIOECONOMY}

Cities, settlements and infrastructure

TS.D.6 Cities and settlements are crucial for delivering urgent climate action. The concentration and interconnection of people, infrastructure and assets within and across cities and into rural areas drives the creation of risks and solutions at a global scale (*high confidence*). Concentrated inequalities in risk are broken through prioritising affordable housing and upgrading of informal and precarious settlements, paying special attention to including marginalised groups and women (*high confidence*). Such actions are most effective when deployed across grey/physical infrastructure, nature-based solutions and social policy and between local and city-wide or national actions (*medium confidence*). City and local governments remain key actors facilitating climate change adaptation in cities and settlements. Community-based action is also critical. Multi-level governance opens an inclusive and accountable adaptation space across scales of decision-making, improving development processes through an understanding of social and economic systems, planning, experimentation and embedded solutions, including processes of social learning. (Figure TS.9 URBAN, Figure TS.11a) {4.6.5, 4.7.1, 6.1, 6.2, 6.3, 6.4, 8.5.2, 10.3.6, 10.4.6, 12.5.5, 13.6.2, 13.11.1, 14.5.5, 15.7, 16.4.2, CWGB URBAN}

TS.D.6.1 Continuing rapid growth in urban populations and unmet needs for healthy, decent, affordable and sustainable housing and infrastructure represent a global opportunity to integrate inclusive adaptation strategies into development (*high confidence*). The urban adaptation gap shows that for all world regions, current adaptation is unable to resolve risks from current climate change associated hazards. Moreover, an additional 2.5 billion people are projected to be living in urban areas by 2050, with up to 90% of this increase concentrated in the regions of Asia and Africa (*high confidence*). Retrofitting, upgrading and redesigning existing urban places and infrastructure combined with planning and design for new urban infrastructure can utilise existing knowledge on social policy, nature-based solutions and grey/physical infrastructure to build inclusive processes of adaptation into everyday urban planning and development. {4.6.5, 6.1, 6.3, 6.4, 9.9.5, 10.3.4, 12.5.5, 13.6.2, 13.11.3}

TS.D.6.2 Diverse adaptation responses to current and near-term climate impacts are already under way in many cities and settlements in different world regions (*very high confidence*). These responses range from hard engineering interventions to nature-based solutions, social policy and social safety nets to disaster management and capacity building, raising or relocation of settlements and combinations of such measures sequenced over time. While many more cities have developed adaptation plans since AR5, few of these

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Ecosystem health influences prospects for climate resilient development

(a) Human activities that degrade ecosystems also drive global warming and negatively impact nature and people

(b) Human activities that protect, conserve and restore ecosystems contribute to climate resilient development

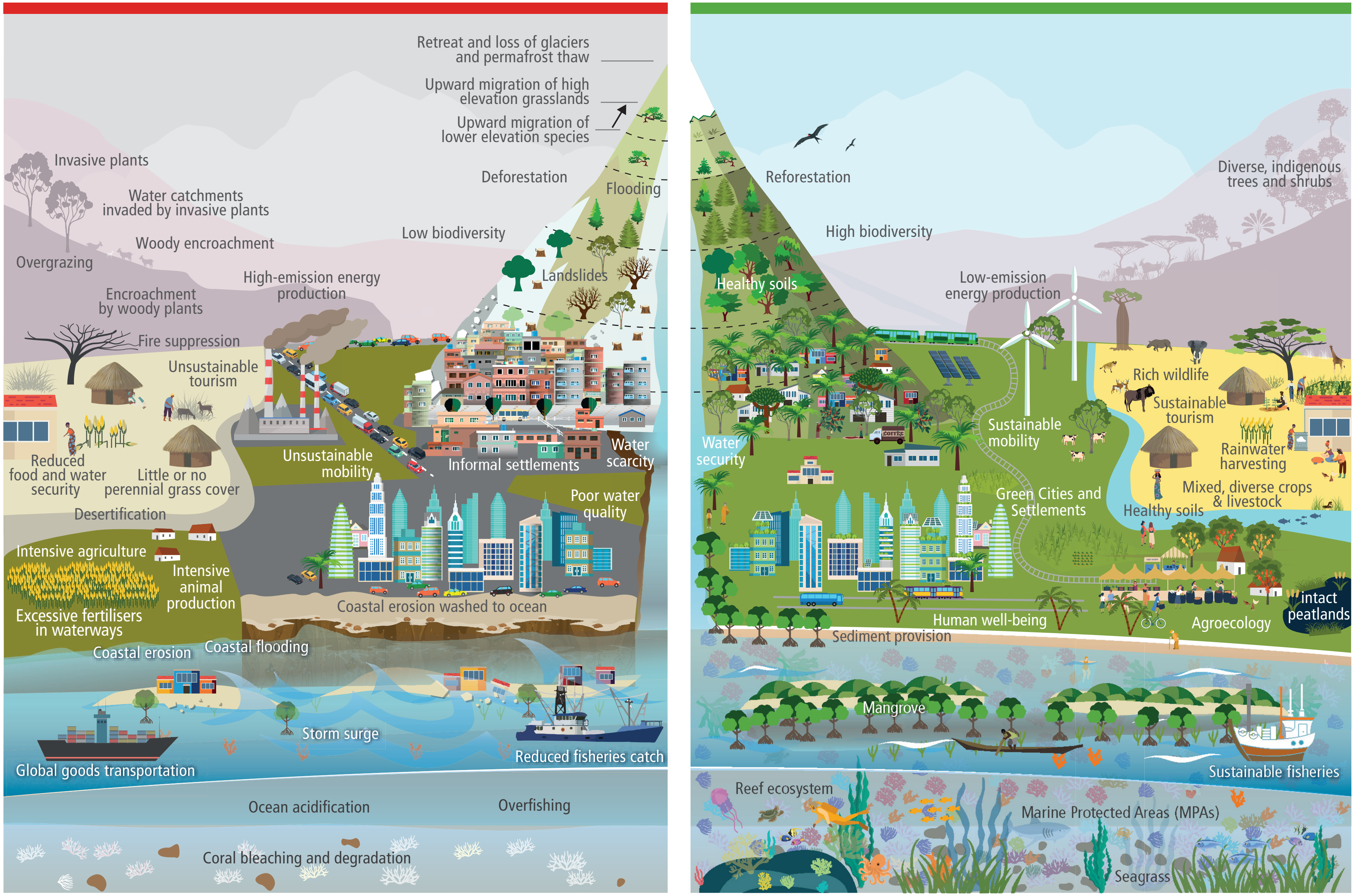

Figure TS.12 | This figure shows the interconnectedness between different ecosystems and system transitions, with human activities in urban, rural and coastal locations embedded in ecosystems. Maintaining biosphere integrity is essential for biodiversity, human and societal health and a precondition for climate resilient development. Panel a) illustrates how adaptation, mitigation and development actions characterised by exploitation and degradation lead to unsustainable development and adverse outcomes for human well-being and ecosystem integrity. Panel b) illustrates how adaptation options, implemented in an integrated way with mitigation and development and based on ecosystem stewardship, can support climate resilient development (Figure TS.13). The protection or restoration of one or more of these ecosystems also provides benefits to the other ecosystems and enhances the services provided that improve livelihoods. Protecting and restoring ecosystem health as a part of societal development and through societal choices is a key transformative solution space for climate resilient development {2.5, 2.6, 3.5, 3.6, 4.3, 5.13, 6.3, 7.4, CCP1, CCP3, CCP5, Box 18.5}

plans have been implemented, and of these fewer still are being developed and evaluated through consultation and co-production with diverse and marginalised urban communities (*medium confidence*). {4.6.5, 6.3.3, 6.3.4, 6.3.5, CCP2.3, CCP2.4, 12.5.5, 13.2.2, 13.6.2, 13.11.3, 14.5.5, 15.3.4, 15.5.4, 15.6.1, 16.4.2, CCB FEASIB}

TS.D.6.3 Globally, urban adaptation gaps exist for all climate change-driven risks, although the limits to adaptation are unevenly distributed (*medium confidence*). Governance capacity, financial support and the legacy of past urban infrastructure investment constrain how cities and settlements can adapt to key climate risks (*medium confidence*). The gap between what can be adapted to and what has been adapted to is uneven; it is larger for the poorest 20% of populations than for the wealthiest 20%. The adaptation gap is also geographically uneven; it is highest in Africa (*medium confidence*). Limits to adaptation are often most pronounced in rapidly growing urban areas and smaller settlements, including those without dedicated local government. At the same time, legacy infrastructure in large and mega cities, designed without taking climate change risk into account, and past adaptation decisions constrain innovation, leading to stranded assets and with increasing numbers of people unable to avoid harm, including heat stress and flooding, without transformative adaptation (*medium confidence*). {6.3, 6.4, 12.5.5, 13.2, 13.2.3, 13.6.2, 13.6.2, 13.11.3, Box 14.4, CCP2.3.6, CCP2.4, CCP2.5, CWGB URBAN}

TS.D.6.4 The greatest gaps between policy and action are in projects to integrate justice concerns into adaptation action, address complex interconnected risks where solutions lie outside as well as within a city, for example in the food–energy–water–health nexus, and resolve compound risks such as the relationships between air quality and climate risk (*medium confidence*). The most critical capacity gaps at the city and community levels that hinder adaptation include an ability to identify social vulnerability and community strengths and to plan in integrated ways to protect communities, alongside the ability to access innovative funding arrangements and manage finance and commercial insurance, as well as locally accountable decision-making with sufficient access to science, technology and local knowledge to support application of adaptation solutions at scale. As ecosystems provide important additional benefits to human well-being and coastal livelihoods, urban adaptation strategies can be developed for settlements and nearby ecosystems; combining these with engineering solutions can extend their lifetime under high rates of sea level rise (*medium confidence*). In Central and South America, the adoption of nature-based solutions and hybrid (green-grey) infrastructure are still emerging. Monitoring and evaluation frameworks that incorporate questions of justice, ecological health and multi-sector considerations can help to move away from more narrow, static, indicator-based approaches to adaptation. (*high confidence*) {4.6.5, Box 4.8, 5.12.5, 6.1, 6.3, 6.4, 10.3.4, 12.5.5, 13.6.1, 13.6.2}

TS.D.6.5 Key innovations in adaptation in social policy and nature-based solutions have not been matched by innovation in adaptation finance, which tends to favour established mechanisms, often led by grey/physical infrastructure at the national scale. Social policy innovations include social safety nets, inclusive approaches to disaster risk reduction and the integration of climate adaptation into education. Nature-based solutions include green and blue infrastructure in and around cities, including hinterlands, that increase water access and reduce hazards for cities and settlements, for example reforestation of hill-slope and coastal areas. In Europe, many urban innovations are pilot tested, but their up-scaling remains challenging. Where inclusive approaches to adaptation policy and action are supported, this can enable wider gains of more equitable urbanisation (*medium confidence*). (Figure TS.9 URBAN) {2.6.3, 4.6.5, 4.7.1, 6.3.3, 6.3.5, 6.4.3, 12.5.5, 13.6.2 13.11.3, CCB FEASIB, CWGB URBAN}

TS.D.6.6 Many urban adaptation plans focus narrowly on climate risk reduction and specific climate-associated risks, missing opportunities to advance co-benefits with climate mitigation and sustainable development (*high confidence*). This narrow approach limits opportunity for urban and infrastructure adaptation to tackle the root causes of inequality and exclusion, especially among marginalised groups, including women. Urban adaptation measures have many opportunities to contribute to climate resilient development pathways (*medium confidence*). They can enhance social capital, livelihoods, human and ecological health and contribute to low-carbon futures. Urban planning, social policy and nature-based solutions bring great flexibility with co-benefits for climate mitigation and sustainable development. Participatory planning for infrastructure provision and risk management in informal, precarious and underserved neighbourhoods, the inclusion of Indigenous knowledge and local knowledge, and communication and efforts to build local leadership especially among women and youth are examples of inclusive approaches with co-benefits for equity. Targeted development planning across the range of innovation and investment in social policy, nature-based solutions and grey/physical infrastructure can significantly increase the adaptive capacity of urban settlements and cities and their contribution to climate resilient development (*high confidence*). (Figure TS.9 URBAN) {4.6.5, 6.1, 6.3, 6.4, Box 6.6, 7.4.1, 7.4.2, 7.4.3, 10.5, 10.6, 12.5.5, 12.5.7, 13.11.3, 14.5.5, 15.6.1, 15.7, CCP5.4.3, CCB COVID, CCB FEASIB}

TS.D.6.7 City and infrastructure planning approaches that integrate adaptation into everyday decision-making are supported by the 2030 Agenda for Sustainable Development: the Paris Agreement, SDGs, New Urban Agenda and Sendai Framework for Disaster Risk Reduction. The 2030 Agenda provides a global framework for city- and community-level action to align Nationally Determined Contributions, national adaptation plans and the

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SDGs. City and local action can complement—and at times go further than—national and international interventions (*high confidence*). Adaptation policy that focuses on informality and sub-serviced or inadequately serviced neighbourhoods and supports inclusive urbanisation by considering the social and economic root causes of unequal vulnerability and exposure can contribute to the broader goals of the 2030 Sustainable Development Agenda and reduce vulnerability to non-climatic risks, including pandemic risk (*high confidence*). More comprehensive and clearly articulated global ambitions for city and community adaptation will contribute to inclusive urbanisation by addressing the root causes of social and economic inequalities that drive social exclusion and marginalisation, so that adaptation can directly support the 2030 Agenda for Sustainable Development (*high confidence*). {6.1.1, 6.2.3, 6.4.1, Table 6.2, 12.5.5, 12.5.7}

Sea level rise

TS.D.7 The ability of societies and ecosystems to adapt to current coastal impacts to address present and future coastal risks under further acceleration of sea level rise depends on immediate and effective mitigation and adaptation actions that keep options open to further adapt (*high confidence*). Adaptation pathways break adaptation planning into manageable steps based on near-term, low-regret actions and aligning adaptation choices with societal goals that account for changing risk, interests and values, uncertain futures and the long-term commitment to adapting to sea level rise (*high confidence*). In charting adaptation pathways, reconciling divergent interests and values is a priority (*high confidence*). (Figure TS.9 URBAN) {11.7.3, 13.10, 14.5.2, Box 14.4, CCP2.3, CCP2.4, CCB DEEP, CCB SLR}

TS.D.7.1 As the scale and pace of sea level rise accelerates beyond 2050, long-term adjustments may in some locations be beyond the limits of current adaptation options and for some species and some locations could be an existential risk in the 21st century (*medium confidence*). Nature-based interventions, for example wetlands and salt marshes, can reduce impacts and costs while supporting biodiversity and livelihoods but have limits under high warming levels and rapid sea level rise (*high confidence*). Ecological limits and socioeconomic, financial and governance barriers will be reached first and are determined by the type of coastline and city or settlement (*medium confidence*). Accommodation can reduce impacts on people and assets but can address only limited sea level rise. Considering the long term now will help to avoid maladaptive lock-in, to build capacity to act in a timely and pre-emptive manner and to reduce risks to ecosystems and people. {3.4.2, 3.6.3, 11.7.3, 13.2, 14.5.2, 15.3.4, CCP2.3, CCB DEEP, CCB SLR}

TS.D.7.2 Adaptation for coastal ecosystems requires space, networks and sediment to keep up with sea level rise (*high confidence*). With higher warming, faster sea level rise and increasing human pressures due to coastal development, the ability to adapt decreases (*high confidence*). Adaptation options, such as providing sufficient space for a coastal system to migrate inland, when combined with ambitious and urgent mitigation measures, can reduce impacts, but they depend on the type of coastline and patterns of coastal development (*high confidence*). With rapid sea level rise, these options will become insufficient to limit risks for marine ecosystems and their services such as food provision, coastal protection and carbon sequestration (*high confidence*). (Figure TS.11a) {3.4.2, 3.5.5, 3.6.3, Box 3.4, 14.5.2, CCB SLR}

TS.D.7.3 A wide range of adaptation options exists for reducing the ongoing multi-faceted coastal risks in cities and settlements (*very high confidence*). A mix of infrastructure, nature-based, institutional and sociocultural interventions can best address the risks. The options include vulnerability-reducing measures, avoidance (e.g., disincentivising developments in high-risk areas and addressing existing social vulnerabilities), hard and soft protection (e.g., sea walls, coastal wetlands), accommodation (e.g., elevating houses), advance (e.g., building up and out to sea) and staged, managed retreat (e.g., landward movement of people and development) interventions (*very high confidence*). (Figure TS.9 URBAN) {3.6.2, 3.6.3, 11.3.5, Box 11.6, 12.5.5, 13.2, 14.5.2, 15.5.1, 15.5.2, 15.5.3, 15.5.4, 15.5.5, 15.5.7, 17.2, CCP2.3, CCP2.4, CCB FEASIB, CCB SLR}

