INTERGOVERNMENTAL PANEL ON climate change

Climate Change 2022

Impacts, Adaptation and Vulnerability

Summary for Policymakers, Technical Summary and Frequently Asked Questions

WGII

Working Group II contribution to the
Sixth Assessment Report of the
Intergovernmental Panel on Climate Change

WMO UNEP

Climate Change 2022:
Impacts, Adaptation and Vulnerability

Summary for Policymakers

A report of Working Group II of the IPCC

Technical Summary

From the report accepted by Working Group II of the IPCC but not approved in detail

and

Frequently Asked Questions

Part of the Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change

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Foreword, Preface and Dedication

Foreword

'*Climate Change 2022: Impacts, Adaptation and Vulnerability*', the Working Group II contribution to the Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report presents a comprehensive assessment of the current state of knowledge of the observed impacts and projected risks of climate change as well as the adaptation options. The report confirms the strong interactions of the natural, social and climate systems and that human-induced climate change has caused widespread adverse impacts to nature and people. It is clear that across sectors and regions, the most vulnerable people and systems are disproportionately affected and climate extremes have led to irreversible impacts. The assessment underscores the importance of limiting global warming to 1.5°C if we are to achieve a fair, equitable and sustainable world. While the assessment concluded that there are feasible and effective adaptation options which can reduce risks to nature and people, it also found that there are limits to adaptation and that there is a need for increased ambition in both adaptation and mitigation. These and other findings confirm and enhance our understanding of the importance of climate-resilient development across sectors and regions and, as such, demands the urgent attention of both policymakers and the general public.

As an intergovernmental body jointly established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), the IPCC has provided policymakers with the most authoritative and objective scientific and technical assessments. Beginning in 1990, this series of IPCC Assessment Reports, Special Reports, Technical Papers, Methodology Reports and other products have become standard works of reference.

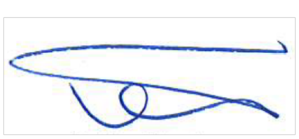
This Working Group II contribution to the IPCC's Sixth Assessment Report contains important new scientific, technical and socio-economic knowledge that can be used to produce information and services for assisting society to act to address the challenges of climate change. The timing is particularly significant, as this information provides a new impetus, through clear assessment findings, to inform the first Global Stocktake under the United Nations Framework Convention on Climate Change.

This Working Group II assessment was made possible thanks to the commitment and dedication of many hundreds of experts worldwide, representing a wide range of disciplines. WMO and UNEP are proud that so many of the experts belong to their communities and networks. We express our deep gratitude to all authors, review editors and expert reviewers for devoting their knowledge, expertise and time especially given the challenges created by the Covid pandemic. We would like to thank the staff of the Working Group II Technical Support Unit, the WGII Science Advisor and the IPCC Secretariat for their dedication.

We are also grateful to the governments that supported their scientists' participation in developing this report and that contributed to the IPCC Trust Fund to provide for the essential participation of experts from developing countries and countries with economies in transition. We would like to express our appreciation to the government of Ethiopia for hosting the scoping meeting for the IPCC's Sixth Assessment Report, to the governments of South Africa, Nepal, Portugal and Guatemala for hosting drafting meetings of the Working Group II contribution and to the government of Germany for hosting the Twelfth Session of Working Group II held virtually for approval of the Working Group II Report. The generous financial support by the government of Germany and the logistical support by the Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research (Germany), enabled the smooth operation of the Working Group II Technical Support Unit in Bremen, Germany. Additional funding from the Governments of Germany, Norway and New Zealand provided key support to the Technical Support Unit office in Durban, South Africa.

We would particularly like to thank Dr Hoesung Lee, Chairman of the IPCC, for his direction of the IPCC and we express our deep gratitude to Dr Hans-Otto Pörtner and Dr Debra Roberts, the Co-Chairs of Working Group II for their tireless leadership throughout the development and production of this report.

Climate change is a long-term challenge, but the need for urgent action now is clear. The conclusion of the report's Summary for Policymakers summarizes this succinctly. 'The cumulative scientific evidence is unequivocal: climate change is a threat to human well-being and planetary health. Any further delay in concerted anticipatory global action on adaptation and mitigation will miss a brief and rapidly closing window of opportunity to secure a livable and sustainable future for all.' We couldn't agree more.



Petteri Taalas
Secretary-General
World Meteorological Organization

Inger Andersen
Executive Director
United Nations Environment Programme

Preface

The Working Group II contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) provides a comprehensive assessment of the scientific, technical and socio-economic literature relevant to impacts, adaptation and vulnerability. It builds upon the Working Group II contribution to the IPCC's Fifth Assessment Report, the three Special Reports of the Sixth Assessment cycle: 'Global Warming of 1.5°C. 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 (SR1.5)'; 'Climate Change and Land: An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (SRCCL)'; 'IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC)', and the Working Group I contribution to the IPCC Sixth Assessment Report.

The report recognizes the interactions of climate, ecosystems and biodiversity, and human societies, and integrates knowledge more strongly across the natural, ecological, social and economic sciences than earlier IPCC assessments. The assessment of climate change impacts and risks as well as adaptation is set against concurrently unfolding non-climatic global trends e.g., biodiversity loss, overall unsustainable consumption of natural resources, land and ecosystem degradation, rapid urbanisation, human demographic shifts, social and economic inequalities and a pandemic.

Working Group II introduces several new components in its latest report: These include the novel cross-chapter papers which provide focused assessments and updates from the special reports and include coverage of topics such as biodiversity hotspots, cities and settlements by the sea, deserts and desertification, mountains, tropical forests as well as the Mediterranean and polar regions. Another new component is an atlas that presents data and findings on observed climate change impacts and projected risks from global to regional scales, thus offering even more insights for decision makers. The Working Group II Report is based on the published scientific and technical literature accepted for publication by 1 September 2021.

Scope of the Report

During the process of scoping and approving the outline of its Sixth Assessment Report, the IPCC focussed on those aspects of the current knowledge of climate change that were judged to be most relevant to policymakers. In this report, Working Group II examines the impacts of climate change on nature and people around the globe. It explores future impacts at different levels of warming and the resulting risks, and offers options to strengthen nature's and society's resilience to ongoing climate change, to fight hunger, poverty, and inequality and keep Earth a place worth living on – for current as well as for future generations.

Structure of the Report

This report consists of a short Summary for Policymakers, a Technical Summary, eighteen Chapters, seven Cross-Chapter Papers, five Annexes including the Global to Regional Atlas, as well as online Supplementary Material.

The introductory chapter (Chapter 1) provides the reader with the framing and context of the report and highlights key concepts used throughout the report.

The sectoral chapters (Chapters 2–8) cover risks, adaptation and sustainability for systems impacted by climate change. They assess impacts, risks, adaptation options and limits and the interactions of risks and responses for climate resilient development for ecosystems, water, food, cities, human health, communities and livelihoods.

The regional chapters (Chapters 9–15) assess the observed impacts and projected risks at regional and sub-regional levels for Africa, Asia, Australasia, Central and South America, Europe, North America and Small Islands. They assess adaptation options including limits, barriers and adaptive capacity, as well as the interaction of risks and responses for climate-resilient development.

The Cross-Chapter Papers (1–7) consider additional regionalisation's including polar regions, tropical forests, deserts, mountains and the Mediterranean, as well as highlighting the topics of biodiversity hotspots and cities by the sea. The cross-chapter papers assess observed impacts and projected risks of climate change, vulnerability, adaptation options and, where applicable, climate resilient development.

The synthesis chapters (Chapters 16–18) address sustainable development pathways integrating adaptation and mitigation. They assess key risks across sectors and regions (Chapter 16) and decision-making options for managing risk (Chapter 17) and the ways climate impacts and risks hinder climate resilient development in different sectoral and regional contexts as well as the pathways to achieving climate resilient development (Chapter 18).

The Process

This Working Group II contribution to the IPCC Sixth Assessment Report represents the combined efforts of hundreds of experts in the scientific, technological and socio-economic fields of climate science and has been prepared in accordance with rules and procedures established by the IPCC. A scoping meeting for the Sixth Assessment Report was held in May 2017 and the outlines for the contributions of the three Working Groups were approved at the 46th Session of the Panel in September 2017. Governments and IPCC observer organisations nominated experts for the author team. The team of 231 Coordinating Lead Authors and Lead Authors plus 39 Review Editors selected by the Working Group II Bureau was accepted at the 55th

Session of the IPCC Bureau in January 2018. In addition, more than 675 Contributing Authors provided draft text and information to the author teams at their request. Drafts prepared by the authors were subject to two rounds of formal review and revision followed by a final round of government comments on the Summary for Policymakers. A total of 62,418 written review comments were submitted by more than 1600 individual expert reviewers and 51 governments. The Review Editors for each chapter monitored the review process to ensure that all substantive review comments received appropriate consideration. The Summary for Policymakers was approved line-by-line and the underlying report was then accepted at the 12th Session of IPCC Working Group II from 14 to 27 February 2022.