TS.D.7.4 Implementation of coastal adaptation can be delayed by competing public and private interests, trade-offs among development and conservation objectives, legacy development, policy inconsistencies, contradictory short- and long-term objectives and uncertainties on the timing and scale of impacts (*high confidence*). Local government barriers to coastal adaptation could lead to courts' becoming *de facto* decision makers for local adaptation, and this could be compounded by legislative shortcomings and fragmentation, insufficient leadership, lack of coordination between governance levels and disagreement about financial responsibility (*high confidence*). {11.7.3, 15.5.6, CCP2.4}

TS.D.7.5 Adaptation is costly, but the benefit-to-cost ratio is high for urbanised coastal areas with high concentrations of assets (*high confidence*). Protection has a high benefit-cost ratio during the 21st century but can become unaffordable and insufficient to reduce coastal risk (e.g., due to salinisation, drainage of rivers and excess water), reaching technical limits (*high confidence*). Hard protection sets up lock-in of assets and people to risks and reaches limits by the end of the century or sooner, depending on the scenario, local sea level rise effects and community tolerance thresholds (*high confidence*). Considering coastal retreat as part of the solution space could lower global adaptation costs but would result in large land losses and high levels of migration for South and Southeast Asia in particular and in relative terms, small island nations would suffer most (*high confidence*). Solutions include disincentivising developments in high-risk areas and addressing existing social vulnerabilities now (*high confidence*). {3.4.2, 3.5.5, 3.6.3, 5.13.4, 9.4.1, Box 11.6, 13.2, 14.5.3, 15.5.1, 15.5.2, 15.5.3, 16.5.2, CCP2.3, CCB MIGRATE, CCB NATURAL, CCB SLR}

TS.D.7.6 Prospects for addressing climate change compounded coastal hazard risk depend on the extent to which societal choices, and associated governance processes and practices, address the drivers and root causes of exposure and social vulnerability (*very high confidence*). Many drivers and root causes of coastal risk are historically and institutionally embedded (*very high confidence*). When national and local authorities work with their communities, sustained risk reduction in the exposure and

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vulnerability of those most at risk is more likely (*high confidence*). Drawing on multiple knowledge systems helps in co-designing and co-producing more acceptable, effective and enduring responses. Reconciling divergent worldviews, values and interests can unlock the productive potential of conflict for transitioning towards pathways that foster climate resilient development, generate equitable adaptation outcomes and remove governance constraints (*high confidence*). Shared understanding and locally appropriate responses are enabled by deliberate experimentation, innovation and social learning (*medium confidence*). External assistance and government support can enhance community capabilities to reduce coastal hazard risk (*high confidence*). {15.6.1, 17.2, CCP2.4, Table CCP2.1}

TS.D.7.7 Experience in coastal cities and settlements highlights critical enablers for addressing coastal hazard risk compounded by sea level rise (*high confidence*). These enablers include building and strengthening governance capacity and capabilities to tackle complex problems; taking a long-term perspective in making short-term decisions; enabling more effective coordination across scales, sectors and policy domains; reducing injustice, inequity and social vulnerability; and unlocking the productive potential of coastal conflict while strengthening local democracy (*medium evidence, high agreement*). Flexible options enable responses to be adjusted as climate risk escalates and circumstances change, which may increase exposure (*medium confidence*). Legal and financial provisions can enable managed retreat from the most at-risk locations (*medium confidence*) but require coordination, trust and legitimate decisions by and across policy domains and sectors (*high confidence*) that prioritise vulnerability, justice and equity (*medium confidence*). Inclusive, informed and meaningful deliberation and collaborative problem-solving depend on safe arenas for engagement by all stakeholders (*high confidence*). {CCP2.4, Table CCP2.1, Table CCP2.2, CCB SLR}

Health, well-being, migration and displacement

TS.D.8 With proactive, timely and effective adaptation, many risks for human health and well-being could be reduced and some potentially avoided (*very high confidence*). Building adaptive capacity through sustainable development and encouraging safe and orderly movements of people within and between states represent key adaptation responses to prevent climate-related involuntary migration (*high confidence*). Reducing poverty, inequity and food and water insecurity and strengthening institutions in particular reduce the risk of conflict and supports climate resilient peace (*high confidence*). (Figure TS.8 HEALTH) {2.6.4, 4.6.4, Box 4.4, 5.12.5, 5.14, Box 6.3, 7.4.1, 8.4.4, 9.10.3, 10.4.7, 11.3.6, 12.5.6, 12.5.7, Table 12.9, 13.7.2, Figure 13.25, 14.5.6, Table 14.5, CCB ILLNESS}

TS.D.8.1 National planning on health and climate change is advancing, but the comprehensiveness of strategies and plans need to be strengthened to reduce future risks, and implementing action on key health and climate change priorities remains challenging (*high confidence*). The COVID-19 pandemic demonstrated the value of coordinated planning across sectors, safety nets and other capacities in societies to cope with a range of shocks and stresses and to alleviate system-wide risks to health (*high confidence*). A significant adaptation gap exists for human health and well-being and for responses to disaster risks (*very high confidence*). Most Nationally Determined Contributions to the Paris Agreement from low- and middle-income countries identify health as a priority concern (*very high confidence*). Effective governance institutions, arrangements, funding and mandates are key for adaptation to climate-related health risks (*high confidence*). {4.6.4, 5.12.5, 5.14, 7.4.1, 7.4.2, 7.4.3, Table 7.2, 9.10.3, 10.4.7.3, 11.3.6, 12.5.6, 13.7.2, CCB ILLNESS, CCB COVID}

TS.D.8.2 Continued investment in general health systems and in systems enhancing health protection is an effective adaptation strategy in the short to medium term (*high confidence*). Although some mortality and morbidity from climate change are already unavoidable, targeted adaptation and mitigation actions can reduce risks and vulnerabilities (*high confidence*). The burden of diseases could be reduced and resilience increased through health systems, generating awareness of climate change impacts on health (*medium confidence*), strengthening access to water and sanitation (*high confidence*), integrating vector control management approaches (*very high confidence*), expanding existing early-warning monitoring systems (*high confidence*), increasing vaccine development and coverage (*medium confidence*), improving the heat resistance of the built environment (*medium confidence*) and building financial safety nets (*medium confidence*). {2.6.4, 4.6.4, 5.12.5, 5.14, 7.4.1, 7.4.2, Table 7.2, 9.10.3, 10.4.7, 11.3.6, 12.5.6, Table 12.9, 13.7.2, Figure 13.25, 14.5.6, Table 14.5, CCP6.2.6, CCB FEASIB, CCB ILLNESS}

TS.D.8.3 Many adaptation measures that benefit health and well-being are found in other sectors (e.g., food, livelihoods, social protection, water and sanitation, infrastructure) (*high confidence*). Such cross-sectoral solutions include improved air quality through renewable energy sources (*very high confidence*), active transport (e.g., walking and cycling) (*high confidence*) and sustainable food systems that lead to healthier diets (*high confidence*). Heat Action Plans have strong potential to prevent mortality from extreme heat events and elevated temperature (*high confidence*). Nature-based solutions reduce a variety of risks to both physical and mental health and well-being (*high confidence*). For example, integrated agroecological food systems offer opportunities to improve dietary diversity while building climate-related local resilience to food insecurity (*high confidence*), especially when combined with gender equity and social justice. Social policy–based adaptation, including education and the adaptation of health systems, offers considerable future scope. The greatest gaps between policy and action are in failures to manage adaptation of social infrastructure (e.g., community facilities, services and networks) and failure to address complex interconnected risks for example in the food–energy–water–health nexus or the inter-relationships of air quality and climate risk (*medium confidence*). {2.6.7, 4.6.4, 4.7.1, 5.12.5, 5.14.1, 6.3.1, 6.4.3, 6.4.5, 6.4.5, 6.4.5, 7.4.2, 9.10.3, 10.4.7, 11.3.6, 12.5.6, Table 12.9, 13.7.2, Figure 13.25, 14.5.6, Table 14.5, CCB GENDER, CCB HEALTH, CCB NATURAL}

TS.D.8.4 Despite acknowledgement of the importance of health adaptation as a key component, action has been slow since AR5 (*high confidence*). Building climate resilient health systems will require multi-sectoral, multi-system and collaborative efforts at all governance scales (*very high confidence*). Globally,

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health systems are poorly resourced in general, and their capacity to respond to climate change is weak, with mental health support being particularly inadequate (*very high confidence*). The health sectors in some countries have focused on implementing incremental changes to policies and measures to respond to impacts (*very high confidence*). As the likelihood of dangerous risks to human health continues to increase, there is a greater need for transformational changes to health and other systems (*very high confidence*). This highlights an urgent and immediate need to address the wider interactions between environmental change, socioeconomic development and human health and well-being (*high confidence*). {7.4.1, 7.4.2, 7.4.3, 9.10.3, Box 9.7, 11.3.6.3, 13.7.2, 14.5.6, CCP6.2.6, Figure CCP6.3}

TS.D.8.5 Financial constraints are the most referenced barrier to health adaptation, and therefore scaling up financial investments remains a key international priority (*very high confidence*). Financial support for health adaptation is currently less than 0.5% of overall dispersed multilateral climate finance projects (*high confidence*). This level of investment is insufficient to protect human health and health systems from most climate-sensitive health risks (*very high confidence*). Adaptation financing often does not reach places where the climate sensitivity of the health sector is greatest (*high confidence*). {7.4.1, 7.4.2, 7.4.3, 9.10.3}

TS.D.8.6 Reducing future risks of involuntary migration and displacement due to climate change is possible by improving outcomes of existing migration patterns, addressing vulnerabilities that pose barriers to *in situ* adaptation and livelihood strategies and meeting existing migration agreements and development objectives (*medium confidence*). Properly supported and where levels of agency and assets are high, migration as an adaptation to climate change can reduce exposure and socioeconomic vulnerability (*medium confidence*). However, migration becomes a risk when climate hazards cause an individual, household or community to move involuntarily or with low agency (*high confidence*). Inability to migrate (i.e., involuntary immobility) in the face of climate hazards is also a potential risk to exposed populations (*medium confidence*). Broad-based institutional and cross-sectoral efforts to build adaptive capacity, including meeting the SDGs, reduce future risks of climate-related involuntary displacement and immobility (*medium confidence*), while policies such as the Global Compact on Safe, Orderly and Regular Migration (*medium confidence*) that are aimed at ensuring safe and orderly movements of people within and between states are potential components of climate resilient development pathways that can improve migration as an adaptation. {4.6.8, 7.4.4, 9.3.1, 12.5.8, CCP5.4.2, CCB FEASIB, CCB MIGRATE}

TS.D.8.7 Improving the feasibility of planned relocation and resettlement is a high priority for managing climate risks (*high confidence*). Residents of small island states do not view relocation as an appropriate or desirable means of adapting to the impacts of climate change (*high confidence*). Previous disaster- and development-related relocation has been expensive and contentious, posed multiple challenges for governments and amplified existing ones and generated new vulnerabilities for the people involved (*high confidence*). In locations where permanent, government-assisted relocation becomes unavoidable, active involvement of local populations in planning and decision-making may lead to more successful outcomes (*medium confidence*). {4.6.8, 7.4.4, 9.3.1, 12.5.8, 15.5.3, CCP5.4.2, CCB FEASIB, CCB MIGRATE}

TS.D.8.8 Meeting SDGs supports adaptive capacity that in turn supports individuals, households and community manage climate risks and supports peace (*high confidence*). By addressing vulnerability, improving livelihoods and strengthening institutions, meeting the SDGs reduces the risks of armed conflict and violence (*medium confidence*). Formal institutional arrangements for natural resource management and environmental peacebuilding, conflict-sensitive adaptation and climate-sensitive peacebuilding and gender-sensitive approaches offer potential new avenues to build peace in conflict-prone regions vulnerable to climate change (*medium confidence*). However, there is currently insufficient evidence on their success and further monitoring and evaluation is required. (Figure TS.11b) {4.8, 7.4.6, Box 9.9, 16.3.2, CCB GENDER}

Justice, equity and governance

TS.D.9 Adaptation actions consistent with climate justice address near- and long-term risks through decision-making processes that attend to moral and legal principles of fairness, equity and responsibility including to historically marginalised communities and that distribute benefits, burdens and risks equitably (*high confidence*). Concepts of justice, consent and rights-based decision-making, together with societal measures of well-being, are increasingly used to legitimate adaptation actions and evaluate the impacts on individuals and ecosystems, diverse communities and across generations (*medium confidence*). Applying these principles as part of monitoring and evaluating the outcomes of adaptation, particularly during system transitions, provide a basis for ensuring that the distribution of benefits and costs are identified (*medium confidence*). {1.4.1, 4.8, 5.10.4, 5.12.3, 6.1.5, 6.3.6, 12.5.7, 14.7.2, 17.5.1, CCB FEASIB, CCB GENDER}

TS.D.9.1 Near-term adaptation responses influence future inequalities, poverty, livelihood security and well-being (*high confidence*). Adaptation and mitigation approaches that exacerbate inequitable access to resources and fail to address injustice increase suffering, including water and food insecurity and malnutrition rates for vulnerable groups that rely directly or indirectly on natural resources for their livelihoods (*high confidence*). {1.4.1, 5.12.3, 5.13.3, 6.3.6, 8.6.2, Box 9.3, 12.5.7, 18.1}

TS.D.9.2 Under an inequality scenario (SSP4), the number of people living in extreme poverty could increase by more than 100 million (*medium confidence*). There is *medium evidence and low agreement* about the adaptation impacts of derivative-based insurance products. Insurance solutions are difficult for low-income groups to access (*medium confidence*). Formal insurance policies come with risks when implemented in a stand-alone manner, including risks of maladaptation (*medium confidence*). {5.13.5, 5.14.1, 9.8.4, 9.11.4}

TS.D.9.3 Climate-induced changes are not experienced equally across genders, income levels, classes, ethnicities, ages or

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physical abilities (*high confidence*). Therefore, participation of historically excluded groups, such as women, youth and marginalised communities (e.g., Indigenous Peoples, ethnic minorities, the disabled and low-income households), contributes to more equitable and socially just adaptation actions. Adaptation actions do not automatically have positive outcomes for gender equality. Understanding the positive and negative links of adaptation actions with gender equality goals (i.e., SDG 5) is important to ensure that adaptive actions do not exacerbate existing gender-based and other social inequalities (*high confidence*). Climate literacy varies across diverse communities, compounding vulnerability {2.6.3, 2.6.7, 4.3, 4.6, 4.6.9, 5.12.5, 5.14, 6.4.4, Box 6.1, 9.4.5, Box 9.1, 12.5.8, 16.1.4, CCB GENDER}

TS.D.9.4 Empowering marginalised communities in the co-production of policy at all scales of decision-making advances equitable adaptation efforts and reduces the risks of maladaptation (*high confidence*). Recognising Indigenous rights and local knowledge in the design and implementation of climate change responses contributes to equitable adaptation outcomes (*high confidence*). Indigenous knowledge and local knowledge play an important role in finding solutions and often creates critical linkages between cultures, policy frameworks, economic systems and natural resource management (*medium confidence*). Intergenerational approaches to future climate planning and policy will become increasingly important in relation to the management, use and valuation of social-ecological systems (*high confidence*). Many regions benefit from the significant diversity of local knowledge and systems of production, informed by long-standing experience with natural variability, providing a rich foundation for adaptation actions effective at local scales (*high confidence*). {2.6.3, 2.6.7, 4.8.3, 4.8.4, 4.8.5, 5.12.5, 6.1, 6.4.1, 8.6.2, 8.6.3, 9.1, 9.12, 11.4.1, 11.4.2, 12.5.7, 12.5.8, 15.5.4, 15.5.5, 17.5.1, CCP6.3.2, CCP 6.6, CCP6.4.3, CCB NATURAL}

TS.D.9.5 Proactive partnerships of government with the community, private sector and national agencies to minimise negative social, environmental or economic impacts of economy-wide transitions are emerging, but their implementation is uneven (*medium confidence*). The greatest gains are achieved by prioritising investment to reduce climate risk for low-income and marginalised residents, particularly in informal settlements and rural communities (*high confidence*). Some city and local governments invest directly in adaptation action and work in partnership with a range of agencies. Legislative frameworks will assist business and insurance sector investment in key infrastructure to drive adaptive action at scale for equitable outcomes (*medium confidence*). {Box 5.8, 6.4, 6.4.1, 8.5.2, 8.6.3, 9.4.2, 17.4.3, CCP5.2.4, CCB FINANCE}

TS.D.9.6 Inter-sectional, gender-responsive and inclusive decision-making can accelerate transformative adaptation over the long term to reduce vulnerability (*high confidence*). Approaches to adaptation that address the needs of the most disadvantaged, through co-production of knowledge, are more sensitive to diverse community priorities and can yield beneficial climate co-adaptation benefits. There are gender differences in climate literacy in many regions exacerbating vulnerability in agricultural contexts in access to resources and opportunities for climate resilient crops (*high confidence*) {3.6.4, 4.6.5, 4.8.5, 5.4.4, 5.13.4, Table 5.6, 6.3.6, 9.4.2, 9.4.5, Box 9.2, CCB FEASIB, CCB MOVING PLATE}