Acknowledgements

We express our deepest appreciation for the expertise and commitment shown by the Coordinating Lead Authors and Lead Authors throughout the process. They were ably helped by the many Contributing Authors who supported the drafting or the report. The Review Editors were critical in assisting the author teams and ensuring the integrity of the review process. We are grateful to the Chapter Scientists who supported the chapter and cross-chapter paper teams in the delivery of the report. We would also like to thank all the expert and government reviewers who submitted comments on the drafts.

The production of the report was guided by members of the Working Group II Bureau. We would like to thank our colleagues who supported and advised us in the development of the report: Working Group II Vice-Chairs Andreas Fischlin, Mark Howden, Carlos Méndez, Joy Jacqueline Pereira, Roberto A. Sánchez-Rodríguez, Sergey Semenov, Pius Yanda, and Taha M. Zatari. Our appreciation also goes to Ko Barrett, Thelma Krug, and Youba Sokona, Vice Chairs of IPCC, who ably supported us during the planning process and approval.

Our sincere thanks go to the hosts and organizers of the Scoping Meeting, the four Lead Author Meetings, and the Working Group II Session. We gratefully acknowledge the support from the United Nations Economic Commission for Africa; the Government of South Africa and the Department of Forestry, Fisheries and the Environment; the Government of Nepal and the International Centre for Integrated Mountain Development; the Government of Portugal, the Center for Marine Sciences, and the University of Algarve; the Government of Guatemala and the Ministry of Environment and Natural Resources; and the Government of Germany. We also note with appreciation the additional support for inclusivity training provided by the International Centre for Integrated Mountain Development. The support provided by many governments as well as through the IPCC Trust Fund for the many experts participating in the process is also noted with appreciation.

The staff of the IPCC Secretariat based in Geneva provided a wide range of support for which we would like to thank Abdalah Mokssit, Secretary of the IPCC, Deputy Secretaries, Ermira Fida and Kerstin Stendahl, and their colleagues Jesbin Baidya, Laura Biagioni, Annie Courtin, Oksana Ekzarkho, Judith Ewa, Joelle Fernandez, Jennifer Lew Schneider, Jonathan Lynn, Andrej Mahecic, Nina Peeva, Sophie Schlingemann, Mxolisi Shongwe, Melissa Walsh, and Werani Zabula.

The report production was managed by the Technical Support Unit of IPCC Working Group II, through the generous financial support of the German Federal Ministry for Education and Research and the Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research. Additional funding from the Governments of Germany, Norway and New Zealand supports the Working Group II Technical Support Unit office in Durban, South Africa. Without the support of all these bodies this report would not have been possible.

This Report could not have been prepared without the dedication, commitment, and professionalism of the members of the Working Group II Technical Support Unit and Science Advisor: Melinda Tignor, Elvira Poloczanska, Katja Mintenbeck, Andrés Alegría, Marlies Craig, Sandra Götze, Tijama Kersher, Stefanie Langsdorf, Sina Löschke, Philisiwe Manqele, Vincent Möller, Anka Mühle, Komila Nabiyeva, Almut Niebuhr, Andrew Okem, Esté Prentzler, Bardhyl Rama, Jussi Savolainen, and Stefan Weisfeld. Additional contributions from Daniel Belling, Wolfgang Dieck, Bastian Maus, Maike Nicolai, Jan Petzold, Hanna Scheuffele, and Nora Weyer are recalled with appreciation. The support provided by Nina Hunter and Michelle North is also recognized.

Our warmest thanks go to the collegial and collaborative support provided by Working Group I and Working Group III Co-Chairs, Vice-Chairs and Technical Support Units. In addition, the following contributions are gratefully acknowledged: le-tex publishing services GmbH (copyedit and layout), Marilyn Anderson (index).

And a final, special thank you to the colleagues, family and friends who supported us through the many long hours and days spent at home and away from home while producing this report.

DEBRA ROBERTS

Hans-Otto Pörtner
IPCC Working Group II Co-Chair

Debra C. Roberts
IPCC Working Group II Co-Chair

Dedication

Bob (Robert) Scholes
(28 October 1957 – 28 April 2021)

The chapter on Africa of the Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), is dedicated to the memory of Bob Scholes who was one of the Review Editors for the chapter.

Bob, one of the world's leading climate change scientists, was a Professor of Systems Ecology, a Director of the Global Change Institute and a Distinguished Professor at the University of the Witwatersrand in Johannesburg, South Africa. Known for his towering intellect and insatiable curiosity, Bob published widely in the fields of savanna ecology, earth observation and global change. As a well-respected member of the global research community he played a major role in the IPCC as a Lead Author and Co-ordinating Lead Author during the third, fourth and fifth assessment cycles and as Co-Chair of the IPBES Land Degradation and Ecosystem Assessment. He was also a leading figure in African scientific circles and undertook multidisciplinary research to support policy development, risk assessment and development planning in South Africa and on the continent.

Bob was acutely aware of the need to build a more equitable and just society and was always generous with his knowledge and wisdom. He will be remembered as a remarkable role model, inspirational teacher and a thoughtful mentor to both students and colleagues. He was a son of African soil and dedicated much of his life to preserving Africa's natural heritage for future generations. But he was also at home anywhere on Earth – truly a person of the planet. Bob lived life to its fullest, as was evident in his love of gourmet cooking.

Bob's loss is felt deeply by all who knew him, and he will be remembered as a multi-talented and passionate scientist who motivated everyone to avoid complacency, think critically and to use their knowledge to improve the world.

Hamba kahle Bob.

Rebecca Mary Bernadette Harris
(01 August 1969 – 24 December 2021)

Chapter 2, 'Terrestrial and freshwater ecosystems and their services', and Cross-Chapter Paper 3, 'Deserts, semi-arid areas and desertification' of the Working Group II contribution to the IPCC Sixth Assessment Report are dedicated to the memory of Rebecca Harris, who was one of the Lead Authors.

Bec was the Director of the Climate Futures Program at the University of Tasmania. This award-winning team is globally recognised for its impacts and adaptation work including for the skiing and wine industries, biosecurity threats to agriculture, and what climate change meant for Tasmanian fire management. Bec helped both government and industry partners better assess their exposure to climate risk, and develop adaptation solutions. A highlight is the work that she launched in 2020: *Australia's Wine Future: A Climate Atlas*. Bec oversaw this multidisciplinary climate modelling and adaptation project (2016-2020) involving 15 researchers from six organisations, bringing national recognition to her work.

Prior to starting her PhD studies relatively late in life, Bec worked in invertebrate and botanical biodiversity assessment, island biogeography and disturbance ecology. In the short decade-long research career, Bec authored 66 publications, won numerous research contracts and consultancy projects and in 2016 was awarded a prestigious Humboldt Fellowship.

Bec also supervised many honours and PhD students over the last decade and was a mentor and sponsor for many early career researchers. She was particularly passionate about supporting women in science. She was an inspiring lecturer and was also committed to enhancing community climate literacy as an avenue for making change. She had a talent for translating the complex science work she undertook for non-expert audiences in a way that was clear and impactful.

As a researcher and scholar, Bec is an exemplar, and she will be very sorely missed.

Summary for Policymakers

SPM

Summary for Policymakers

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SPM

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A: Introduction

This Summary for Policymakers (SPM) presents key findings of the Working Group II (WGII) contribution to the Sixth Assessment Report (AR6) of the IPCC[1]. The report builds on the WGII contribution to the Fifth Assessment Report (AR5) of the IPCC, three Special Reports[2], and the Working Group I (WGI) contribution to the AR6 cycle.

This report recognizes the interdependence of climate, ecosystems and biodiversity[3], and human societies (Figure SPM.1) and integrates knowledge more strongly across the natural, ecological, social and economic sciences than earlier IPCC assessments. The assessment of climate change impacts and risks as well as adaptation is set against concurrently unfolding non-climatic global trends e.g., biodiversity loss, overall unsustainable consumption of natural resources, land and ecosystem degradation, rapid urbanisation, human demographic shifts, social and economic inequalities and a pandemic.

The scientific evidence for each key finding is found in the 18 chapters of the underlying report and in the 7 cross-chapter papers as well as the integrated synthesis presented in the Technical Summary (hereafter TS) and referred to in curly brackets {}. Based on scientific understanding, key findings can be formulated as statements of fact or associated with an assessed level of confidence using the IPCC calibrated language[4]. The WGII Global to Regional Atlas (Annex I) facilitates exploration of key synthesis findings across the WGII regions.

The concept of risk is central to all three AR6 Working Groups. A risk framing and the concepts of adaptation, vulnerability, exposure, resilience, equity and justice, and transformation provide alternative, overlapping, complementary, and widely used entry points to the literature assessed in this WGII report.