TS.D.9.7 Local leadership, especially among women and youth, can advance equity within and between generations (*medium confidence*). Since AR5, social movements, including movements led by youth, Indigenous and ethnic communities, have heightened public awareness about the need for urgent, inclusive action to achieve adaptation that can also enhance well-being and advance climate justice. {4.8.3, Box 5.13, 6.1.5, 6.2, 6.3.5, 6.4, 6.4.1, 6.4.7, Box 6.6, Box 9.1, Box 9.2}

TS.D.9.8. Climate justice initiatives that explicitly address multi-dimensional inequalities as part of a climate change adaptation strategy can reduce inequities in access to resources, assets and services as well as participation in decision-making and leadership, and are essential to achieving gender and climate justice (*high confidence*). {Box 6.1, Box 9.2, 13.7.2, 13.11.1, CCB GENDER}

Enabling implementation

TS.D.10. Various tools, measures and processes are available that can enable, accelerate and sustain adaptation implementation (*high confidence*), in particular when anticipating climate change impacts, and empower inclusive decision-making and action when they are supported by adaptation finance and leadership across all sectors and groups in society (*high confidence*). The actions and decisions taken today determine future impacts and play a critical role in expanding the solution space for future adaptation. Breaking adaptation down into manageable steps over time, while acknowledging potential long-term adaptation needs and options, can increase the prospect that effective adaptation plans will be actioned in timely and effective ways by stakeholders, sectors and institutions (*high confidence*). {2.6.7, 3.6.3, 3.6.5, 4.8, 11.7.3, 13.10, 15.3.4, 15.6, 17.5, CCP2.2.4, , CCB DEEP, CCB NATURAL, CCB SLR}

TS.D.10.1 Institutional frameworks, policies and plans that set out adaptation goals, define responsibilities and commitment devices, coordinate among actors and build adaptive capacity will facilitate sustained adaptation actions (*very high confidence*). Adaptation is considered in the climate policies of at least 170 countries. Opportunities exist to integrate adaptation into institutionalised decision cycles (e.g., budget reforms, statutory monitoring and evaluation, election cycles) and during windows of opportunity (e.g., recovery after disastrous events, designing new or replacing existing critical infrastructure or developing COVID recovery projects) (*high confidence*). Appraisal of adaptation options for policy and implementation that considers the risks of adverse effects can help prevent maladaptive adaptation and take advantage of possible co-benefits (*medium confidence*). Instruments such as behavioural nudges, re-directing subsidies and taxes and the regulation of marketing and insurance schemes have proven useful to strengthening societal responses beyond governmental actors (*medium confidence*). {1.4.4, 3.6.3, 3.6.5, 4.8.5, 4.8.6, 5.12.6, 5.13.3, 5.13.5, 6.1, 6.2, 6.3, 6.4, 7.4.1, 7.4.2, 9.4.2, 9.11.5, 10.3.6, 10.5.3, 11.4, 11.7, Table 11.14, Table 11.16, 13.5.2, 13.10, 13.11, 14.7.2, 17.3.1, 17.3.2, 17.3.3, 17.4, 17.5.1, 17.6, 18.4, CCP2.4, CCP 2.4.3, CCP5.4.2, CCP6.3, CCP6.4, CCB DEEP, CCB INDIG}

TS.D.10.2 Access to and mobilising adequate financial resources for vulnerable regions is an important catalysing factor for timely climate resilient development and climate risk management (*high confidence*). Total tracked climate finance has increased from USD364 billion yr^{-1} in 2010/2011 to USD579 billion in 2017/2018, with only 4–8% of this allocated to adaptation and more than 90% of adaptation finance coming from public sources. Developed-country climate finance leveraged for developing countries for mitigation and adaptation has shown an upward trend, but it has fallen short of the USD100 billion yr^{-1} 2020 target of the Copenhagen commitment, and less than 20% has been for adaptation. Estimated global and regional costs of adaptation vary widely due to differences in assumptions, methods and data; the majority of more recent estimates are higher than the figures presented in AR5. Median (and ranges) estimated costs for developing country adaptation from recent studies are USD127 (15–411) and USD295 (47–1088) billion yr^{-1} for 2030 and 2050 respectively. Examples of estimated regional adaptation include USD50 billion yr^{-1} in Africa for 1.5°C of warming in 2050, increasing to USD100–350 billion yr^{-1} for 4°C of global warming towards the end of the century. Increasing public and private finance flows by billions of dollars per year, increasing direct access to multilateral funds, strengthening project pipeline development and shifting finance from readiness activities to project implementation can enhance implementation of climate change adaptation and are fundamental to achieving climate justice for highly vulnerable countries, including small island states and African countries. {3.6.3, 4.8.2, 5.14.2, 9.1.1, 9.4.1, 13.9.4, 15.6, 15.6.1, 15.6.3, 15.7, 17.4.3, CCB FINANCE}

TS.D.10.3 Decision-support tools and decision-analytic methods are available and being applied for climate adaptation and climate risk management in different contexts (*high confidence*). Integrated adaptation frameworks and decision-support tools that anticipate multi-dimensional risks and accommodate community values are more effective than those with a narrow focus on single risks (*medium confidence*). Approaches that integrate the adaptation needs of multiple sectors such as disaster management, account for different risk perceptions and integrate multiple knowledge systems are better suited to addressing key risks (*medium confidence*). Reliable climate services, monitoring and early warning systems are the most commonly used strategies for managing the key risks, complementing long-term investments in risk reduction (*high confidence*). While these strategies are applicable to society as a whole, they need to be tailored to specific contexts in order to be adopted effectively. {2.6.7, 3.6.3, 3.6.5, 4.5.5, 5.14.1, 7.2.2, 7.4.1, 7.4.2, 9.5.1, 9.4.3, 9.10.3, 9.11.4, Box 9.2, Box 9.7, 15.5.7, 17.1.2, 17.2, 17.3.2, 17.4.4, 17.6, 18.4, CCP5.4.1, CCP5.6, CCB DEEP}

TS.D.10.4 Effective management of climate risks is dependent on systematically integrating adaptations across interacting climate risks and across sectors (*very high confidence*). Integrated pathways for managing climate risks will be most suitable when so-called 'low-regret' anticipatory options are established jointly across sectors in a timely manner and are feasible and effective in their local context, when path dependencies are avoided so as not to limit future options for climate resilient development and when maladaptations across sectors are avoided (*high confidence*). Integration of risks across sectors can be assisted by mainstreaming climate considerations across institutions and decision-making processes (*high confidence*). Many forms of climate adaptation are *likely* to be more effective, efficient and equitable when organised collectively and with multiple objectives. Using different assessment, modelling, monitoring and evaluation approaches can facilitate understanding of the societal implications of trade-offs. {1.4.2, 2.6, 4.5.1, 4.5.2. 11.3.11, 11.5.1, 11.5.2, 11.7, 11.7.2, 11.7.3, 13.5.2, 13.10, 13.11.2, 13.11.3, 15.7; 17.3.1, 17.6, CCP2.3.6, CCP5.4.2, CCB DEEP}

TS.D.10.5 Forward-looking adaptive planning and iterative risk management can avoid path dependencies and maladaptation and ensure timely action (*high confidence*). Approaches that break down adaptation into manageable steps over time and use pathway analyses to determine low-regret actions for the near-term and long-term options are a useful starting point for adaptation (*medium confidence*). Decision frameworks that consider multiple objectives, scenarios, time frames and strategies can avoid privileging some views over others and help multiple actors to identify resilient and equitable solutions to complex, deeply uncertain challenges and explicitly deal with trade-offs. Considering socioeconomic developments and climatic changes beyond 2100 is particularly relevant for long-lived investment decisions such as new harbours, airports, urban expansions and flood defences to avoid lock-ins (*medium confidence*). Monitoring climate change, socioeconomic developments and progress on implementation is critical for learning about adaptation success and maladaptation and to assess whether, when and what further actions are needed for informing iterative risk management (*high confidence*). {1.5.2, 11.7, 13.2.2, 13.11.1, 17.5.2, CCP2.3.6, CCB DEEP}

TS.D.10.6 Enhancing climate change literacy on impacts and possible solutions is necessary to ensure widespread, sustained implementation of adaptation by state and non-state actors (*high confidence*). Ways to enhance climate literacy and foster behavioural change include access to education and information, programmes involving the performing and visual arts, storytelling, training workshops, participatory three-dimensional modelling, climate services and community-based monitoring. The use of Indigenous knowledge and local knowledge represents and codifies actual experiences and autonomous adaptations and facilitates awareness, clarifies risk perception and enhances the understanding and adoption of solutions. Narratives can effectively communicate climate information and link this to societal goals and the actions needed to achieve them (*high confidence*). {1.2.2, 1.3.2, 1.3.3, 1.5.2, 5.4.4, 5.5.4, 5.8.4, 5.13.2, 5.14.1, 5.14.2, 9.4.5, 14.3, 15.6.4, 15.6.5}

TS.D.10.7 Political commitment and follow-through across all levels of government are important to accelerate the implementation of adequate and timely adaptation actions (*high confidence*). Implementing actions often requires large upfront investments of human and financial resources and political capital by public, private and societal actors, while the benefits of these actions may only become visible in the mid to long term (*medium confidence*). Examples that can accelerate adaptation action include accountability and transparency mechanisms, monitoring and evaluation of adaptation progress, social movements, climate litigation, building the economic case for adaptation and increased adaptation finance (*medium evidence, high agreement*). {3.6.3, 3.6.5, 4.8.5, 4.8.6, 4.8.7, 6.3, 6.4, 7.4.3, 9.4.2, 9.4.4, 11.7, 11.7.3, 11.8.1, 12.5, 12.5.6, 13.11, 14.6, 15.6, 15.6.3, 17.4.2, 17.5.2, 17.6, 18.4, CCB COVID}

System transitions and transformational adaptation

TS.D.11 Deep-rooted transformational adaptation opens new options for adapting to the impacts and risks of climate change (*high confidence*) by changing the fundamental attributes of a system, including altered goals or values and addressing the root causes of vulnerability. AR6 focuses on five system transitions to a just and climate resilient future: societal, energy, land and ocean ecosystems, urban and infrastructure, and industrial. These transitions call for transformations in existing social and social-technological and environmental systems that include shifts in most aspects of society. Managing transition risk is a critical element of transforming society, increasingly acknowledging the importance of transparent, informed and inclusive decision-making and evaluation, including a role for Indigenous knowledge and local knowledge. (Figure TS.11a, b) {1.2.1, 1.4.4, 1.5.1, 3.6.4, 4.7.1, 6.1.1, 6.4, Box 6.6, 11.4, 14.7.2, 18.3, Figure 18.3, CCB FEASIB}

TS.D.11.1 A sub-set of adaptation options has been implemented that cuts across sectors to enable sector-specific adaptation responses. These options, such as disaster risk management, climate services and risk sharing, increase the feasibility and effectiveness of other options by expanding the solution space available (*high confidence*). For example, carefully designed and implemented disaster risk management and climate services can increase the feasibility and effectiveness of adaptation responses to improve agricultural practices, income diversification, urban and critical services and infrastructure planning (*very high confidence*). Risk insurance can be a feasible tool to adapt to transfer climate risks and support sustainable development (*high confidence*). They can reduce both vulnerability and exposure, support post-disaster recovery and reduce financial burden on governments, households and business. {3.6.3, 3.6.5, 4.6, 4.7.1, 5.4.4, 5.6.3, 5.5.4, 5.8.4, 5.9.4, 5.12.4, 5.14.1, 5.14.2, 13.11.2, 14.7.2, 15.5.7, CCB FEASIB, CCB GENDER, CCB MOVING PLATE}

TS.D.11.2 Transformations for energy include the options of efficient water use and water management, infrastructure resilience and reliable power systems, including the use of intermittent renewable energy sources, such as solar and wind energy, with the use of storage (*very high confidence*). These options are not sufficient for the far-reaching transformations required in the energy sector, which tend to focus on technological transitions from a fossil-based to a renewable energy regime. A resilient power infrastructure is considered for energy generation, transmission and distribution systems. Distributed generation utilities, such as microgrids, are increasingly being considered, with growing evidence of their role in reducing vulnerability, especially within underserved populations (*high confidence*). Infrastructure resilience and reliable power are particularly important in reducing risk in peri-urban and rural areas when they are supported by distributed generation of renewable energy by isolated systems (*high confidence*). The option for a resilient power infrastructure is considered for all types of power generation sources and transmission and distribution systems. Efficient water use and water management especially in hydropower and combined cycle power plants in drought-prone areas have a high feasibility (*high confidence*) with multiple co-benefits (*medium confidence*). Water-related adaptation in the energy sector is highly effective up to 1.5°C but declines with increasing warming (*medium confidence*). {4.6.2, 4.7.1, 4.7.2, 4.7.3, Figure 4.28, Figure 4.29, 13.6.2, 15.7, 18.3, CCP5.4.2, CCB FEASIB}

TS.D.11.3 Adaptation options that are feasible and effective to the 3.4 billion people living in rural areas around the world and who are especially vulnerable to climate change, include the provision of basic services, livelihood diversification and strengthening of food systems (*high confidence*). The vulnerability of rural areas to climate risks increases due to the long distances to urban centres and the lack of or deficient critical infrastructure such as roads, electricity and water. Providing critical infrastructure, including through distributed generation power systems through renewable energy, has provided many co-benefits (*high confidence*). Biodiversity management strategies have social co-benefits, including improved community health, recreational activities and ecotourism, which are co-produced by harnessing ecological and social capital to promote resilient ecosystems with high connectivity and functional diversity. Strengthening local and regional food systems through strategies such as collective trademarks, participatory guarantee systems and city–rural links build rural livelihoods, resilience and self-reliance (*medium confidence*). Livelihood diversification is a key coping and adaptive strategy to climatic and non-climatic risks. There is *high evidence* (*medium agreement*) that diversifying livelihoods improves incomes and reduces socioeconomic vulnerability, but feasibility changes depending on livelihood type, opportunities and local context. Key barriers to livelihood diversification include sociocultural and institutional barriers as well as inadequate resources and livelihood opportunities that hinder the full adaptive possibilities of existing livelihood diversification practices (*high confidence*). (Figure TS.11b) {4.6.2, 4.7.1, 5, 8, 14.5.9, CCB FEASIB}

TS.D.11.4 Adaptation can require system-wide transformation of ways of knowing, acting and lesson-drawing to rebalance the relation between human and nature (*high confidence*). Indigenous knowledge and local knowledge, ecosystem-based adaptation and community-based adaptation are often found together in effective adaptation strategies and actions and together can generate transformative sustainable changes, but they need the resources, legal basis and an inclusive decision process to be most effective (*medium confidence*). Governance measures that transparently accommodate science and Indigenous knowledge can act as enablers of such co-production. {1.3.3, 2.6.5, 2.6.7, 5.14.1, 5.14.2, 6.4.7, 9.12, Box 9.1, 11.3.3, 11.4.1, 11.4.2, 11.5.1, 11.6, Box 11.3, Box 11.7, 12.5.8, 14.4, Box 14.7, 15.5.4, 15.5.5, 17.2.2, 17.3.1, 17.4.4, CCP6.3.2, CCP 6.6, CCP6.4.3}

TS.D.11.5 Factors motivating transformative adaptation actions include risk perception, perceived efficacy, sociocultural norms and beliefs, previous experiences of impacts, levels of education and awareness (*medium confidence*). Risk responsibilities across the globe are unclear and unevenly defined (*high confidence*). In the face of climate change, assigning risk responsibilities facilitates upgrading and supporting adaptation efforts (risk governance). There are at least two contrasting approaches for pursuing deliberate transformation: one seeking rapid, system-wide change and the other a collection of incremental actions that together catalyse desired system changes (*medium confidence*). {1.5.2, 6.4.7, 17.2.1, 17.2.2, CCP5.4.2}

TS.E Climate Resilient Development

Sustainable development, equity and justice

TS.E.1 Climate resilient development implements greenhouse gas mitigation and adaptation options to support sustainable development. With accelerated warming and the intensification of cascading impacts and compounded risks above 1.5°C warming, there is a sharply increasing demand for adaptation and climate resilient development linked to achieving SDGs and equity and balancing societal priorities. There is only limited opportunity to widen the remaining solution space and take advantage of many potentially effective, yet unimplemented, options for reducing society and ecosystem vulnerability (*high confidence*). (Figure TS.2, Figure TS.9 URBAN, Figure TS.11a, Figure TS.13) {1.2.3, 1.5.1, 1.5.2, 1.5.3, 2.6.7, 3.6.5, 4.8, Box 4.7, 7.1.5, 7.4.6, 13.10.2, 13.11, 17.2.1, 18.1, CCB COVID, CCB FINANCE, CCB HEALTH, CCB NATURAL}

TS.E.1.1 Prevailing development pathways do not advance climate resilient development (*very high confidence*). Societal choices in the near term will determine future pathways. There is no single pathway or climate that represents climate resilient development for all nations, actors or scales, as well as globally, and many solutions will emerge locally and regionally. Global trends including rising income inequality, urbanisation, migration, continued growth in greenhouse gas emissions, land use change, human displacement and reversals of long-term trends toward increased life expectancy run counter to the SDGs as well as efforts to reduce greenhouse gas emissions and adapt to a changing climate. With progressive climate change, enabling conditions will diminish, and opportunities for successfully transitioning systems for both mitigation and adaptation will become more limited (*high confidence*). Investments in economic recovery from COVID-19 offer opportunities to promote climate resilient development (*high confidence*). (Figure TS.13) {16.6.1, 17.2.1, 18.2, 18.4, CCP5.4.4, CCB COVID}

TS.E.1.2 System transitions can enable climate resilient development when accompanied by appropriate enabling conditions and inclusive arenas of engagement (*very high confidence*). Five system transitions are considered: energy, industry, urban and infrastructure, land and ecosystems, and society. Advancing climate resilient development in specific contexts may necessitate simultaneous progress on all five transitions. Collectively, these system transitions can widen the solution space and accelerate and deepen the implementation of sustainable development, adaptation and mitigation actions by equipping actors and decision makers with more effective options (*high confidence*). For example, urban ecological infrastructure linked to an appropriate land use mix, street connectivity, open and green spaces and job-housing proximity provides adaptation and mitigation benefits that can aid urban transformation (*medium confidence*). These system transitions are necessary precursors for more fundamental climate and sustainable-development transformations but can simultaneously be outcomes of transformative actions. Enhancing equity and agency are cross-cutting considerations for all five transitions. Such transitions can generate benefits across different sectors and regions, provided they are facilitated by appropriate enabling conditions, including effective governance, policy implementation, innovation and climate and development finance, which are currently insufficient (*high confidence*). {3.6.4, 15.7, 18.3, 18.4, Table 18.5, CCB FEASIB, CWGB URBAN}

TS.E.1.3 System transitions are highly feasible. For energy system transitions, there is *medium confidence* in the high feasibility of resilient infrastructure and efficient water use for power plants and *high confidence* in the synergies of this option with mitigation. For coastal ecosystem transitions, there is *medium* to *high confidence* that ecosystem conservation and biodiversity management are increasing adaptive and ecological capacity with socioeconomic co-benefits and positive synergies with carbon sequestration. However, opportunity costs can be a barrier. For land ecosystem transitions, there is *high confidence* in the role of agroforestry to increase ecological and adaptive capacity, once economic and cultural barriers and potential land use change trade-offs are overcome. There is *high confidence* in improved cropland management and its economic feasibility due to improved productivity. For efficient livestock systems, there is *medium confidence* in the high technological and ecological feasibility. (Figure TS.11a) {CCB FEASIB}

TS.E.1.4 For urban and infrastructure system transitions, there is *medium confidence* for sustainable land use and urban planning. There is *high confidence* in the economic and ecological feasibility of green infrastructure and ecosystem services, as well as sustainable urban water management, once institutional barriers in the form of limited social and political acceptability are overcome. Social safety nets, disaster risk management and climate services and population health and health systems are considered overarching adaptation options due to their applicability across all system transitions. There is *medium* to *high confidence* in the high feasibility of disaster risk management and the use of demand-driven and context-specific climate services as well as in the socioeconomic feasibility of social safety nets. Improving health systems through enhancing access to medical services and developing or strengthening surveillance systems can have high feasibility when there is a robust institutional and regulatory framework (*high confidence*). (Figure TS.8 HEALTH, Figure TS.9 URBAN, Figure TS.11a, Figure TS.13) {6.3, CCB FEASIB}

TS.E.1.5 There are multiple possible pathways by which communities, nations and the world can pursue climate resilient development. Moving towards different pathways involves confronting complex synergies and trade-offs between development pathways and the options, contested values and interests that underpin climate mitigation and adaptation choices (*very high confidence*). Climate resilient development pathways are trajectories for the pursuit of climate resilient development and navigating its complexities. Different actors, the private sector and civil society, influenced by science, local and Indigenous knowledges, and the media, are both active and passive in designing and navigating climate resilient development pathways. Increasing levels of warming may narrow the options and choices available for local survival and sustainable development for human societies and ecosystems. Limiting warming to Paris Agreement goals will reduce the magnitude of climate risks to which people, places, the economy and ecosystems will have to adapt. Reconciling the costs, benefits and trade-offs associated with

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adaptation, mitigation and sustainable development interventions and how they are distributed among different populations and geographies is essential and challenging but also creates the potential to pursue synergies that benefit human and ecological well-being (*high confidence*). {1.2.1, 18.1, 18.4}

TS.E.1.6. Economic sectors and global regions are exposed to different opportunities and challenges in facilitating climate resilient development, suggesting adaptation and mitigation options should be aligned to local and regional context and development pathways (*very high confidence*). Given their current state of development, some regions may prioritise poverty and inequality reduction and economic development over the near term as a means of building capacity for climate action and low-carbon development over the long term. In contrast, developed economies with mature economies and high levels of resilience may prioritise climate action to transition their energy systems and reduce greenhouse gas emissions. Some interventions may be robust in that they are relevant to a broad range of potential development trajectories and could be deployed in a flexible manner. However, other types of interventions, such as those that are dependent upon emerging technologies, may require a specific set of enhanced enabling conditions or factors, including infrastructure, supply chains, international cooperation and education and training that currently limit their implementation to certain settings. Notwithstanding national and regional differences, development practices that are aligned to people, prosperity, partnerships, peace and the planet as defined in Agenda 2030 could enable more climate resilient development. (*high confidence*) {18.5, Figure 18.1}

TS.E.1.7 Pursuing climate resilient development involves considering a broader range of sustainable development priorities, policies and practices, as well as enabling societal choices to accelerate and deepen their implementation (*very high confidence*). Scientific assessments of climate change have traditionally framed solutions around the implementation of specific adaptation and mitigation options as mechanisms for reducing climate-related risks. They have given less attention to a fuller set of societal priorities and the role of non-climate policies, social norms, lifestyles, power relationships and worldviews in enabling climate action and sustainable development. Because climate resilient development involves different actors pursuing plural development trajectories in diverse contexts, the pursuit of solutions that are equitable for all requires opening the space for engagement and action to a diversity of people, institutions, forms of knowledge and worldviews. Through inclusive modes of engagement that enhance knowledge sharing and realise the productive potential of diverse perspectives and worldviews, societies could alter institutional structures and arrangements, development processes, choices and actions that have precipitated dangerous climate change, constrained the achievement of SDGs and thus limited pathways to achieving climate resilient development. The current decade is critical to charting climate resilient development pathways that catalyse the transformation of prevailing development practices and offer the greatest promise and potential for human well-being and planetary health (*very high confidence*). {18.4, Box 18.1}

TS.E.2 Climate action and sustainable development are interdependent. Pursued in an inclusive and integrated manner, they enhance human and ecological well-being. Sustainable development is fundamental to capacity for climate action, including reductions in greenhouse gas emissions as well as enhancing social and ecological resilience to climate change. Increasing social and gender equity is an integral part of the technological and social transitions and transformation towards climate resilient development. Such transitions in societal systems reduce poverty and enable greater equity and agency in decision-making. They often require rights-based approaches to protect the livelihoods, priorities and survival of marginalised groups including Indigenous Peoples, women, ethnic minorities and children (*high confidence*). {2.6.7, 4.8, 6.3.7, 6.4, 6.4.7, 18.2, 18.4, CCB NATURAL}

TS.E.2.1 Conditions enabling rapid increases and innovative climate responses include experience of extreme events or climate education influencing perceptions of urgency, together with the actions of catalysing agents such as social movements and technological entrepreneurs. People who have experienced climate shocks are more likely to implement risk management measures (*high confidence*). Autonomous adaptation is very common in locations where people are more exposed to extreme events and have the resources and the temporal capacity to act on their own, for example in remote communities (*high confidence*).{3.5.2, 4.2.1, 4.6, 4.7.1, 6.4.7, 8.5.2, 9.4.5, 17.4.5, 18.5}

TS.E.2.2 A range of policies, practices and enabling conditions accelerate efforts towards climate resilient development. Diverse actors including youth, women, Indigenous communities and business leaders are the agents of societal changes and transformations that enable climate resilient development (*high confidence*). Greater attention to which actors benefit, fail to benefit or are directly harmed by different types of interventions could significantly advance efforts to pursue climate resilient development. (*medium* to *high confidence*). {4.6, 4.7.1, 5.13, 5.14, 6.4.7, 8.4.5, 9.4.5, 17.4, 18.5}

TS.E.2.3 Climate adaptation actions are grounded in local realities so understanding links with SDG 5 on gender equality ensures that adaptive actions do not worsen existing gender and other inequities within society (e.g., leading to maladaptation practices) (*high confidence*). Adaptation actions do not automatically have positive outcomes for gender equality. Understanding the positive and negative links of adaptation actions with gender equality goals (i.e., SDG 5) is important to ensure that adaptive actions do not exacerbate existing gender-based and other social inequalities. Efforts are needed to change unequal power dynamics and to foster inclusive decision-making for climate adaptation to have a positive impact for gender equality (*high confidence*). There are very few examples of successful integration of gender and other social inequities in climate policies to address climate change vulnerabilities and questions of social justice (*very high confidence*). Yet inequities in climate change literacy compounds women's vulnerability to climate change through its negative effect on climate risk perception {4.8.3, 9.4.5, 16.1.4, 17.5.1, CCB GENDER}

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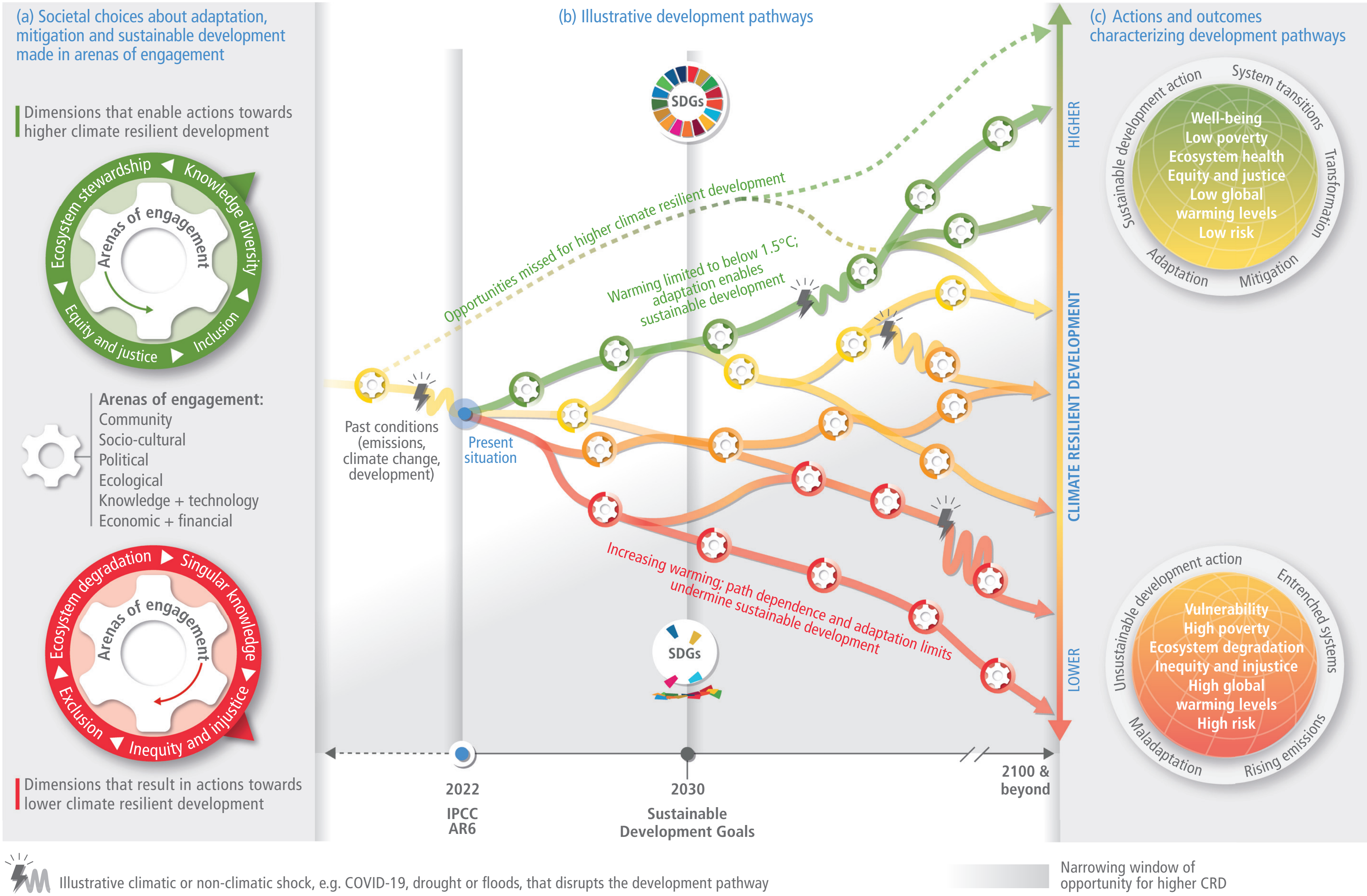
There is a rapidly narrowing window of opportunity to enable climate resilient development



(d) **Representative Key Risks**

	General	Agriculture	Water	Built	Ecosystems
Coastal socio-ecological systems				Water scarcity; extreme events; sea level rise ●●	Habitat loss; Extreme events ●●●
Terrestrial and ocean ecosystem services		Habitat loss; Fish declines; Invasives ●●●			Heat stress; ocean acidification; Extreme events; declining fisheries ●●●
Critical infrastructure, networks & services			Irrigation; Energy ●●	Flood damages ●●●	
Living standards & equity		Wild harvest declines, food insecurity ●●●	Irrigation revenues ●●	Poverty alleviation; Water security; SME impacts ●●●	Livelihoods dependent on wild systems (tropics) ●●●
Human health		Water competition; malnutrition ●●●		Disruption, loss of life; Cascading risks; Sanitation ●●	
Food Security		Reduced production (crops, livestock, fisheries); woody plant encroachment; water scarcity, competition ●●●	Irrigation; Infrastructure; Cascading risks ●●	Water security, sanitation in food processing,distribution ●●	
Water Security			Drought; Urbanisation; Energy ●●	Water scarcity; Cascading risks ●●●	
Peace & human mobility			Extreme events; drought; urban pressure; Poverty ●●	Water scarcity; Floods; Landslides; Poverty ●●●	

Adaptation Gap: large, moderate, small

Global warming level (GWL) adaptation limited: <1.5°C, 1.5°C, 2°C, 3°C, >3°C, Not assessed

Confidence level: ●●● high, ●● medium, ● low

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Adaptation potential for Representative Key Risks

	General	Agriculture	Water	Built	Ecosystems
Coastal socio-ecological systems				Habitat restoration; Storm surge protection; EbA ●●●	Maintenance and restoration ●●●
Terrestrial and ocean ecosystem services		Natural forest maintenances ●●			Maintenance and restoration. Protection of hotspots. EbA. ●●●
Critical infrastructure, networks & services			Eco-urban infrastructure ●●	Risk-sensitive design; water and sanitation access ●●●	
Living standards & equity		Social protection ●●●	Inclusive sustainable development; social protection ●●	Social protection; Health care ●●●	Social protection ●●●
Human health		Food supply chains; social protection ●●		Water management; Sanitation; Social protection; Nature-based solutions ●●	
Food Security		Irrigation; Water management, Land management; Climate smart agriculture ●●●	Irrigation; Planting regimes; Cropping Patterns ●●	Urban agriculture, forestry; mental health; heat management ●●	
Water Security			Dams; irrigation ●●	Water management; Integrated solutions; Flood management ●●●	
Peace & human mobility			Opportunities for movement ●●	Support networks; Financial support; Agency for migrants ●●	

Feasibility: large, moderate, small

Global warming level (GWL) adaptation limited (°C): <1.5°C, 1.5°C, 2°C, 3°C, >3°C, Not assessed