Across all three AR6 working groups, **risk**[5] provides a framework for understanding the increasingly severe, interconnected and often irreversible impacts of climate change on ecosystems, biodiversity, and human systems; differing impacts across regions, sectors and communities; and how to best reduce adverse consequences for current and future generations. In the context of climate change, risk can arise from the dynamic interactions among climate-related **hazards**[6] (see Working Group I), the **exposure**[7] and **vulnerability**[8] of affected human and ecological systems. The risk that can be introduced by human responses to climate change is a new aspect considered in the risk concept. This report identifies 127 key risks[9]. {1.3, 16.5}

The vulnerability of exposed human and natural systems is a component of risk, but also, independently, an important focus in the literature. Approaches to analysing and assessing vulnerability have evolved since previous IPCC assessments. Vulnerability is widely understood to differ within communities and across societies, regions and countries, also changing through time.

Adaptation[10] plays a key role in reducing exposure and vulnerability to climate change. Adaptation in ecological systems includes autonomous adjustments through ecological and evolutionary processes. In human systems, adaptation can be anticipatory or reactive, as well as incremental

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1 Decision IPCC/XLVI-3, The assessment covers scientific literature accepted for publication by 1 September 2021.

2 The three Special Reports are: 'Global Warming of 1.5°C. 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 (SR1.5)'; 'Climate Change and Land. An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (SRCCL)'; 'IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC)'.

3 Biodiversity: Biodiversity or biological diversity means the variability among living organisms from all sources including, among other things, terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems.

4 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, e.g., *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, e.g., *very likely*. This is consistent with AR5 and the other AR6 Reports.

5 Risk is defined as the potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems.

6 Hazard is defined as the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources. Physical climate conditions that may be associated with hazards are assessed in Working Group I as climatic impact-drivers.

7 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.

8 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.

9 Key risks have potentially severe adverse consequences for humans and social-ecological systems resulting from the interaction of climate related hazards with vulnerabilities of societies and systems exposed.

10 Adaptation is defined, in human systems, as the process of adjustment to actual or expected climate and its effects in order to moderate harm or take advantage of beneficial opportunities. In natural systems, adaptation is the process of adjustment to actual climate and its effects; human intervention may facilitate this.

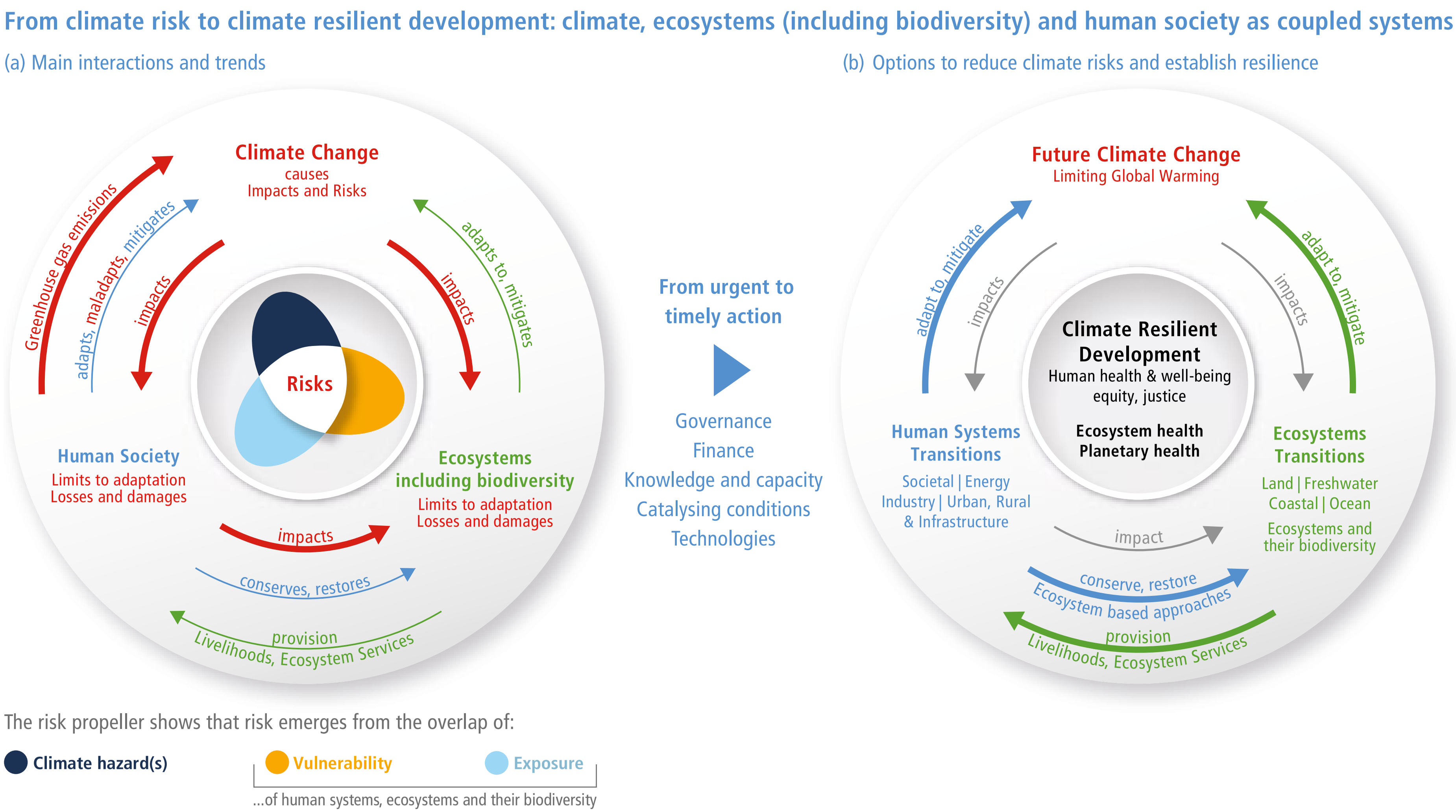

Figure SPM.1 | This report has a strong focus on the interactions among the coupled systems climate, ecosystems (including their biodiversity) and human society. These interactions are the basis of emerging risks from climate change, ecosystem degradation and biodiversity loss and, at the same time, 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 D). 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, Figure TS. 2} and/ or transformational. The latter changes the fundamental attributes of a social-ecological system in anticipation of climate change and its impacts. Adaptation is subject to hard and soft limits[11].

Resilience[12] in the literature has a wide range of meanings. Adaptation is often organized around resilience as bouncing back and returning to a previous state after a disturbance. More broadly the term describes not just the ability to maintain essential function, identity and structure, but also the capacity for transformation.

This report recognises the value of diverse forms of knowledge such as scientific, as well as Indigenous knowledge and local knowledge in understanding and evaluating climate adaptation processes and actions to reduce risks from human-induced climate change. AR6 highlights adaptation solutions which are effective, feasible[13], and conform to principles of justice[14]. The term climate justice, while used in different ways in different contexts by different communities, generally includes three principles: *distributive justice* which refers to the allocation of burdens and benefits among individuals, nations and generations; *procedural justice* which refers to who decides and participates in decision-making; and *recognition* which entails basic respect and robust engagement with and fair consideration of diverse cultures and perspectives.

Effectiveness refers to the extent to which an action reduces vulnerability and climate-related risk, increases resilience, and avoids maladaptation[15].

This report has a particular focus on transformation[16] and system transitions in energy; land, ocean, coastal and freshwater ecosystems; urban, rural and infrastructure; and industry and society. These transitions make possible the adaptation required for high levels of human health and well-being, economic and social resilience, ecosystem health[17], and planetary health[18] (Figure SPM.1). These system transitions are also important for achieving the low global warming levels (Working Group III) that would avoid many limits to adaptation[11]. The report also assesses economic and non-economic losses and damages[19]. This report labels the process of implementing mitigation and adaptation together in support of sustainable development for all as climate resilient development[20].

Box SPM.1 | AR6 Common 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)[21] and Shared Socioeconomic Pathways (SSPs)[22] scenarios, respectively[23]. 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

11 Adaptation limits: The point at which an actor's objectives (or system needs) cannot be secured from intolerable risks through adaptive actions.
Hard adaptation limit—No adaptive actions are possible to avoid intolerable risks.
Soft adaptation limit—Options may exist but are currently not available to avoid intolerable risks through adaptive action.

12 Resilience in this report is defined as the capacity of social, economic and ecosystems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure as well as biodiversity in case of ecosystems while also maintaining the capacity for adaptation, learning and transformation. Resilience is a positive attribute when it maintains such a capacity for adaptation, learning, and/or transformation.

13 Feasibility refers to the potential for an adaptation option to be implemented.

14 Justice is concerned with setting out the moral or legal principles of fairness and equity in the way people are treated, often based on the ethics and values of society. *Social justice* comprises just or fair relations within society that seek to address the distribution of wealth, access to resources, opportunity and support according to principles of justice and fairness. *Climate justice* comprises justice that links development and human rights to achieve a rights-based approach to addressing climate change.

15 Maladaptation refers to actions that may lead to increased risk of adverse climate-related outcomes, including via increased greenhouse gas emissions, increased or shifted vulnerability to climate change, more inequitable outcomes, or diminished welfare, now or in the future. Most often, maladaptation is an unintended consequence.