Confidence level: ●●● high, ●● medium, ● low

Potentially interacting mitigation measures

	General	Agriculture	Water	Built	Ecosystems
Land management		(-) Energy (renewable energy farms, biofuel crops), Carbon (afforestation of ancient grasslands) (+) Carbon (Protection/restoration of indigenous vegetation) ●●● +|−	(-) Carbon (afforestation of ancient grasslands); (+) Energy (hydro dams) ●●● +|−		(-) Carbon (Afforestation using water, taking over ancient grasslands) ●●● +
Nature-based		(+) Carbon (ecosystem protection & restoration; forest sustainability, soil management ●●● +	(+) Carbon (forest restoration) ●●● +		(+) Carbon (Forest restoration & sustainable management; Soil management)●●● +
Technology		(+) Carbon (soils - climate - smart agriculture) ●●● +		(+) Energy (Decentralised & low carbon energy access) ●●● +	
Buildings & Infrastructure			(+/-) Energy (Dams - take water, store water); (-) Carbon (afforestation ●●● −	(+) Energy (transport diversification, ecobuilding) (-) Energy (Dams divert water) ●●● +|−	(-) Energy (dams altering water flows) ●●● −
Energy			(-) Energy (Hydropower) (+) Cross basin risk pooling / transfer ●●● +|−		
Societal (behavioural)				(-) Options affected by social inequality in energy, water and food security ●●● −	(+) Governance (Indigenous systems); land management (reduce emissions) ●●● +

Importance

Mitigation measures − +|− +

Important enablers considered within sectors

	General	Agriculture	Water	Built	Ecosystems
Governance	Adaption Legal frameworks ●●●			Multi-level Engagement ●●● X	Protected areas to support biodiversity and livelihoods. ●●●
Coordination and integration			Integrated approaches across related sectors ●●●	Options to improve multiple sectors ●●● X	Coordination; Transboundary agreements ●●
Institutions and decision processes	Engagement Options ●●●	Stakeholder Engagement ●●●	Multi-level Inclusivity ●●●		Inclusivity ●●
Finance	Broad-based ●●●	Ownership; Targeted projects ●●●		Adaptation finance ●●● X	Response to extreme events ●●●
Technology, information, decision support, climate services & literacy	Climate services & literacy; Planning, Information, Diverse Knowledges ●●●	Information-technology; climate services ●●●	Tools to address complexity, uncertainty, change & contestation ●●●	Early warning systems; Perception management ●●● X	
Processes for Innovation, adjustment and learning				Innovation & planning; social learning ●●● X	Diversification ●●●
Poverty reduction		Drought-resistant crops; agroforestry, diversification ●●●			
Cross-sectoral and transboundary solutions	Integrated Planning, Options across multiple sectors; Transboundary and multistake-holder cooperation; Multilevel Equity; Benefit sharing ●●●		Options to improve multiple sectors ●●●		

Importance

Enabling Gap: Large, moderate, small, X not asseessed

Figure TS.13 | Climate resilient development is the process of implementing greenhouse gas mitigation and adaptation measures to support sustainable development. This figure builds on Figure SPM.9 in AR5 WGII (depicting climate resilient pathways) by describing how climate resilient development pathways are the result of cumulative societal choices and actions within multiple arenas.

Panel (a) Societal choices towards higher climate resilient development (green cog) or lower climate resilient development (red cog) result from interacting decisions and actions by diverse government, private sector and civil society actors, in the context of climate risks, adaptation limits and development gaps. These actors engage with adaptation, mitigation and development actions in political, economic and financial, ecological, socio-cultural, knowledge and technology, and community arenas from local to international levels. Opportunities for climate resilient development are not equitably distributed around the world.

Panel (b) Cumulatively, societal choices, which are made continuously, shift global development pathways towards higher (green) or lower (red) climate resilient development. Past conditions (past emissions, climate change and development) have already eliminated some development pathways towards higher climate resilient development (dashed green line).

Panel (c) Higher climate resilient development is characterised by outcomes that advance sustainable development for all. Climate resilient development is progressively harder to achieve with global warming levels beyond 1.5°C. Inadequate progress towards the Sustainable Development Goals (SDGs) by 2030 reduces climate resilient development prospects. There is a narrowing window of opportunity to shift pathways towards more climate resilient development futures as reflected by the adaptation limits and increasing climate risks, considering the remaining carbon budgets. (Figure TS.3, Figure TS.4) {2.6, 3.6, 7.2, 7.3, 7.4, 8.3, 8.4, 8.5, 16.4, 16.5, 17.3, 17.4, 17.5, 18.1, 18.2, 18.3, 18.4, Box 18.1, Figure 18.1, Figure 18.2, Figure 18.3, CCB COVID, CCB GENDER, CCB HEALTH, CCB INDIG, CCB SLR, WGI AR6 Table SPM.1, WGI AR6 Table SPM.2, SR1.5 Figure SPM.1}.

Panel (d) Appropriate choices for fostering climate resilient development pathways involve considering the portfolio of risks, the potential for adaptations to satisfactorily reduce risks and not exacerbate others, the potential for mitigation measures to interact with risks and adaptations within and across sectors, and how and whether adaptations can be enabled. The graphic table illustrates a possible assembly (not exhaustive) of these considerations for four sectors (agriculture, water, built environments, ecosystems) in the region Africa, showing (i) *top panel*: the potential for cascading and compounding effects amongst risks within sectors, between sectors and across boundaries and the possible constraints for adaptation (at what global warming level might risks become too great for adaptation – cell colour) and the adaptation gap to be filled (cell border) (risks are grouped by Representative Key Risks); (ii) *second panel*: the potential for adaptations to reduce risks, including their feasibility (cell border), their interaction with other adaptations addressing the same or interacting risks, and whether they are limited by global warming level (cell colour) (possible adaptations are identified for Representative Key Risks); (iii) *third panel*: the mitigation measures grouped into categories that might interact with risks and adaptations, including showing their importance (cell border) and whether the interaction would be potentially positive, negative or a mixture of both (cell colour) (note: 'carbon' refers to carbon sequestration); (iv) *bottom panel*: Enabling conditions for sectors grouped into categories of enablers common across many sectors, showing their importance (cell border) and how they may be suitable across a number of sectors, along with an assessment of the gap in the enabler for satisfactory adaptation (cell colour). Confidence levels on each cell are indicated as *= *low confidence*, ** = *medium confidence*, *** = *high confidence.* (see also SMTS.4, Table SMTS.5) {16.5.2, Table SM16.4}

TS.E.2.4 Gender-sensitive, equity- and justice-based adaptation approaches, integration of Indigenous knowledge systems within legal frameworks and the promotion of Indigenous land tenure rights reduce vulnerability and increase resilience (*high confidence*). Integrating adaptation into social protection programmes can build long-term resilience to climate change (*high confidence*). Nevertheless, social protection programmes can increase resilience to climate related shocks, even if they do not specifically address climate risks (*high confidence*). Climate adaptation actions are grounded in local realities so understanding links with SDGs is important to ensure that adaptive actions do not worsen existing gender and other inequities within society, leading to maladaptation practices (*high confidence*). {3.6.4, 4.8.3, 4.8.4, 9.4.5, Box 9.1, Box 9.2, Box 9.7, Box 9.8, Box 9.9, Box 9.10, Box 9.11, 14.4, Box 14.1, 17.5.1, CCP6.3, Box CCP6.2 CCB GENDER}

TS.E.2.5 Water can be either an enabler or a hindrance to successful adaptation and sustainable development. Central to equity issues about water is that it remains a public good (*high confidence*). Overcoming institutional and financial constraints (governance, institutions, policies), including path dependency, is among the most important requirements enabling effective adaptation in the water sector (*high confidence*). Water-related challenges, despite reported adaptation efforts, indicate limits of adaptation in the absence of water neutral mitigation action (*medium confidence*). For some regions, such as small island states, coastal areas and mountainous regions, water availability already has the potential to become a hard limit on adaptation (*limited evidence*, *medium agreement*). (Figure TS.6 FOOD-WATER) {4.5.3, 4.5.4, 4.5.5, 4.8, 4.6, 4.7.1, 4.7.2, 4.7.6, 6.4 case study 6.1, 15.3.4, CCP5.2.2}

TS.E.2.6 Procedural and distributional justice and flexible institutions facilitate successful adaptation and minimise maladaptive outcomes. Reorienting existing institutions to become more flexible (e.g., through capacity building and institutional reform) and inclusive is key to building adaptive governance systems that are equipped to take long-term decisions (*medium confidence*). Enhancing climate governance, institutional capacity and differentiated policies and regulation from the local to global scale enables and accelerates climate resilient development. Transforming financial systems to deliver the SDGs, while accelerating system transitions and addressing physical and transition risks, is a precondition. Changes in lifestyles, human behaviour and preferences can have a significant impact on adaptation implementation, demand and hence emissions and decision-making around climate action (*high confidence*). Additionally, the use of customary and traditional justice systems, such as those of Indigenous peoples, can enhance the equity of adaptation policy processes (*high confidence*). {4.8, 4.6,8, 5.2.3, 13.8, 15.6.1, 15.6.3, 15.6.4, 15.6.5, 17.1, 18.4}

TS.E.2.7 Enabling environments for adaptation that support equitable sustainable development are essential for those with climate-sensitive livelihoods who are often least able to adapt and influence decision-making (*high confidence*). Enabling environments share common governance characteristics, including the meaningful involvement of multiple actors and assets, alongside multiple centres of power at different levels that are well integrated, vertically and horizontally (*high confidence*). Enabling conditions harness synergies, address moral and ethical choices and divergent values and interests and support just approaches to livelihood transitions that do not undermine human well-being (*medium confidence*). Climate solutions for health, well-being and the changing structure of communities are complex and closely interconnected and call for new approaches to sustainable development that consider interactions between climate, human and socioecological systems to generate climate resilient development (*high confidence*). To address regionally specific adaptation and developmental needs, five key dimensions of climate resilient development are identified for Africa: climate finance, governance, cross-sectoral and transboundary solutions, adaptation law and climate services and climate change literacy (*high confidence*). {4.6, 4.8, 6.4.7, 7.1.7, 8.5.1, 8.5.2, 8.6.3, 9.4.1, 9.4.2, 9.4.3, 9.4.4, 9.4.5, 17.4}

TS.E.2.8 Prevailing ideologies or worldviews, institutions and sociopolitical relations influence development trajectories by framing climate narratives and possibilities for action (*medium confidence*). The interplay between worldviews and ethics, sociopolitical relations, institutions and human behaviour influence public engagement by individuals and communities. These open up opportunities for meaningful engagement and co-production of pathways towards climate resilient development. The urgency of climate action is a potential enabler of climate decision-making (*medium confidence*). Perceptions of urgency encourage communities, businesses and leaders to undertake climate adaptation and mitigation measures more quickly and to prioritise climate action (*high confidence*). {1.1.3, 6.4.3, 17.1, 17.4.5, 18.5}

Enablers of societal resilience

TS.E.3 A focus on climate risk alone does not enable effective climate resilience (*high confidence*). The integration of consideration of non-climatic drivers into adaptation pathways can reduce climate impacts across food systems, human settlements, health, water, economies and livelihoods (*high confidence*). Strengthened health, education and basic social services are vital for improving population well-being and supporting climate resilient development (*high confidence*). The use of climate-smart agriculture technologies that strengthen synergies among productivity and mitigation is growing as an important adaptation strategy (*high confidence*). Pertinent information for farmers provided by climate information services is helping them to understand the role of climate compared with other drivers in perceived productivity changes (*medium confidence*). Index insurance builds resilience and contributes to adaptation both by protecting farmers' assets in the face of major climate shocks, by promoting access to credit and by adopting improved farm technologies and practices (*high confidence*). {3.6.4, 4.6, 4.7.1, 7.4.6, Box 9.1, Box 9.7, Box 9.8, Box 9.9, Box 9.10, Box 9.11, 12.5.4}

TS.E.3.1 Societal resilience is strengthened by improving the management of environmental resources and ecosystem health, boosting adaptive capabilities of individuals and communities to anticipate future risks and minimise them and removing drivers of vulnerability to bring together gender justice, equity, Indigenous and local knowledge systems and adaptation planning (*very high confidence*). Societal resilience is founded on strengthening local democracy, empowering citizens to shape societal choices to support gender and equity inclusive climate resilient development (*very high confidence*). {7.4.1, 7.4.2, 7.4.3, 7.4.4, 7.4.5, 7.4.6, 9.4.5, 13.11.3, 14.4, Box 14.1, 15.5.5, 17.5.1, CCP6.3, CCP6.4, Box CCP6.2, CCB GENDER}

TS.E.3.2 Some communities/regions are resilient with strong social safety nets and social capital that support responses and actions already occurring, but there is limited information on the effectiveness of adaptation practices and the scale of action needed (*high confidence*). Among island communities, greater insights into which drivers weaken local communities and Indigenous Peoples' resilience, together with recognition of the sociopolitical contexts within which communities operate, can assist in identifying opportunities at all scales to enhance climate adaptation and enable action towards climate resilient development pathways (*medium evidence, high agreement*). Adaptation responses to climate-driven impacts in mountain regions vary significantly in terms of goals and priorities, scope, depth and speed of implementation, governance and modes of decision-making and the extent of financial and other resources to implement them (*high confidence*). Adaptation in Africa has multiple benefits, and most assessed adaptation options have medium effectiveness at reducing risks for present-day global warming, but their efficacy at future warming levels is largely unknown (*high confidence*). In Australia and New Zealand, a range of incremental and transformative adaptation options and pathways is available as long as enablers are in place to implement them (*high confidence*). Several enablers can be used to improve adaptation outcomes and to build resilience (*high confidence*), including better governance and legal reforms; improving justice, equity and gender considerations; building human resource capacity; increased finance and risk transfer mechanisms; education and awareness programmes; increased access to climate information; adequately downscaled climate data; inclusion of Indigenous knowledge; and integrating cultural resources into decision-making (*high confidence*). {9.3, 9.6.4, 9.8.3, 9.11.4, 11.7.3, 14.4, Box 14.1, 15.6.1, 15.6.5, 15.7, 15.6.3, 15.6.4, 15.6.5, CCP5.2.4, CCP5.2.7, CCP6.3, CCP6.4, Box CCP6.2, CCB GENDER}

TS.E.3.3 Identifying and advancing synergies and co-benefits of mitigation, adaptation and SDGs has occurred slowly and unevenly (*high confidence*). One area of sustained effort is community-based adaptation planning actions that have potential to be better integrated to enhance well-being and create synergies with the SDG ambitions of leaving no one behind (*high confidence*). Complex trade-offs and gaps in alignment between mitigation and adaptation over scale and across policy areas where sustainable development is hindered or reversed also remain (*medium confidence*). Globally, decisions about key infrastructure systems and urban expansion drive risk creation and potential action on climate change (*high confidence*). {4.7.6, 6.4.1, 6.4.3, 6.4.4, 6.1, 6.2, 6.2.3, 6.3, 6.3.5.1, 6.4, 7.4.7, 9.3.2, CCB HEALTH, CWGB BIOECONOMY}

TS.E.3.4 Indigenous knowledge and local knowledge are crucial for social-ecological system resilience (*high confidence*). Indigenous Peoples have been faced with adaptation challenges for centuries and have developed strategies for resilience in changing environments that can enrich and strengthen other adaptation efforts (*high confidence*). Supporting indigenous self-determination, recognising Indigenous Peoples' rights and supporting Indigenous knowledge-based adaptation can accelerate effective robust climate resilient development pathways (*very high confidence*). Indigenous knowledge underpins successful understanding of, responses to and governance of climate change risks (*high confidence*). For example, Indigenous knowledge contains resource-use practices and ecosystem stewardship strategies that conserve and enhance both wild and domestic biodiversity, resulting in terrestrial and aquatic ecosystems and species that are often less degraded in Indigenous managed lands in other lands (*medium confidence*). Valuing Indigenous knowledge systems is a key component of climate justice (*high confidence*). {2.6.5, 2.6.7, 4.8.3, 3.6.3, 3.6.4, 3.6.5, 4.8.4, 4.8.5, 4.8.6, 7.4.7, Box 7.1, Box 9.2, 12.5.1, 12.5.8, 12.6.2, 13.2.2, 13.8, 13.11, 14.4, 14.7.3, Box 14.1, CCP5.2.6, CP5.4.2, CCP6.3, CCP6.4, Box CCP6.2, CCB INDIG, CCB NATURAL}

TS.E.3.5 Ecosystem-based adaptation reduces climate risk across sectors, providing social, economic, health and environmental co-benefits (*high confidence*). Direct human dependence on ecosystem services, ecosystem health, and ecosystem protection and restoration, conservation agriculture, sustainable land management and integrated catchment management support climate resilience. Inclusion of interdisciplinary scientific information, Indigenous knowledge and practical expertise is essential to effective ecosystem-based adaptation (*high confidence*), and there is a large risk of maladaptation where this does not happen (*high confidence*). (Figure TS.9 URBAN) {1.4.2, 2.2, 2.3, 2.5. 2.6, Table 2.7, 3.6.2, 3.6.3, 3.6.4, 3.6.5, 4.6.6, Box 4.6, 5.14.2, 7.4.2, 9.6, 9.7, 9.8, 9.9, 9.10, 9.11, 9.12, CCP1, CCP6.3, CCP6.4, CCB NATURAL}

Ecosystem health and resilience

TS.E.4 Maintaining planetary health is essential for human and societal health and a pre-condition for climate resilient development (*very high confidence*). Effective ecosystem conservation on approximately 30% to 50% of Earth's land, freshwater and ocean areas, including all remaining areas with a high degree of naturalness and ecosystem integrity, will help protect biodiversity, build ecosystem resilience and ensure essential ecosystem services (*high confidence*). In addition to this protection, sustainable management of the rest of the planet is also important. The protected area required to maintain ecosystem integrity varies by ecosystem type and region, and their placement will determine the quality and ecological representativeness of the resulting network. Ecosystem services that are under threat from a combination of climate change and other anthropogenic pressures include climate change mitigation, flood-risk management and water supply (*high confidence*). (Figure TS.12) {2.5.4, 2.6.7, 3.4.2, 3.4.3, 3.6.3, 3.6.5, 13.3.2, 13.5.2, 13.10.2, CCB NATURAL}

TS.E.4.1 Species conservation is an internationally recognised objective in its own right and is also important for human life and well-being: there is a strong positive association between species diversity and ecosystem health that is essential for providing critical regulating services, including climate regulation, water provisioning, pest and disease control and crop pollination (*high confidence*). The loss of species also lowers the resilience of the ecosystem as a whole, including its capacity to persist through climate change and recover from extreme events (*high confidence*). Species extinction levels that are more than 1000 times natural background rates as a result of anthropogenic pressures, and climate change will increasingly exacerbate this (*high confidence*). Conservation efforts are more effective when integrated into local spatial plans inclusive of adaptation responses, alongside sustainable food and fiber production systems (*high confidence*). Strong inclusive governance systems and participatory planning processes that support equitable and effective adaptation outcomes, are gender sensitive and reduce intergroup conflict are required for enhanced ecosystem protection and restoration (*high confidence*). {2.2, 2.5.2, 2.5.3, 2.5.4, 2.6.1-3, 2.6.5, 2.6.7, Table 2.6, Table 2.7, 3.6.3, 3.6.4, 3.6.5, 5.8.4, 5.13.5, 5.14.1, 5.14.2, 7.4.7, CCP1, CCB COVID, CCB GENDER, CCB ILLNESS, CCB INDIG, , CCB MIGRATE, CCB NATURAL}

TS.E.4.2 Solutions that support biodiversity and the integrity of ecosystems deliver essential co-benefits for people including livelihoods, food and water security and human health and well-being (*high confidence*). Limiting warming to 2°C and protecting 30% of high-biodiversity regions in Africa, Asia and Latin America is estimated to reduce the risk of species extinctions by half (*high confidence*). Meeting the increasing needs of the human population for food and fibre production requires transformation in management regimes to recognise dependencies on local healthy ecosystems, with greater sustainability, including through increased use of agroecological farming approaches and adaptation to the changing climate (*high confidence*). People with higher levels of contact with nature have been found to be significantly happier, healthier and more satisfied with their lives (*high confidence*). Participatory, inclusive governance approaches such as adaptive co-management or community-based planning, which integrate those groups who rely on these ecosystems (e.g., Indigenous Peoples, local communities), support equitable and effective adaptation outcomes (*high confidence*). {2.5.4, 2.6.7, 3.4.2, 3.4.3, 3.6.3, 3.6.4, 3.6.5, 4.8.5, 4.8.6, 5.8.4, 5.13.5, 5.14.1, 5.14.2, 17.3.1, 17.3.2, 17.6, CCB NATURAL}

TS.E.4.3 Protecting and building the resilience of ecosystems through restoration, in ways which are consistent with sustainable development, are essential for effective climate change mitigation (*high confidence*). Degradation and loss of ecosystems is a major cause of greenhouse gas emissions, which is increasingly exacerbated by climate change (*very high confidence*). Globally, there is a 38% overlap between areas of high carbon storage and high intact biodiversity, but only 12% of that is protected (*high confidence*). Addressing this gap will require an approach which takes account of human needs, particularly food security. Tropical rainforests and global peatlands are particularly important carbon stores but are highly threatened by human disturbance, land conversion and fire. Climate resilient development will require strategies for land-based climate change mitigation to be integrated with adaptation, biodiversity and sustainable development objectives; there is good potential for positive synergies, but also the potential for conflict, including with afforestation and bioenergy crops, when these objectives are pursued in isolation (*high confidence*). {2.4.3, 2.4.4, 2.5.3, 2.6.3, 2.6.5-7, 2.6.7, Box 2.2, 3.4.2, 3.5.5, Box 3.4, CCP7.3.2, CCB NATURAL, CWGB BIOECONOMY}

TS.E.4.4 Adaptive management in response to ecosystem change is increasingly necessary, and more so under higher emissions scenarios (*high confidence*). Feedback from monitoring and assessments of the changing state of planetary conditions and local ecosystems enables proactive adaptation to manage risks and minimise impacts (*medium confidence*). Integrated sectoral approaches promoting climate resilience, particularly for addressing the impacts of extreme events, are key to effective climate resilient development (*medium confidence*). {2.6.2, 2.6.3, 2.6.6, 2.6.7, 3.4.2, 3.4.3, 3.6.3, 3.6.5, Box 3.4, 17.3.2, 17.6, CCB EXTREMES, SR1.5, SRCCL, SROCC}

TS.E.4.5 Adaptation cannot prevent all risks to biodiversity and ecosystem services (*high confidence*). Adaptation of conservation strategies, by building resilience and planning for unavoidable change, can reduce harm but will not be possible in all systems, for example, fragile ecosystems that reach critical thresholds or tipping points such as coral reefs, some forests, sea ice and permafrost systems. Conservation and restoration will alone be insufficient to protect coral reefs beyond 2030 (*high confidence*) and to protect mangroves beyond the 2040s (*high confidence*). Deep cuts in emissions will be necessary to minimise irreversible loss and damage (*high confidence*). (Figure TS.5 ECOSYSTEMS) {2.5.1, 2.5.2, 2.5.4, 2.6.1, 2.6.6, 3.4.2, 3.4.3, 3.6.3, Figure 3.26, Table SM3.5, Table SM3.6}

Governance

TS.E.5 Governance arrangements and practices are presently ineffective to reduce risks, reverse path dependencies and maladaptation and facilitate climate resilient development (*very high confidence*). Governance for climate resilient development involves diverse societal actors, including the most vulnerable, who can work collectively, drawing upon local and Indigenous knowledges and science, and are supported by strong political will and climate change leadership (*medium confidence*). Governance practices will work best when they are coordinated within and between multiple scales and levels (institutional, geographical and temporal) and sectors, with supporting financial resources, are tailored for local conditions, are gender-responsive and gender-inclusive and are founded upon enduring institutional and social learning capabilities to address the complexity, dynamism, uncertainty and contestation that characterise escalating climate risk (*medium confidence*). {1.4.2, 3.6.2, 3.6.3, 4.8, 4.8.1, 4.8.2, 4.8.3, 4.8.4, 4.8.5, 4.8.6, 4.8.7, 6.4.3, 6.4.4, 9.4.5, 17.4, 17.6}

TS.E.5.1 Prevailing governance efforts have not closed the adaptation gap (*very high confidence*), in part due to the complex interconnections between climate and non-climate risk and the limits of the predominant development and governance practices (*high confidence*). Institutional fragmentation, under-resourcing of services, inadequate adaptation funding, uneven capability to manage uncertainties and conflicting values and reactive governance across competing policy domains collectively lock in existing exposures and vulnerabilities, creating barriers and limits to adaptation, and undermine climate resilient development prospects (*high confidence*). This is amplified by inequity, poverty, population growth and high population density, land use change, especially deforestation, soil degradation, biodiversity loss, high dependence of national and local economies on natural resources for production of commodities, weak governance, unequal access to safe water and sanitation services and a lack of infrastructure and financing, which reduce adaptation capacity and deepen vulnerability (*high confidence*). {3.6.3, 3.6.5, 6.4.3, Figure 6.5, 9.4.1, 11.7, Table 11.14, Table 11.16, 12.1.1, 12.2, 12.3, 12.5.5, 12.5.7, Figure 12.2}

TS.E.5.2 Climate governance arrangements and practices are enabled when they are embedded in societal systems that advance human well-being and planetary health (*very high confidence*). Collective action and strengthened networked collaboration, more inclusive governance, spatial planning and risk-sensitive infrastructure delivery will contribute to reducing risks (*medium confidence*). Enablers for climate governance include better practices and legal reforms, improving justice, equity and gender considerations, building human resource capacity, increased finance and risk transfer mechanisms, education and climate change literacy programmes, increased access to climate information, adequately downscaled climate data and embedding Indigenous knowledge and local knowledge as well as integrating cultural resources into decision-making (*high confidence*). {4.8.7, 9.4.5, 15.6.1, 15.6.3, 15.6.4, 15.6.5, 17.4, 17.6}

TS.E.5.3 Climate governance will be most effective when it has meaningful and ongoing involvement of all societal actors from local to global levels (*very high confidence*). Actors, including individuals and households, communities, governments at all levels, private-sector businesses, non-governmental organisations, Indigenous Peoples, religious groups and social movements, at many scales and in many sectors, are adapting already and can take stronger adaptation and mitigation actions. Many forms of adaptation are more effective, more cost-efficient and more equitable when organised inclusively (*high confidence*). Greater coordination and engagement across levels of government, business and community serves to move from planning to action and from reactive to proactive adaptation (*high confidence*). Inclusion of all societal actors helps to secure credibility, relevance and legitimacy, while fostering commitment and social learning (*medium* to *high confidence*), as well as equity and well-being, and reduces long-term vulnerability across scales (*high evidence, medium agreement*). Social movements in many cities, including those led by youth, have heightened public awareness about the need for urgent, inclusive adaptation that can enhance well-being, foster formal and informal cooperation and coherence between different institutions and build new adaptive capacities. City and local governments remain key actors facilitating climate change adaptation in cities and settlements (*medium confidence*). Private and business investment in key infrastructure, housing construction and insurance can drive adaptive action at scale but can exclude the priorities of the poor (*medium confidence*). Networked community actions can address neighbourhood-scale improvements and vulnerability at scale (*very high confidence*). {1.4.2, 3.6.5, 6.1, 6.4, 9.4.5, Box 9.4, 11.4.1, 11.4.2, 14.6.3, Box 14.8, 17.2}

TS.E.5.4 Governance practices for climate resilient development will be most effective when supported by formal (e.g., the law) and informal (e.g., local customs and rituals) institutional arrangements providing for ongoing coordination between and alignment of local to international arrangements across sectors and policy domains (*high confidence*). Aligned national and

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international legal and policy instruments can support the development and implementation of adaptation and climate risk management (*medium confidence*) and reduce exposure to key risks (*high confidence*). Dedicated climate change acts can play a foundational and distinctive role in supporting effective climate governance, and are drivers of subsequent activity in both developing and developed countries (*high confidence*). The transboundary nature of many climate change risks and species responses will require transboundary solutions through multi-national or regional governance processes on land (*medium confidence*) and at sea (*high confidence*). {3.6.5, Table 3.28, 4.6.2, 4.6, 6.1, 9.4.3, 9.4.4, Box 9.5, 11.7.1, 11.7.3, 17.2.1, 17.3.2, 17.4.2, 17.5.1, 17.6, 18.4.3, CCP5.4.2, CCP6.3, CCB MOVING PLATE}

TS.E.5.5 Multi-lateral governance efforts can help reconcile contested interests, worldviews and values about how to address climate change (*medium confidence*). Policy responses and strategies that localise development and expand the adaptation and mobility options of populations exposed to climatic risks can also reduce risks of climate-related conflict and political instability (*high agreement, medium evidence*). Formal institutional arrangements for natural resource management can contribute to wider cooperation and peacebuilding (*high confidence*). Reducing vulnerability depends on the inclusive engagement of the most vulnerable, is gender-responsive and includes key societal actors from civil society, the private sector and government, with an especially important role played by local government in partnership with local communities. Strong governance and gender-sensitive approaches to natural resource management reduce the risk of intergroup conflict in climate-disrupted areas (*medium confidence*). {3.6.3, 3.6.4, 3.6.5, 4.8.5, 4.8.6, 4.8.7, 6.1, 7.4.4, 7.4.5, CCB COVID, CCB GENDER, CCB HEALTH, CCB INDIG}

TS.E.5.6 A range of governance processes, practices and tools that are applicable across a range of temporal and spatial scales are available to support inclusive decision-making for adaptation and risk management in diverse settings (*high confidence*). National guidance and laws, policies and regulations, decision tools that can be tailored to local circumstances, innovative engagement processes and collaborative governance can motivate better understanding of climate risk and build climate resilient development (*high confidence*). Collaborative networks and institutions, including among local communities and their governing authorities, can help resolve conflicts (*high confidence*). A combination of robust climate information, adaptive decision-making under uncertainty, land use planning, public engagement and conflict resolution approaches can help to address governance constraints to prepare for climate risks and build adaptive capacity (*high confidence*). New modelling, monitoring and evaluation approaches, alongside disruptive technologies, can help understand the societal implications of trade-offs and build integrated pathways of low-regret anticipatory options, established jointly across sectors in a timely manner, to avoid locked-in development pathways (*high confidence*). {3.6.2, 3.6.3, 3.6.4, 3.6.5, 5.14.1, 5.14.4, 11.4.1, 11.4.2, 11.7.1, 11.7.3, Box 11.5, 15.5.3, 15.5.4, 15.6.3, 15.6.4, 15.6.5, 17.3.1, 17.3.2, 17.4.2, 17.4.4, 17.6, CCP2.4.3, CCB DEEP, CCB NATURAL, CCB SLR, CWGB BIOECONOMY}

Transformation towards climate resilient development

TS.E.6 Accelerating climate change and trends in exposure and vulnerability underscore the need for rapid action on the range of transformational approaches to expand the future set of effective, feasible and just solutions (*very high confidence*). Transformation towards climate resilient development is advanced most effectively when actors work in inclusive and enabling ways to reconcile divergent interests, values and worldviews, building on information and knowledge on climate risk and adaptation options derived from different knowledge systems (*high confidence*). Taking action now provides the foundation for adaptation to current and future risks, for large-scale mitigation measures and for effective outcomes for both. (Figure TS.13) {2.6.7, 3.4.2, 3.4.3, 3.6.5, 7.2.1, 7.3.1, 8.3.3, 8.3.4, 8.4.5, Figure 8.12, 13.3.2, 13.4.2, 13.8, 13.10.2, 18.3.2, Box 18.1, Figure 18.1, Table 18.5, CCB FEASIB, CCB FINANCE, CCB ILLNESS, CCB NATURAL}

TS.E.6.1 Large-scale, transformational adaptation necessitates enabling improved approaches to governance and coordination across sectors and jurisdictions to avoid overwhelming current adaptive capacities and to avoid future maladaptive actions (*high confidence*). Response options in one sector can become response risks that exacerbate impacts in other sectors. A deliberate shift from primarily technological adaptation strategies to those that additionally incorporate behavioural and institutional changes, adaptation finance, equity and environmental justice and that align policy with global sustainability goals will facilitate transformational adaptation (*high confidence*). Application and efficacy testing of climate resilient development, or adaptation pathways, show promise for implementing transformational approaches (*medium confidence*), including expansion of ecosystem-based adaptation approaches. Climate information services that are demand driven and context specific, combined with climate change literacy, have the potential to improve adaptation responses (*high confidence*). {5.14.3, 9.4.5, 14.7.2, 14.6, 17.6}

TS.E.6.2 Climate resilient development pathways depend on how contending societal interests, values and worldviews are reconciled through inclusive and participatory interactions between governance actors in these arenas of engagement (*high confidence*). These interactions occur in many different arenas (e.g., governmental, economic and financial, political, knowledge, science and technology, community) that represent the settings, places and spaces in which societal actors interact to influence the nature and course of development. For instance, Agenda 2030 highlights the importance of multi-level adaptation governance, including non-state actors from civil society and the private sector. This implies the need for wider arenas of engagement for diverse actors to collectively solve problems and to unlock the synergies between adaptation and mitigation and sustainable development (*high confidence*). {18.4.3}

TS.E.6.3 Managing transition risk is a critical element of transforming society (*high confidence*). System transitions towards climate resilient development pose potential risks to sectors and regions. This implies managing climate risk in the