16 Transformation refers to a change in the fundamental attributes of natural and human systems.

17 Ecosystem health: a metaphor used to describe the condition of an ecosystem, by analogy with human health. Note that there is no universally accepted benchmark for a healthy ecosystem. Rather, the apparent health status of an ecosystem is judged on the ecosystem's resilience to change, with details depending upon which metrics (such as species richness and abundance) are employed in judging it and which societal aspirations are driving the assessment.

18 Planetary health: a concept based on the understanding that human health and human civilisation depend on ecosystem health and the wise stewardship of ecosystems.

19 In this report, the term 'losses and damages' refers to adverse observed impacts and/or projected risks and can be economic and/or non-economic.

20 In the WGII report, climate resilient development refers to the process of implementing greenhouse gas mitigation and adaptation measures to support sustainable development for all.

21 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.

22 SSP-based scenarios are referred to as SSPx-y, where 'SSPx' refers to the Shared Socioeconomic Pathway describing the socioeconomic 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.

23 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.

Box SPM.1 (continued)

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[22]. 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, AR5 WGI}

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 the increase in global surface temperature is 1.09 [0.95 to 1.20][24] °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).[25] 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[26]. { WGI AR6 SPM A1.2, WGI AR6 SPM B1.3, WGI AR6 Table SPM.1, WGI AR6 CCB 2.3}

B: Observed and Projected Impacts and Risks

Since AR5, the knowledge base on observed and projected impacts and risks generated by climate hazards, exposure and vulnerability has increased with impacts attributed to climate change and key risks identified across the report. Impacts and risks are expressed in terms of their damages, harms, economic, and non-economic losses. Risks from observed vulnerabilities and responses to climate change are highlighted. Risks are projected for the near-term (2021–2040), the mid (2041–2060) and long term (2081–2100), at different global warming levels and for pathways that overshoot 1.5°C global warming level for multiple decades[27]. Complex risks result from multiple climate hazards occurring concurrently, and from multiple risks interacting, compounding overall risk and resulting in risks transmitting through interconnected systems and across regions.

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

25 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.

26 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.

27 Overshoot: In this report, pathways that first exceed a specified global warming level (usually 1.5°C, by more than 0.1°C), and then return to or below that level again before the end of a specified period of time (e.g., before 2100). Sometimes the magnitude and likelihood of the overshoot is also characterized. The overshoot duration can vary from at least one decade up to several decades.

Observed Impacts from Climate Change

B.1 Human-induced climate change, including more frequent and intense extreme events, has caused widespread adverse impacts and related losses and damages to nature and people, beyond natural climate variability. Some development and adaptation efforts have reduced vulnerability. Across sectors and regions the most vulnerable people and systems are observed to be disproportionately affected. The rise in weather and climate extremes has led to some irreversible impacts as natural and human systems are pushed beyond their ability to adapt. (*high confidence*) (Figure SPM.2) {TS B.1, Figure TS.5, 1.3, 2.3, 2.4, 2.6, 3.3, 3.4, 3.5, 4.2, 4.3, 5.2, 5.12, 6.2, 7.2, 8.2, 9.6, 9.8, 9.10, 9.11, 10.4, 11.3, 12.3, 12.4, 13.10, 14.4, 14.5, 15.3, 16.2, CCP1.2, CCP3.2, CCP4.1, CCP5.2, CCP6.2, CCP7.2, CCP7.3, CCB DISASTER, CCB EXTREMES, CCB ILLNESS, CCB MIGRATE, CCB NATURAL, CCB SLR}

B.1.1 Widespread, pervasive impacts to ecosystems, people, settlements, and infrastructure have resulted from observed increases in the frequency and intensity of climate and weather extremes, including hot extremes on land and in the ocean, heavy precipitation events, drought and fire weather (*high confidence*). Increasingly since AR5, these observed impacts have been attributed[28] to human-induced climate change particularly through increased frequency and severity of extreme events. These include increased heat-related human mortality (*medium confidence*), warm-water coral bleaching and mortality (*high confidence*), and increased drought-related tree mortality (*high confidence*). Observed increases in areas burned by wildfires have been attributed to human-induced climate change in some regions (*medium* to *high confidence*). Adverse impacts from tropical cyclones, with related losses and damages[19], have increased due to sea level rise and the increase in heavy precipitation (*medium confidence*). Impacts in natural and human systems from slow-onset processes[29] such as ocean acidification, sea level rise or regional decreases in precipitation have also been attributed to human induced climate change (*high confidence*). {1.3, 2.3, 2.4, 2.5, 3.2, 3.4, 3.5, 3.6, 4.2, 5.2, 5.4, 5.6, 5.12, 7.2, 9.6, 9.7, 9.8, 9.11, 11.3, Box 11.1, Box 11.2, Table 11.9, 12.3, 12.4, 13.3, 13.5, 13.10, 14.2, 14.5, 15.7, 15.8, 16.2, CCP1.2, CCP2.2, Box CCP5.1, CCP7.3, CCB DISASTER, CCB EXTREME, CCB ILLNESS, WGI AR6 SPM.3, WGI AR6 9, WGI AR6 11.3–11.8, SROCC Chapter 4}

B.1.2 Climate change has caused substantial damages, and increasingly irreversible losses, in terrestrial, freshwater and coastal and open ocean marine ecosystems (*high confidence*). The extent and magnitude of climate change impacts are larger than estimated in previous assessments (*high confidence*). Widespread deterioration of ecosystem structure and function, resilience and natural adaptive capacity, as well as shifts in seasonal timing have occurred due to climate change (*high confidence*), with adverse socioeconomic consequences (*high confidence*). Approximately half of the species assessed globally have shifted polewards or, on land, also to higher elevations (*very high confidence*). Hundreds of local losses of species have been driven by increases in the magnitude of heat extremes (*high confidence*), as well as mass mortality events on land and in the ocean (*very high confidence*) and loss of kelp forests (*high confidence*). Some losses are already irreversible, such as the first species extinctions driven by climate change (*medium confidence*). Other impacts are approaching irreversibility such as the impacts of hydrological changes resulting from the retreat of glaciers, or the changes in some mountain (*medium confidence*) and Arctic ecosystems driven by permafrost thaw (*high confidence*). (Figure SPM.2a). { TS B.1, Figure TS.5, 2.3, 2.4, 3.4, 3.5, 4.2, 4.3, 4.5, 9.6, 10.4, 11.3, 12.3, 12.8, 13.3, 13.4, 13.10, 14.4, 14.5, 14.6, 15.3, 16.2, CCP1.2, CCP3.2, CCP4.1, CCP5.2, Figure CCP5.4, CCP6.1, CCP6.2, CCP7.2, CCP7.3, CCB EXTREMES, CCB ILLNESS, CCB MOVING PLATE, CCB NATURAL, CCB PALEO, CCB SLR, SROCC 2.3}

B.1.3 Climate change including increases in frequency and intensity of extremes have reduced food and water security, hindering efforts to meet Sustainable Development Goals (*high confidence*). Although overall agricultural productivity has increased, climate change has slowed this growth over the past 50 years globally (*medium confidence*), related negative impacts were mainly in mid- and low latitude regions but positive impacts occurred in some high latitude regions (*high confidence*). Ocean warming and ocean acidification have adversely affected food production from shellfish aquaculture and fisheries in some oceanic regions (*high confidence*). Increasing weather and climate extreme events have exposed millions of people to acute food insecurity[30] and reduced water security, with the largest impacts observed in many locations and/or communities in Africa, Asia, Central and South America, Small Islands and the Arctic (*high confidence*). Jointly, sudden losses of food production and access to food compounded by decreased diet diversity have increased malnutrition in many communities (*high confidence*), especially for Indigenous Peoples, small-scale food producers and low-income households (*high confidence*), with children, elderly people and pregnant women particularly impacted (*high confidence*). Roughly half of the world's population currently experience severe water scarcity for at least some part of the year due to climatic and non-climatic drivers (*medium confidence*). (Figure SPM.2b) {3.5, 4.3, 4.4, Box 4.1, 5.2, 5.4, 5.8, 5.9, 5.12, 7.1, 7.2, 9.8, 10.4, 11.3, 12.3, 13.5, 14.4, 14.5, 15.3, 16.2, CCP5.2, CCP6.2}

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28 Attribution is defined as the process of evaluating the relative contributions of multiple causal factors to a change or event with an assessment of confidence. {Annex II Glossary, CWGB ATTRIB}