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event that greenhouse gas mitigation efforts over- or underperform. In addition, decision makers should be aware of the financial risks associated with stranded assets, technology risks and the risks to social equity or ecosystem health. By acknowledging, assessing and managing such risks, actors will have a greater likelihood of achieving success in making development climate resilient. Opportunities exist to promote synergies between sustainable development, adaptation and mitigation, but trade-offs are likely unavoidable, and managing trade-offs and synergies will be important (*high confidence*). Climate resilient development risks and opportunities vary by location with uncertainty about global mitigation effort and future climates relevant to local planning (*high confidence*). {4.7.6, 4.8, 17.4, 17.6, 18.4, 18.5}

TS.E.6.4 Prospects for transformation towards climate resilient development increase when key governance actors work together in inclusive and constructive ways to create a set of appropriate enabling conditions (*high confidence*). These enabling conditions include effective governance and information flow, policy frameworks that incentivise sustainability solutions, adequate financing for adaptation, mitigation and sustainable development, institutional capacity, science, technology and innovation, monitoring and evaluation of climate resilient development policies, programmes and practices and international cooperation. Investment in social and technological innovation could generate the knowledge and entrepreneurship needed to catalyse system transitions and their transfer. The implementation of policies that incentivise the deployment of low-carbon technologies and practices within specific sectors, such as energy, buildings and agriculture, could accelerate greenhouse gas mitigation and deployment of climate resilient infrastructure in both urban and rural areas. Civic engagement is an important element of building societal consensus and reducing barriers to action on adaptation, mitigation and sustainable development (*very high confidence*). {18.4}

Appendix TS.AI: List and Location of WGII AR6 Cross-Chapter Boxes (CCBs) and Cross-Working Group Boxes (CWGBs)

Host Chapter	CCB/CWGB Type/Acronym	CCB/CWGB Title
1	CCB CLIMATE	AR6 WGI Climate change Projections, Global Warming Levels and WGII Common Climate Dimensions
1	CCB PALEO	Observed Vulnerability and Adaptation to Past Climate Changes
1	CCB ADAPT	Adaptation Science
1	CWGB ATTRIB (WGI & WGII)	Attribution in the IPCC Sixth Assessment Report
2	CCB NATURAL	Nature-based Solutions for Climate Change Mitigation and Adaptation
2	CCB EXTREMES	Ramifications of Climatic Extremes for Marine, Terrestrial, Freshwater and Polar Natural Systems
2	CCB ILLNESS	Human Health, Biodiversity and Climate: Serious Risks Posed by Vector- and Water-borne Diseases
3	CCB SLR	Sea Level Rise
4	CCB DISASTER	Disasters as the Public Face of Climate Change
5	CCB MOVING PLATE	The Moving Plate: Sourcing Food When Species Distributions Change
5	CWGB BIOECONOMY (WGII & WGIII)	Mitigation and Adaptation via the Bioeconomy
6	CWGB URBAN (WGII & WGIII)	Cities and Climate Change in the Age of the Anthropocene
7	CCB COVID	COVID-19
7	CCB MIGRATE	Climate-related Migration
7	CCB HEALTH	Co-benefits of Climate Solutions for Human Health and Well-being
16	CCB INTEREG	Inter-regional Flows of Risks and Responses to Risk
16	CWGB SRM (WGII & WGIII)	Solar Radiation Modification
16	CWGB ECONOMIC (WGII & WGIII)	Estimating Global Economic Impacts from Climate Change and the Social Cost of Carbon
17	CCB LOSS	Loss and Damage
17	CCB DEEP	Effective Adaptation and Decision-making under Deep Uncertainties
17	CCB FINANCE	Finance for Adaptation and Resilience
17	CCB PROGRESS	Approaches and Challenges to Assess Adaptation Progress at the Global Level
18	CCB GENDER	Gender, Climate Justice and Transformative Pathways
18	CCB INDIG	The Role of Indigenous Knowledge and Local Knowledge in Understanding and Adapting to Climate Change
18	CCB FEASIB	Feasibility Assessment of Adaptation Options: an Update of SR1.5C

Appendix TS.AII: Aggregated Climate Risk Assessments in WGII AR6

This supplementary material presents the various aggregated risk assessments applied in the WGII AR6. This includes the key risks identified by all the chapters and the way they can be clustered into Representative Key Risks (RKRs) (Section TS.AII.1), with a summary of the severity conditions for these RKRs across climate and development pathways, and the interactions among these risks (Section TS.AII.2). The assessment of the five Reasons for Concern (RFC), presented in the iconic 'burning embers', provides a complementary cross-cutting impact and risk assessment. This approach is described in Section TS.AII.3, along with a comparison with the RKRs (Section TS.AII.4). The burning embers for the global and cross-cutting RFCs are complemented by similar depictions for specific regional and thematic concerns (Section SMTS2.1).

TS.AII.1 Key Risks and Representative Key Risks

Regional and sectoral chapters of this report identified 127 key risks that could become severe under particular conditions of climate hazards, exposure and vulnerability (Table SMTS.4). These key risks are assessed to be potentially severe, that is, relevant to the interpretation of dangerous anthropogenic interference (DAI) with the climate system, along levels for warming, exposure/vulnerability and adaptation. Severity has been assessed looking at the magnitude of adverse consequences, the likelihood of adverse consequences, the temporal characteristics of the risk and the ability to respond to the risks. Key risks cover scales from the local to the global, are especially prominent in particular regions or systems and are particularly large for vulnerable sub-groups, especially low-income populations, and already at-risk ecosystems (*high confidence*). {16.5, Table SM16.4}

These key risks can be represented in eight RKR clusters of key risks relating to low-lying coastal systems; terrestrial and ocean ecosystems; critical physical infrastructure, networks and services; living standards; human health; food security; water security; and peace and mobility (*high confidence*) (Table TS.AII.1). The assessment of these RKRs, which is presented in detail in Chapter 16, has also been used to organise the synthetic assessment of adaptation options in Chapter 17 and is integrated across various sections in the TS and SPM. {16.5, SM16.2.1, 17.2.1, 17.5.1}

TS.AII.2 Assessment of Severity Conditions for Representative Key Risks

Figure TS.AII.1 presents a synthesis of the severity conditions for RKRs by the end of this century. As an illustration of the more specific sets of conditions that result in severe risk for a particular RKR, Figure TS.AII.2 provides examples from individual studies of risks to living standards and the conditions under which they could become severe in terms of aggregate economic output, poverty and livelihoods.

The assessment of RKRs demonstrates that severe risk is rarely driven by a single determinant (warming, exposure/vulnerability, adaptation), but rather by a combination of conditions that jointly produce the level of pervasiveness of consequences, irreversibility, thresholds, cascading effects, likelihood of consequences, temporal characteristics of risk and systems' ability to respond (*medium* to *high confidence*). In other words, climate risk is not a matter of changing hazards (or climatic impact drivers) only but of the confrontation between changing hazards and changing socioecological conditions.

For most RKRs, potentially global and systemically pervasive risks become severe in the case of high levels of warming, combined with high exposure/vulnerability, low adaptation or both (*high confidence*). Under these conditions there would be severe and pervasive risks to critical infrastructure (*high confidence*), to human health from heat-related mortality, to low-lying coastal areas, aggregate economic output and livelihoods (all *medium confidence*) from armed conflict (*low confidence*) and to various aspects of food security (with different

Table TS.AII.1 | Climate-related representative key risks (RKRs). {16.5, Table 16.6}

Code	RKR	Scope	Sub-section assessment of RKR
RKR-A	Risk to low-lying coastal socioecological systems	Risks to ecosystem services, people, livelihoods and key infrastructure in low-lying coastal areas and associated with a wide range of hazards, including sea level change, ocean warming and acidification, weather extremes (storms, cyclones) and sea ice loss, for example	16.5.2.3.1
RKR-B	Risk to terrestrial and ocean ecosystems	Transformation of terrestrial and ocean/coastal ecosystems, including change in structure and/or functioning and/or loss of biodiversity	16.5.2.3.2
RKR-C	Risks associated with critical physical infrastructure, networks and services	Systemic risks due to extreme events leading to the breakdown of physical infrastructure and networks providing critical goods and services	16.5.2.3.3
RKR-D	Risk to living standards	Economic impacts across scales, including impacts on GDP, poverty and livelihoods, as well as the exacerbating effects of impacts on socioeconomic inequality between and within countries	16.5.2.3.4
RKR-E	Risk to human health	Human mortality and morbidity, including heat-related impacts and vector-borne and water-borne diseases	16.5.2.3.5
RKR-F	Risk to food security	Food insecurity and the breakdown of food systems due to climate change effects on land or ocean resources	16.5.2.3.6
RKR-G	Risk to water security	Risk from water-related hazards (floods and droughts) and water quality deterioration; focus on water scarcity, water-related disasters and risk to Indigenous and traditional cultures and ways of life	16.5.2.3.7
RKR-H	Risks to peace and to human mobility	Risks to peace within and among societies from armed conflict as well as risks to low-agency human mobility within and across state borders, including the potential for involuntarily immobile populations	16.5.2.3.8

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levels of confidence). Severe risks interact through cascading effects, potentially causing amplification of RKRs over the course of this century (*low evidence, high agreement*). (Figure TS.AII.1) {16.5.2, 16.5.4, Figure 16.10}

For some RKRs, potentially global and systemically pervasive risks would become severe even with medium to low warming (i.e., 1.5°C–2°C) if exposure/vulnerability is high and/or adaptation is low (*medium to high confidence*). Under these conditions there would be severe and pervasive risks associated with water scarcity and water-related disasters (*high confidence*), poverty, involuntary mobility and insular ecosystems and biodiversity hotspots (all *medium confidence*). {16.5.2}

All potentially severe risks that apply to particular sectors or groups of people at more specific regional and local levels require high exposure/vulnerability or low adaptation (or both), but they do not necessarily require high warming (*high confidence*). Under these conditions there would be severe, specific risks to low-lying coastal systems, to people and economies from critical infrastructure disruption, to economic output in developing countries and to livelihoods in climate-sensitive sectors from water-borne diseases, especially in children in low- and middle-income countries, water-related impacts on traditional ways of life and involuntary mobility, for example in small islands and low-lying coastal areas (*medium to high confidence*). {16.5.2}

Some severe impacts are already occurring (*high confidence*) and will occur in many more systems before mid-century (*medium confidence*). Tropical and polar low-lying coastal human communities are experiencing severe impacts today (*high confidence*), and abrupt ecological changes resulting from mass population-level mortality are already being observed following climate extreme events. Some systems will experience severe risks before the end of the century (*medium confidence*), for example critical infrastructure affected by extreme events (*medium confidence*). Food security for millions of people, particularly low-income populations, also faces significant risks with moderate to high warming or high vulnerability, with a growing challenge by 2050 in terms of providing nutritious and affordable diets (*high confidence*). {16.5.2, 16.5.3}

In specific systems already marked by high exposure and vulnerability, intensive adaptation efforts will not be sufficient to prevent severe risks from occurring under high levels of warming (*low evidence, medium agreement*). This is particularly the case for some ecosystems and water-related risks (from water scarcity and to Indigenous and traditional cultures and ways of life). {16.5.2, 16.5.3}

Key risks increase the challenges in achieving global sustainability goals (*high confidence*). The greatest challenges will be from risks to water (RKR-G), living standards (RKR-D), coastal socioecological systems (RKR-A) and peace and human mobility (RKR-H). The most relevant goals are zero hunger (SDG 2), sustainable cities and communities (SDG 11), life below water (SDG 14), decent work and economic growth (SDG 8), and no poverty (SDG 1). Priority areas for regions are indicated by the intersection of hazards, risks and challenges, where, in the near term, challenges to SDGs indicate probable systemic vulnerabilities and issues in responding to climatic hazards (*high confidence*). {16.6.1}

Multiple feedbacks between individual risks exist that have the potential to create cascades and then to amplify systemic risks and impacts far beyond the level of individual RKRs (*medium confidence*), as also reflected in TS.C.11. These are illustrated in Figure TS.AII.3, panel A at the RKR level, and in Figure TS.AII.3, panel B at the key risk level.

TS.AII.3 Framework and Approach for Assessment of Burning Embers for Reasons for Concern

The RFC framework communicates scientific understanding about accrual of risk in relation to varying levels of warming for five broad categories: risk associated with (a) unique and threatened systems, (b) extreme weather events, (c) distribution of impacts, (d) global aggregate impacts and (e) large-scale singular events. The RFC framework was first developed during the Third Assessment Report along with a visual representation of these risks as 'burning embers' figures, and this assessment framework has been further developed and updated in subsequent IPCC reports including AR5. RFCs reflect risks aggregated globally that together inform the interpretation of dangerous anthropogenic interference with the climate system. (Figure TS.AII.1) {16.6.2}

The risk transition or 'ember' diagram illustrates the progression of socioecological risk from climate change as a function of global temperature change, taking into account the exposure and vulnerability of people and ecosystems, as assessed by literature-based expert judgement. The definitions of risk levels used to make the expert judgements are presented in Table TS.AII.2 {16.6.2}. Further details are provided in Section 16.6.3. (Figure TS.4)

TS.AII.4 Relationship between Representative Key Risks and Reasons for Concern

The RKRs and RFCs are complementary methods that aggregate individual risks in different ways, as displayed in Figure TS.AII.4. They have differences in scale, transitions, timing and treatment of vulnerability and adaptation {16.6.2}

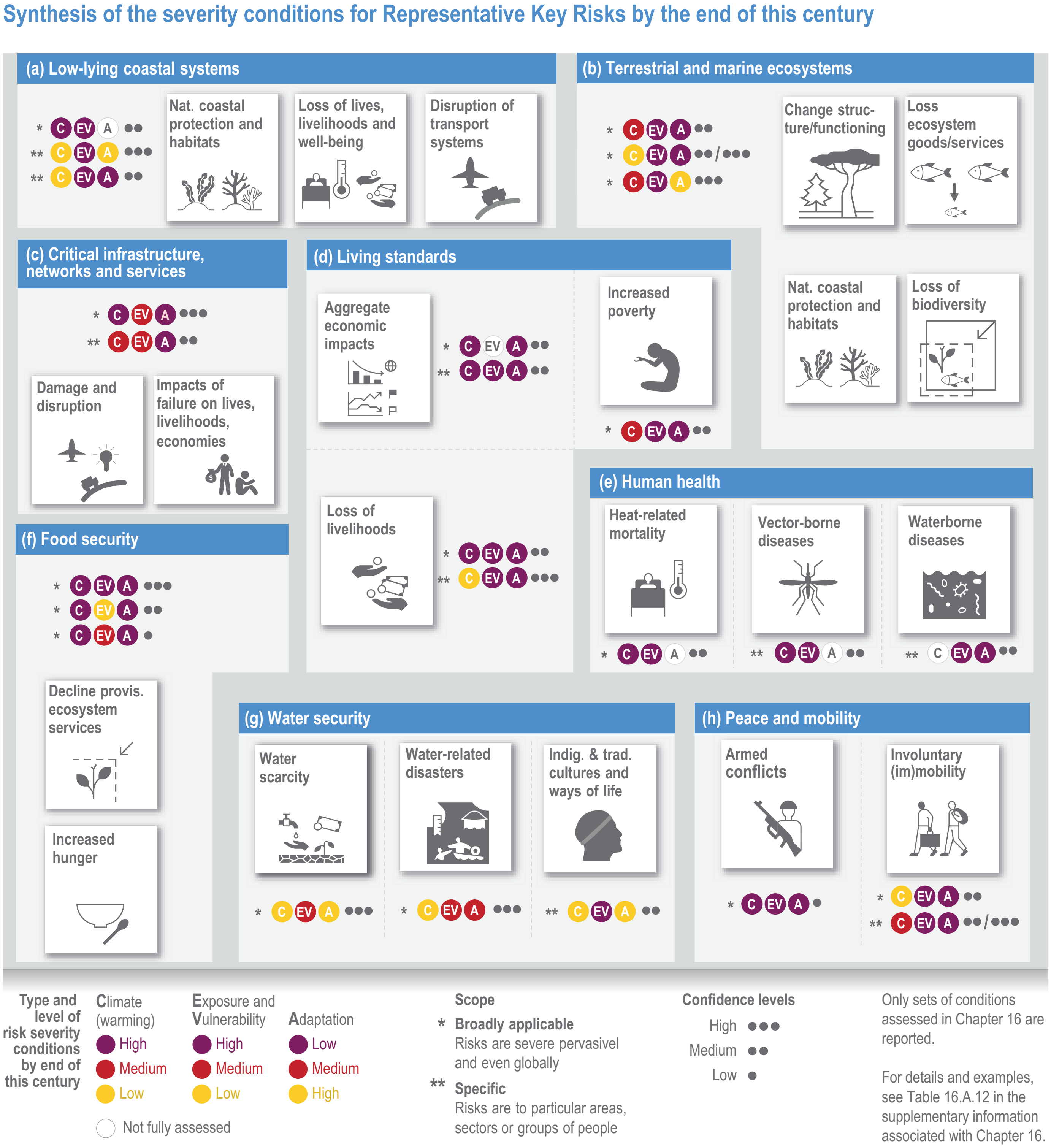
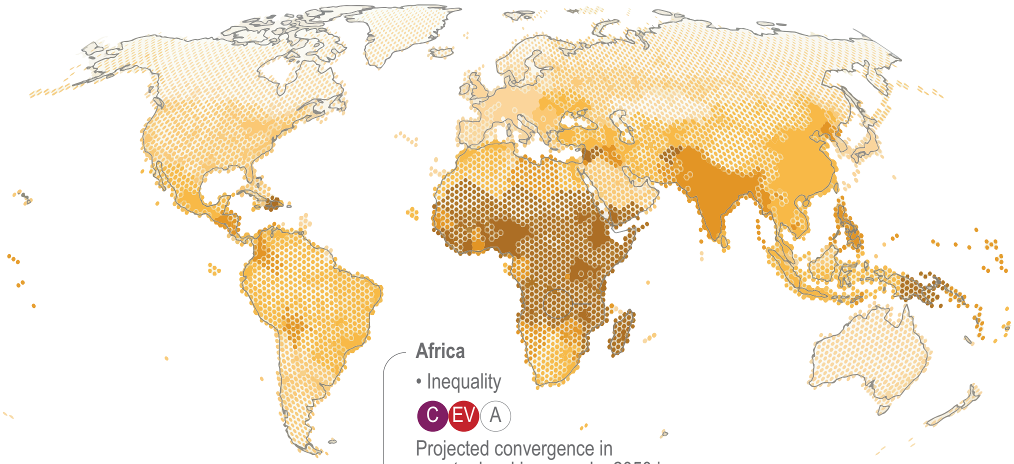