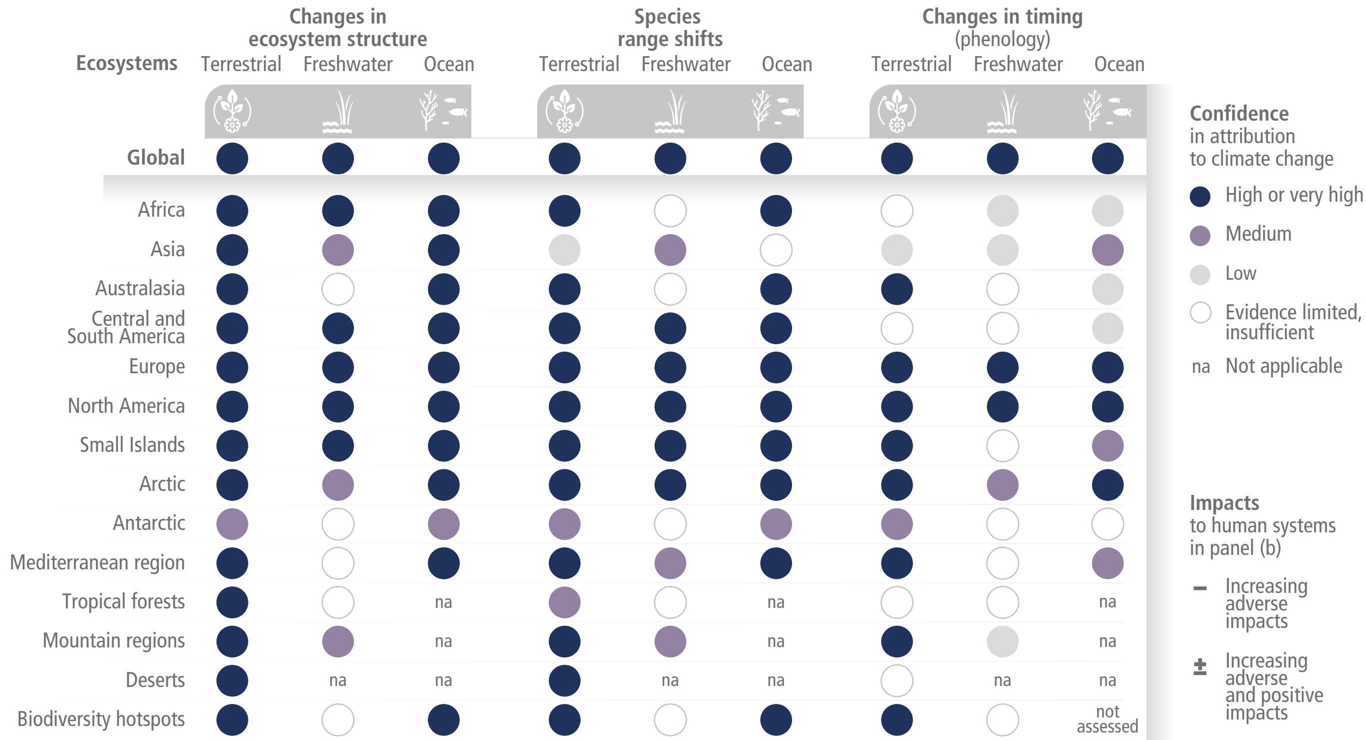
29 Impacts of climate change are caused by slow onset and extreme events. Slow onset events are described among the climatic-impact drivers of the WGI AR6 and refer to the risks and impacts associated with e.g., increasing temperature means, desertification, decreasing precipitation, loss of biodiversity, land and forest degradation, glacial retreat and related impacts, ocean acidification, sea level rise and salinization (https://interactive-atlas.ipcc.ch).

30 Acute food insecurity can occur at any time with a severity that threatens lives, livelihoods or both, regardless of the causes, context or duration, as a result of shocks risking determinants of food security and nutrition, and used to assess the need for humanitarian action.

SPM

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

(a) Observed impacts of climate change on ecosystems



(b) Observed impacts of climate change on human systems

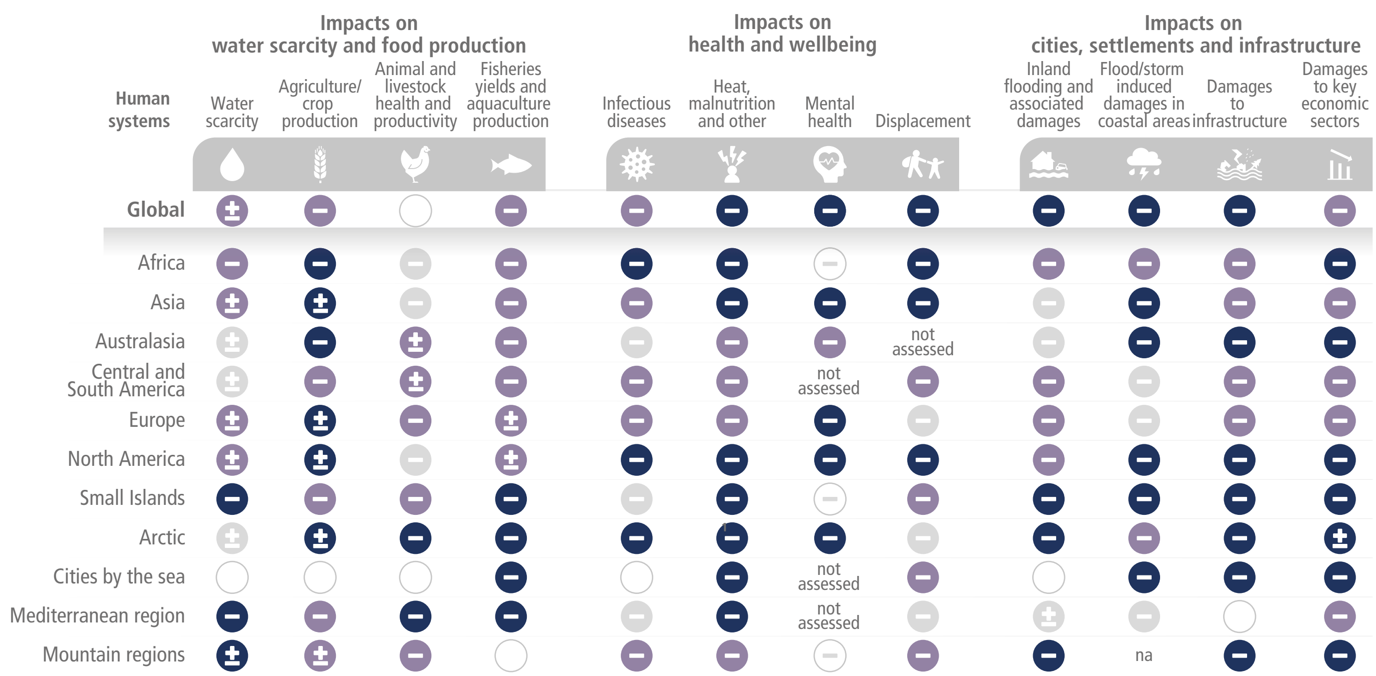


Figure SPM.2 | Observed global and regional impacts on ecosystems and human systems attributed to climate change. Confidence levels reflect uncertainty in attribution of the observed impact to climate change. Global assessments focus on large studies, multi-species, meta-analyses and large reviews. For 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.

(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).

B.1.4 Climate change has adversely affected physical health of people globally (*very high confidence)* and mental health of people in the assessed regions (*very high confidence*). Climate change impacts on health are mediated through natural and human systems, including economic and social conditions and disruptions (*high confidence*). In all regions extreme heat events have resulted in human mortality and morbidity (*very high confidence*). The occurrence of climate-related food-borne and water-borne diseases has increased (*very high confidence*). The incidence of vector-borne diseases has increased from range expansion and/or increased reproduction of disease vectors (*high confidence*). Animal and human diseases, including zoonoses, are emerging in new areas (*high confidence*). Water and food-borne disease risks have increased regionally from climate-sensitive aquatic pathogens, including *Vibrio* spp. (*high confidence*), and from toxic substances from harmful freshwater cyanobacteria (*medium confidence*). Although diarrheal diseases have decreased globally, higher temperatures, increased rain and flooding have increased the occurrence of diarrheal diseases, including cholera (*very high confidence*) and other gastrointestinal infections (*high confidence*). In assessed regions, some mental health challenges are associated with increasing temperatures (*high confidence*), trauma from weather and climate extreme events (*very high confidence*), and loss of livelihoods and culture (*high confidence*). Increased exposure to wildfire smoke, atmospheric dust, and aeroallergens have been associated with climate-sensitive cardiovascular and respiratory distress (*high confidence*). Health services have been disrupted by extreme events such as floods (*high confidence*). {4.3, 5.12, 7.2, Box 7.3, 8.2, 8.3, Box 8.6, Figure 8.10, 9.10, Figure 9.33, Figure 9.34, 10.4, 11.3, 12.3, 13.7, 14.4, 14.5, Figure 14.8, 15.3, 16.2, CCP5.2, Table CCP5.1, CCP6.2, Figure CCP6.3, Table CCB ILLNESS.1}

B.1.5 In urban settings, observed climate change has caused impacts on human health, livelihoods and key infrastructure (*high confidence*). Multiple climate and non-climate hazards impact cities, settlements and infrastructure and sometimes coincide, magnifying damage (*high confidence*). Hot extremes including heatwaves have intensified in cities (*high confidence*), where they have also aggravated air pollution events (*medium confidence*) and limited functioning of key infrastructure (*high confidence*). Observed impacts are concentrated amongst the economically and socially marginalized urban residents, e.g., in informal settlements (*high confidence*). Infrastructure, including transportation, water, sanitation and energy systems have been compromised by extreme and slow-onset events, with resulting economic losses, disruptions of services and impacts to well-being (*high confidence*). {4.3, 6.2, 7.1, 7.2, 9.9, 10.4, 11.3, 12.3, 13.6, 14.5, 15.3, CCP2.2, CCP4.2, CCP5.2}