Figure TS.AII.1 | Synthesis of the severity conditions for Representative Key Risks (RKRs) by the end of this century. The figure does not aim to describe severity conditions exhaustively for each RKR, but rather to illustrate the risks highlighted in this report (Sections 16.5.2.3.1 to 16.5.2.3.8). Coloured circles represent the levels of warming (climate), exposure/vulnerability and adaptation that would lead to severe risks for particular key risks and RKRs. Each set of three circles represents a combination of conditions that would lead to severe risk with a particular level of confidence, indicated by the number of black dots to the right of the set, and for a particular scope, indicated by the number of stars to the left of the set. The two scopes are 'broadly applicable', meaning applicable pervasively and even globally, and 'specific', meaning applicable to particular areas, sectors or groups of people. Details of confidence levels and scopes can be found in Section 16.5.2.3. In terms of severity condition levels (Section 16.5.2.3), for warming levels (coloured circles labelled 'C' in the figure), high refers to climate outcomes consistent with RCP8.5 or higher, low refers to climate outcomes consistent with RCP2.6 or lower, and medium refers to intermediary climate scenarios. Exposure-vulnerability levels are determined relative to the range of future conditions considered in the literature. For adaptation, high refers to near maximum potential and low refers to the continuation of today's trends. Despite being intertwined in reality, exposure-vulnerability and adaptation conditions are distinguished to help understand their respective contributions to risk severity. {Figure 16.10}

TS

Illustrative examples from individual studies of risks to living standards and the conditions under which they could become severe



World

• Aggregate GDP

C EV A

Global GDP losses of 10–23% by 2100 due to temperature impacts alone (**3; 12; 13**)

• Poverty

C EV A

35–132 million people pushed to extreme poverty by 2030 (**6; 10**)

• Livelihoods

C EV A

330–396 million people could be exposed to lower agricultural yields and associated livelihood impacts (**4**)

Arctic Regions

Livelihoods

C EV A

Populations dependent on hunting and fishing face severe livelihood, cultural, and economic risks (**14**)

United States of America

• Inequality

C EV A

Economic damages as share of income in 2100 are 9 times larger in the poorest 5% of counties than in the richest 5% (**5; 9**)

Latin American and the Caribbean

• Poverty

C EV A

5.8 million people pushed to extreme poverty by 2030 (**7; 11**)

Developing Countries

• Aggregate GDP

C EV A

9% average loss in GDP by 2100 (**1**)

Tropics and Coastal Regions

• Livelihoods

C EV A

Climate-sensitive livelihoods, such as agriculture and fisheries, would be severely impacted (**8; 15**)

Africa

• Inequality

C EV A

Projected convergence in country-level incomes by 2050 is delayed by 10 years (**2**)

Sub-Saharan Africa

• Aggregate GDP

C EV A

GDP losses of 10–15% by 2050 (**2**)

C EV A

GDP losses of 80% by 2100 (**3**)

• Livelihoods

C EV A

62% of the population are currently employed in climate-sensitive agricultural sector (**16**)

• Poverty

C EV A

39.7 million people pushed to extreme poverty by 2030 (**7; 11**)

East Asia and Pacific

• Poverty

C EV A

7.5 million people pushed to extreme poverty by 2030 (**7; 11**)

South Asia

• Poverty

C EV A

35.7 million people pushed to extreme poverty by 2030 (**7; 11**)

• Livelihoods

C EV A

40% of the population are currently employed in climate-sensitive agricultural sector (**16**)

References:
1. Acevedo (2017); **2.** Baarsch et al. (2020); **3.** Burke et al. (2015); **4.** Byers et al. (2018); **5.** Carleton and Greenstone (2021); **6.** Hallegatte (2017); **7.** Hallegatte and Rozenberg (2017); **8.** Hoegh-Guldberg (2018); **9.** Hsiang et al. (2017); **10.** Jafino (2020); **11.** Jafino et al. (2020); **12.** Kahn (2019); **13.** Kalkuhl (2020); **14.** Norden (2014); **15.** Roy (2018); **16.** World Bank (2020)

Human vulnerability: Very high – Very low

Population density: High – Low

Type and level of risk severity conditions

Climate (warming)	Exposure and Vulnerability	Adaptation
High	High	Low
Medium	Medium	Medium
Low	Low	High

Not fully assessed

Figure TS.AII.2 | Illustrative examples from individual studies of risks to living standards and the conditions under which they could become severe in terms of aggregate economic output, poverty and livelihoods. High, medium and low levels of warming, exposure/vulnerability and adaptation are defined as in Figure TS.AII.1. {Figure 16.9}

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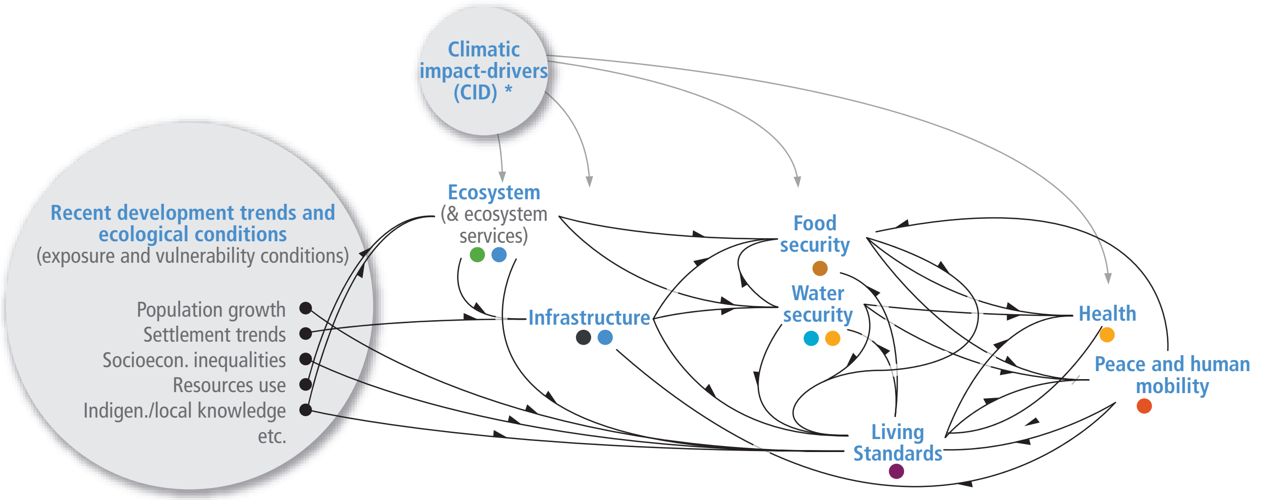
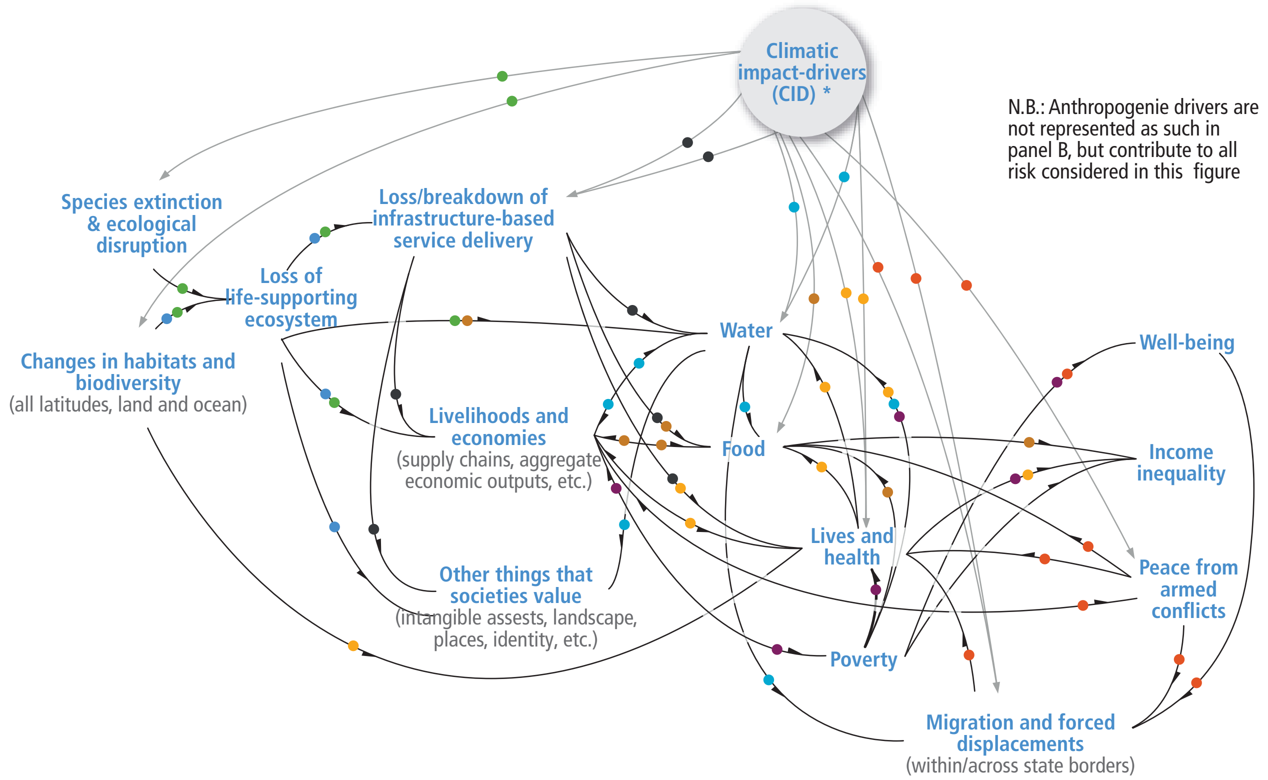
Illustration of some connections across key risks

(a) Interactions across the eight Representative Key Risk level



(b) Illustration of interactions at the Key Risk level (e.g. from ecological risk to key dimensions for human societies)



* CIDs are physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems. Indiced changes are system-dependent and can be detrimenlal, beneficial, neutral, or a mixture of each. {WGI AR6 SPM}

Risk cascades **

- **Across key risks**
- **Climate-driven**

Representative Key Risks

- A (Low-lying coasts)
- B (Ecosystems)
- C (Infrastructure)
- D (Living standards)
- E (Human health)
- F (Food security)
- G (Water security)
- H (Peace and human mobility)

** As illustrative suggested rather across than RKR comprehensive, assessments; and qualitative rather than quantitative

Figure TS.AII.3 | Illustration of some connections across key risks. Panel A describes all the cross-RKR risk cascades that are described in RKR assessments (Sections 16.5.2.3.2 to 16.5.2.3.9). Panel B provides an illustration of such interactions at the key risk level, for example from ecological risk to key dimensions for human societies (building on Section 16.5.2.2 and Table 16.A.4). The arrows are representative of interactions as qualitatively identified; they do not result from any quantitative modelling exercise. {Figure 16.11}

Table TS.AII.4 | Definition of risk levels for reasons for concern. {Table 16.7}

Level	Definition
Undetectable (white)	No associated impacts are detectable and attributable to climate change
Moderate (yellow)	Associated impacts are both detectable and attributable to climate change with at least *medium confidence*, also accounting for the other specific criteria for key risks
High (red)	Severe and widespread impacts that are judged to be high on one or more criteria for assessing key risks
Very high (purple)	Very high risk of severe impacts and the presence of significant irreversibility or the persistence of climate-related hazards, combined with limited ability to adapt due to the nature of the hazard or impacts/risks

Interconnections between the Key Risks, Representative Key Risks and the Reasons for Concern

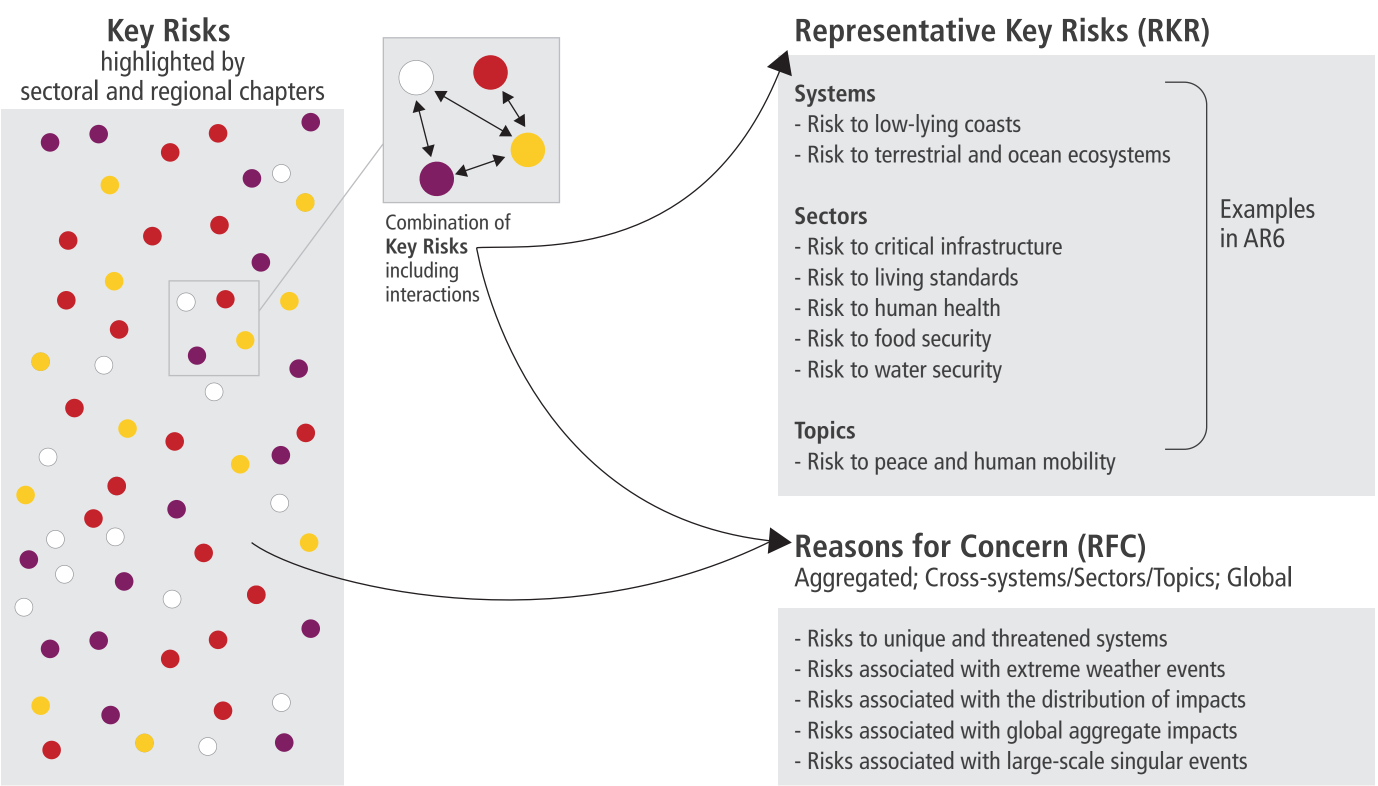


Figure TS.AII.4 | Interconnections among key risks, representative key risks and reasons for concern {Figure 16.13}

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