B.1.6 Overall adverse economic impacts attributable to climate change, including slow-onset and extreme weather events, have been increasingly identified (*medium confidence*). Some positive economic effects have been identified in regions that have benefited from lower energy demand as well as comparative advantages in agricultural markets and tourism (*high confidence*). Economic damages from climate change have been detected in climate-exposed sectors, with regional effects to agriculture, forestry, fishery, energy, and tourism (*high confidence*), and through outdoor labour productivity (*high confidence*). Some extreme weather events, such as tropical cyclones, have reduced economic growth in the short-term (*high confidence*). Non-climatic factors including some patterns of settlement, and siting of infrastructure have contributed to the exposure of more assets to extreme climate hazards increasing the magnitude of the losses (*high confidence*). Individual livelihoods have been affected through changes in agricultural productivity, impacts on human health and food security, destruction of homes and infrastructure, and loss of property and income, with adverse effects on gender and social equity (*high confidence*). {3.5, 4.2, 5.12, 6.2, 7.2, 8.2, 9.6, 10.4, 13.10, 14.5, Box 14.6, 16.2, Table 16.5, 18.3, CCP6.2, CCB GENDER, CWGB ECONOMICS}

B.1.7 Climate change is contributing to humanitarian crises where climate hazards interact with high vulnerability (*high confidence*). Climate and weather extremes are increasingly driving displacement in all regions (*high confidence*), with Small Island States disproportionately affected (*high confidence*). Flood and drought-related acute food insecurity and malnutrition have increased in Africa (*high confidence*) and Central and South America (*high confidence*). While non-climatic factors are the dominant drivers of existing intrastate violent conflicts, in some assessed regions extreme weather and climate events have had a small, adverse impact on their length, severity or frequency, but the statistical association is weak (*medium confidence*). Through displacement and involuntary migration from extreme weather and climate events, climate change has generated and perpetuated vulnerability (*medium confidence*). {4.2, 4.3, 5.4, 7.2, 9.8, Box 9.9, Box 10.4, 12.3, 12.5, 16.2, CCB DISASTER, CCB MIGRATE}

Vulnerability and Exposure of Ecosystems and People

B.2 Vulnerability of ecosystems and people to climate change differs substantially among and within regions (*very high confidence*), driven by patterns of intersecting socioeconomic development, unsustainable ocean and land use, inequity, marginalization, historical and ongoing patterns of inequity such as colonialism, and governance[31] (*high confidence*). Approximately 3.3 to 3.6 billion people live in contexts that are highly vulnerable to climate change (*high confidence*). A high proportion of species is vulnerable to climate change (*high confidence*). Human and ecosystem vulnerability are interdependent (*high confidence*). Current unsustainable development patterns are increasing exposure of ecosystems and people to climate hazards (*high confidence*). {2.3, 2.4, 3.5, 4.3, 6.2, 8.2, 8.3, 9.4, 9.7, 10.4, 12.3, 14.5, 15.3, CCP5.2, CCP6.2, CCP7.3, CCP7.4, CCB GENDER}

B.2.1 Since AR5 there is increasing evidence that degradation and destruction of ecosystems by humans increases the vulnerability of people (*high confidence*). Unsustainable land-use and land cover change, unsustainable use of natural resources, deforestation, loss of biodiversity, pollution, and their interactions, adversely affect the capacities of ecosystems, societies, communities and individuals to adapt to climate change (*high confidence*). Loss of ecosystems and their services has cascading and long-term impacts on people globally, especially for Indigenous Peoples and local communities who are directly dependent on ecosystems, to meet basic needs (*high confidence*). {2.3, 2.5, 2.6, 3.5, 3.6, 4.2, 4.3, 4.6, 5.1, 5.4, 5.5, 5.7, 5.8, 7.2, 8.1, 8.2, 8.3, 8.4, 8.5, 9.6, 10.4, 11.3, 12.2, 12.5, 13.8, 14.4, 14.5, 15.3, CCP1.2, CCP1.3, CCP2.2, CCP3, CCP4.3, CCP5.2, CCP6.2, CCP7.2, CCP7.3, CCP7.4, CCB ILLNESS, CCB MOVING PLATE, CCB SLR}

B.2.2 Non-climatic human-induced factors exacerbate current ecosystem vulnerability to climate change (*very high confidence*). Globally, and even within protected areas, unsustainable use of natural resources, habitat fragmentation, and ecosystem damage by pollutants increase ecosystem vulnerability to climate change (*high confidence*). Globally, less than 15% of the land, 21% of the freshwater and 8% of the ocean are protected areas. In most protected areas, there is insufficient stewardship to contribute to reducing damage from, or increasing resilience to, climate change (*high confidence*). {2.4, 2.5, 2.6, 3.4, 3.6, 4.2, 4.3, 5.8, 9.6, 11.3, 12.3, 13.3, 13.4, 14.5, 15.3, CCP1.2, Figure CCP1.15, CCP2.1, CCP2.2, CCP4.2, CCP5.2, CCP6.2, CCP7.2, CCP7.3, CCB NATURAL}

B.2.3 Future vulnerability of ecosystems to climate change will be strongly influenced by the past, present and future development of human society, including from overall unsustainable consumption and production, and increasing demographic pressures, as well as persistent unsustainable use and management of land, ocean, and water (*high confidence*). Projected climate change, combined with non-climatic drivers, will cause loss and degradation of much of the world's forests (*high confidence*), coral reefs and low-lying coastal wetlands (*very high confidence*). While agricultural development contributes to food security, unsustainable agricultural expansion, driven in part by unbalanced diets[32], increases ecosystem and human vulnerability and leads to competition for land and/or water resources (*high confidence*). {2.2, 2.3, 2.4, 2.6, 3.4, 3.5, 3.6, 4.3, 4.5, 5.6, 5.12, 5.13, 7.2, 12.3, 13.3, 13.4, 13.10, 14.5, CCP1.2, CCP2.2, CCP5.2, CCP6.2, CCP7.2, CCP7.3, CCB HEALTH, CCB NATURAL}

B.2.4 Regions and people with considerable development constraints have high vulnerability to climatic hazards (*high confidence*). Global hotspots of high human vulnerability are found particularly in West-, Central- and East Africa, South Asia, Central and South America, Small Island Developing States and the Arctic (*high confidence*). Vulnerability is higher in locations with poverty, governance challenges and limited access to basic services and resources, violent conflict and high levels of climate-sensitive livelihoods (e.g., smallholder farmers, pastoralists, fishing communities) (*high confidence*). Between 2010–2020, human mortality from floods, droughts and storms was 15 times higher in highly vulnerable regions, compared to regions with very low vulnerability (*high confidence*). Vulnerability at different spatial levels is exacerbated by inequity and marginalization linked to gender, ethnicity, low income or combinations thereof (*high confidence*), especially for many Indigenous Peoples and local communities (*high confidence*). Present development challenges causing high vulnerability are influenced by historical and ongoing patterns of inequity such as colonialism, especially for many Indigenous Peoples and local communities (*high confidence*). {4.2, 5.12, 6.2, 6.4, 7.1, 7.2, Box 7.1, 8.2, 8.3, Box 8.4, Figure 8.6, Box 9.1, 9.4, 9.7, 9.9, 10.3, 10.4, 10.6, 12.3, 12.5, Box 13.2, 14.4, 15.3, 15.6, 16.2, CCP6.2, CCP7.4}

B.2.5 Future human vulnerability will continue to concentrate where the capacities of local, municipal and national governments, communities and the private sector are least able to provide infrastructures and basic services (*high confidence*). Under the global trend of urbanization, human vulnerability will also concentrate in informal settlements and rapidly growing smaller settlements (*high*

31 Governance: The structures, processes and actions through which private and public actors interact to address societal goals. This includes formal and informal institutions and the associated norms, rules, laws and procedures for deciding, managing, implementing and monitoring policies and measures at any geographic or political scale, from global to local.

32 Balanced diets feature plant-based foods, such as those based on coarse grains, legumes fruits and vegetables, nuts and seeds, and animal-source foods produced in resilient, sustainable and low-greenhouse gas emissions systems, as described in SRCCL.

confidence). In rural areas vulnerability will be heightened by compounding processes including high emigration, reduced habitability and high reliance on climate-sensitive livelihoods (*high confidence*). Key infrastructure systems including sanitation, water, health, transport, communications and energy will be increasingly vulnerable if design standards do not account for changing climate conditions (*high confidence*). Vulnerability will also rapidly rise in low-lying Small Island Developing States and atolls in the context of sea level rise and in some mountain regions, already characterised by high vulnerability due to high dependence on climate-sensitive livelihoods, rising population displacement, the accelerating loss of ecosystem services and limited adaptive capacities (*high confidence*). Future exposure to climatic hazards is also increasing globally due to socioeconomic development trends including migration, growing inequality and urbanization *(high confidence*). {4.5, 5.5, 6.2, 7.2, 8.3, 9.9, 9.11, 10.3, 10.4, 12.3, 12.5, 13.6, 14.5, 15.3, 15.4, 16.5, CCP2.3, CCP4.3, CCP5.2, CCP5.3, CCP5.4, CCP6.2, CCB MIGRATE}

Risks in the near term (2021–2040)

B.3 Global warming, reaching 1.5°C in the near-term, would cause unavoidable increases in multiple climate hazards and present multiple risks to ecosystems and humans (*very high confidence*). The level of risk will depend on concurrent near-term trends in vulnerability, exposure, level of socioeconomic development and adaptation (*high confidence*). Near-term actions that limit global warming to close to 1.5°C would substantially reduce projected losses and damages related to climate change in human systems and ecosystems, compared to higher warming levels, but cannot eliminate them all (*very high confidence*). (Figure SPM.3, Box SPM.1) {16.4, 16.5, 16.6, CCP1.2, CCP5.3, CCB SLR, WGI AR6 SPM B1.3, WGI AR6 Table SPM.1}

B.3.1 Near-term warming and increased frequency, severity and duration of extreme events will place many terrestrial, freshwater, coastal and marine ecosystems at high or very high risks of biodiversity loss (*medium to very high confidence*, depending on ecosystem). Near-term risks for biodiversity loss are moderate to high in forest ecosystems (*medium confidence*), kelp and seagrass ecosystems (*high* to *very high confidence*), and high to very high in Arctic sea-ice and terrestrial ecosystems (*high confidence*) and warm-water coral reefs (*very high confidence*). Continued and accelerating sea level rise will encroach on coastal settlements and infrastructure (*high confidence*) and commit low-lying coastal ecosystems to submergence and loss (*medium confidence*). If trends in urbanisation in exposed areas continue, this will exacerbate the impacts, with more challenges where energy, water and other services are constrained (*medium confidence*). The number of people at risk from climate change and associated loss of biodiversity will progressively increase (*medium confidence*). Violent conflict and, separately, migration patterns, in the near-term will be driven by socioeconomic conditions and governance more than by climate change (*medium confidence*). (Figure SPM.3) {2.5, 3.4, 4.6, 6.2, 7.3, 8.7, 9.2, 9.9, 11.6, 12.5, 13.6, 13.10, 14.6, 15.3, 16.5, 16.6, CCP1.2, CCP2.1, CCP2.2, CCP5.3, CCP6.2, CCP6.3, CCB MIGRATE, CCB SLR}

B.3.2 In the near term, climate-associated risks to natural and human systems depend more strongly on changes in their vulnerability and exposure than on differences in climate hazards between emissions scenarios (*high confidence*). Regional differences exist, and risks are highest where species and people exist close to their upper thermal limits, along coastlines, in close association with ice or seasonal rivers (*high confidence*). Risks are also high where multiple non-climate drivers persist or where vulnerability is otherwise elevated (*high confidence*). Many of these risks are unavoidable in the near-term, irrespective of emissions scenario (*high confidence*). Several risks can be moderated with adaptation (*high confidence*). (Figure SPM.3, Section C) {2.5, 3.3, 3.4, 4.5, 6.2, 7.1, 7.3, 8.2, 11.6, 12.4, 13.6, 13.7, 13.10, 14.5, 16.4, 16.5, CCP2.2, CCP4.3, CCP5.3, CCB SLR, WGI AR6 Table SPM.1}

B.3.3 Levels of risk for all Reasons for Concern (RFC) are assessed to become high to very high at lower global warming levels than in AR5 (*high confidence*). Between 1.2°C and 4.5°C global warming level very high risks emerge in all five RFCs compared to just two RFCs in AR5 (*high confidence*). Two of these transitions from high to very high risk are associated with near-term warming: risks to unique and threatened systems at a median value of 1.5 [1.2 to 2.0] °C (*high confidence*) and risks associated with extreme weather events at a median value of 2.0 [1.8 to 2.5] °C (*medium confidence*). Some key risks contributing to the RFCs are projected to lead to widespread, pervasive, and potentially irreversible impacts at global warming levels of 1.5–2°C if exposure and vulnerability are high and adaptation is low (*medium confidence*). Near-term actions that limit global warming to close to 1.5°C would substantially reduce projected losses and damages related to climate change in human systems and ecosystems, compared to higher warming levels, but cannot eliminate them all (*very high confidence*). (Figure SPM.3b) {16.5, 16.6, CCB SLR}

Mid to Long-term Risks (2041–2100)

B.4 Beyond 2040 and depending on the level of global warming, climate change will lead to numerous risks to natural and human systems (*high confidence*). For 127 identified key risks, assessed mid- and long-term impacts are up to multiple times higher than currently observed (*high confidence*). The magnitude and rate of climate change and associated risks depend strongly on near-term mitigation and adaptation actions, and projected adverse impacts and related losses and damages escalate with every increment of global warming (*very high confidence*). (Figure SPM.3) {2.5, 3.4, 4.4, 5.2, 6.2, 7.3, 8.4, 9.2, 10.2, 11.6, 12.4, 13.2, 13.3, 13.4, 13.5, 13.6, 13.7, 13.8, 14.6, 15.3, 16.5, 16.6, CCP1.2, CCP2.2, CCP3.3, CCP4.3, CCP5.3, CCP6.3, CCP7.3}

B.4.1 Biodiversity loss and degradation, damages to and transformation of ecosystems are already key risks for every region due to past global warming and will continue to escalate with every increment of global warming (*very high confidence*). In terrestrial ecosystems, 3 to 14% of species assessed[33] will *likely* face very high risk of extinction[34] at global warming levels of 1.5°C, increasing up to 3 to 18% at 2°C, 3 to 29% at 3°C, 3 to 39% at 4°C, and 3 to 48% at 5°C. In ocean and coastal ecosystems, risk of biodiversity loss ranges between moderate and very high by 1.5°C global warming level and is moderate to very high by 2°C but with more ecosystems at high and very high risk (*high confidence*), and increases to high to very high across most ocean and coastal ecosystems by 3°C (*medium* to *high confidence*, depending on ecosystem). Very high extinction risk for endemic species in biodiversity hotspots is projected to at least double from 2% between 1.5°C and 2°C global warming levels and to increase at least tenfold if warming rises from 1.5°C to 3°C (*medium confidence*). (Figure SPM.3c, d, f) {2.4, 2.5, 3.4, 3.5,12.3, 12.5, Table 12.6, 13.4, 13.10, 16.4, 16.6, CCP1.2, Figure CCP1.6, Figure CCP1.7, CCP5.3, CCP6.3, CCB PALEO}

B.4.2 Risks in physical water availability and water-related hazards will continue to increase by the mid- to long-term in all assessed regions, with greater risk at higher global warming levels (*high confidence*). At approximately 2°C global warming, snowmelt water availability for irrigation is projected to decline in some snowmelt dependent river basins by up to 20%, and global glacier mass loss of 18 ± 13% is projected to diminish water availability for agriculture, hydropower, and human settlements in the mid- to long-term, with these changes projected to double with 4°C global warming (*medium confidence*). In Small Islands, groundwater availability is threatened by climate change (*high confidence*). Changes to streamflow magnitude, timing and associated extremes are projected to adversely impact freshwater ecosystems in many watersheds by the mid- to long-term across all assessed scenarios (*medium confidence*). Projected increases in direct flood damages are higher by 1.4 to 2 times at 2°C and 2.5 to 3.9 times at 3°C compared to 1.5°C global warming without adaptation (*medium confidence*). At global warming of 4°C, approximately 10% of the global land area is projected to face increases in both extreme high and low river flows in the same location, with implications for planning for all water use sectors (*medium confidence*). Challenges for water management will be exacerbated in the near, mid and long term, depending on the magnitude, rate and regional details of future climate change and will be particularly challenging for regions with constrained resources for water management (*high confidence*). {2.3, 4.4, 4.5, Box 4.2, Figure 4.20, 15.3, CCP5.3, CCB DISASTER, SROCC 2.3}

B.4.3 Climate change will increasingly put pressure on food production and access, especially in vulnerable regions, undermining food security and nutrition (*high confidence*). Increases in frequency, intensity and severity of droughts, floods and heatwaves, and continued sea level rise will increase risks to food security (*high confidence*) in vulnerable regions from moderate to high between 1.5°C and 2°C global warming level, with no or low levels of adaptation (*medium confidence*). At 2°C or higher global warming level in the mid-term, food security risks due to climate change will be more severe, leading to malnutrition and micro-nutrient deficiencies, concentrated in Sub-Saharan Africa, South Asia, Central and South America and Small Islands (*high confidence).* Global warming will progressively weaken soil health and ecosystem services such as pollination, increase pressure from pests and diseases, and reduce marine animal biomass, undermining food productivity in many regions on land and in the ocean (*medium confidence*). At 3°C or higher global warming level in the long term, areas exposed to climate-related hazards will expand substantially compared with 2°C or lower global warming level (*high confidence*), exacerbating regional disparity in food security risks (*high confidence*). (Figure SPM.3) {1.1, 3.3, 4.5, 5.2, 5.4, 5.5, 5.8, 5.9, 5.12, 7.3, 8.3, 9.11, 13.5, 15.3, 16.5, 16.6, CCB MOVING PLATE, CCB SLR}

33 Numbers of species assessed are in the tens of thousands globally.

34 The term 'very high risks of extinction' is used here consistently with the IUCN categories and criteria and equates with 'critically endangered'.

B.4.4 Climate change and related extreme events will significantly increase ill health and premature deaths from the near- to long-term (*high confidence*). Globally, population exposure to heatwaves will continue to increase with additional warming, with strong geographical differences in heat-related mortality without additional adaptation (*very high confidence*). Climate-sensitive food-borne, water-borne, and vector-borne disease risks are projected to increase under all levels of warming without additional adaptation (*high confidence*). In particular, dengue risk will increase with longer seasons and a wider geographic distribution in Asia, Europe, Central and South America and sub-Saharan Africa, potentially putting additional billions of people at risk by the end of the century (*high confidence*). Mental health challenges, including anxiety and stress, are expected to increase under further global warming in all assessed regions, particularly for children, adolescents, elderly, and those with underlying health conditions (*very high confidence*). {4.5, 5.12, Box 5.10, 7.3, Figure 7.9, 8.4, 9.10, Figure 9.32, Figure 9.35, 10.4, Figure 10.11, 11.3, 12.3, Figure 12.5, Figure 12.6, 13.7, Figure 13.23, Figure 13.24, 14.5, 15.3, CCP6.2}

B.4.5 Climate change risks to cities, settlements and key infrastructure will rise rapidly in the mid- and long-term with further global warming, especially in places already exposed to high temperatures, along coastlines, or with high vulnerabilities (*high confidence*). Globally, population change in low-lying cities and settlements will lead to approximately a billion people projected to be at risk from coastal-specific climate hazards in the mid-term under all scenarios, including in Small Islands (*high confidence*). The population potentially exposed to a 100-year coastal flood is projected to increase by about 20% if global mean sea level rises by 0.15 m relative to 2020 levels; this exposed population doubles at a 0.75 m rise in mean sea level and triples at 1.4 m without population change and additional adaptation (*medium confidence*). Sea level rise poses an existential threat for some Small Islands and some low-lying coasts (*medium confidence*). By 2100 the value of global assets within the future 1-in-100 year coastal floodplains is projected to be between US$7.9 and US$12.7 trillion (2011 value) under RCP4.5, rising to between US$8.8 and US$14.2 trillion under RCP8.5 (*medium confidence*). Costs for maintenance and reconstruction of urban infrastructure, including building, transportation, and energy will increase with global warming level (*medium confidence*), the associated functional disruptions are projected to be substantial particularly for cities, settlements and infrastructure located on permafrost in cold regions and on coasts (*high confidence*). {6.2, 9.9, 10.4, 13.6, 13.10, 15.3, 16.5, CCP2.1, CCP2.2, CCP5.3, CCP6.2, CCB SLR, SROCC 2.3, SROCC CCB9}

B.4.6 Projected estimates of global aggregate net economic damages generally increase non-linearly with global warming levels (*high confidence*).[35] The wide range of global estimates, and the lack of comparability between methodologies, does not allow for identification of a robust range of estimates (*high confidence*). The existence of higher estimates than assessed in AR5 indicates that global aggregate economic impacts could be higher than previous estimates (*low confidence*).[36] Significant regional variation in aggregate economic damages from climate change is projected (*high confidence*) with estimated economic damages per capita for developing countries often higher as a fraction of income (*high confidence*). Economic damages, including both those represented and those not represented in economic markets, are projected to be lower at 1.5°C than at 3°C or higher global warming levels (*high confidence*). {4.4, 9.11, 11.5, 13.10, Box 14.6, 16.5, CWGB ECONOMIC}

B.4.7 In the mid- to long-term, displacement will increase with intensification of heavy precipitation and associated flooding, tropical cyclones, drought and, increasingly, sea level rise (*high confidence*). At progressive levels of warming, involuntary migration from regions with high exposure and low adaptive capacity would occur (*medium confidence*). Compared to other socioeconomic factors the influence of climate on conflict is assessed as relatively weak (*high confidence*). Along long-term socioeconomic pathways that reduce non-climatic drivers, risk of violent conflict would decline (*medium confidence*). At higher global warming levels, impacts of weather and climate extremes, particularly drought, by increasing vulnerability will increasingly affect violent intrastate conflict (*medium confidence*). {TS B.7.4, 7.3, 16.5, CCB MIGRATE }

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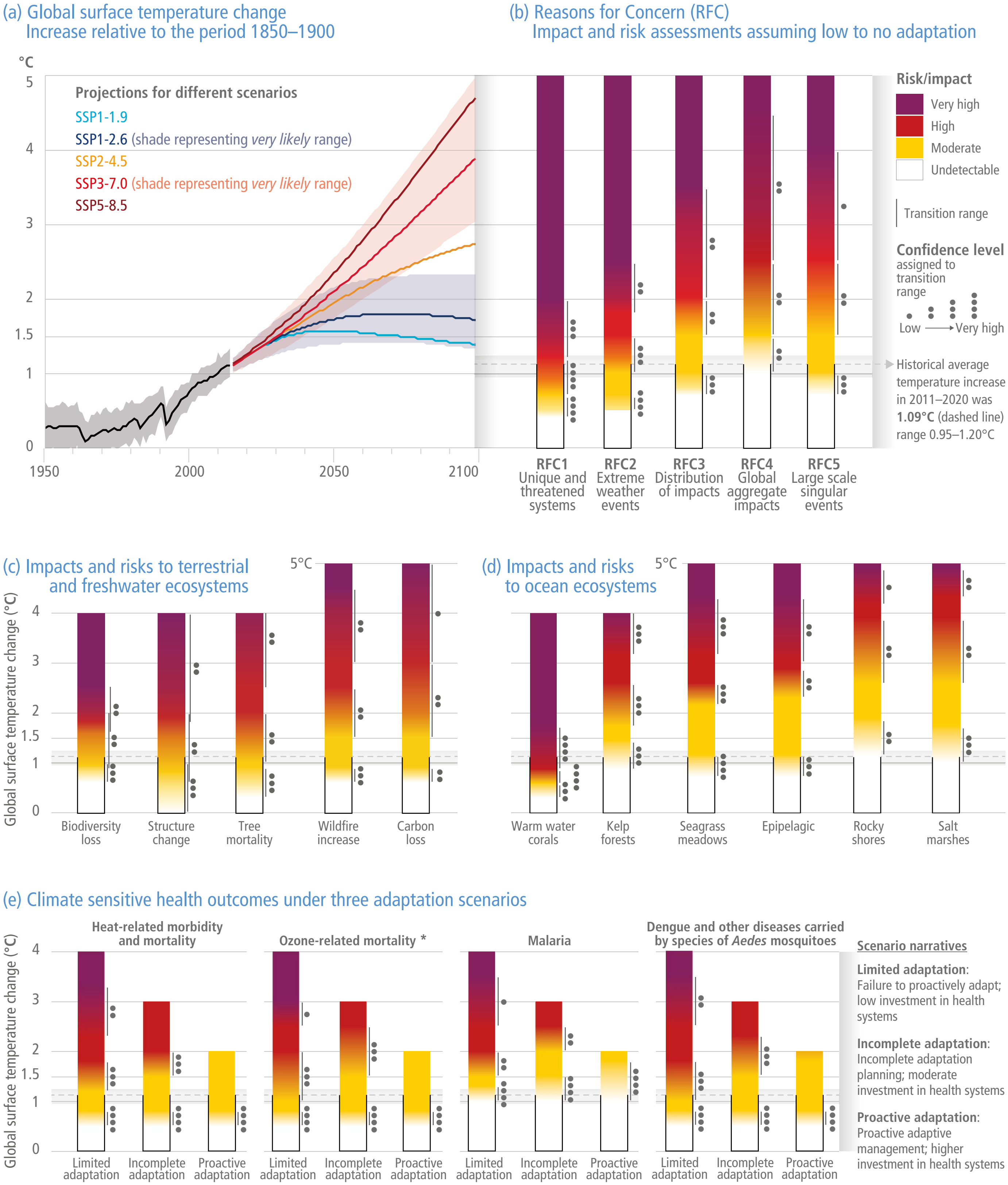
35 The assessment found estimated rates of increase in projected global economic damages that were both greater than linear and less than linear as global warming level increases. There is evidence that some regions could benefit from low levels of warming (*high confidence*). {CWGB ECONOMIC}

36 *Low confidence* assigned due to the assessed lack of comparability and robustness of global aggregate economic damage estimates. {CWGB ECONOMIC}

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.

(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

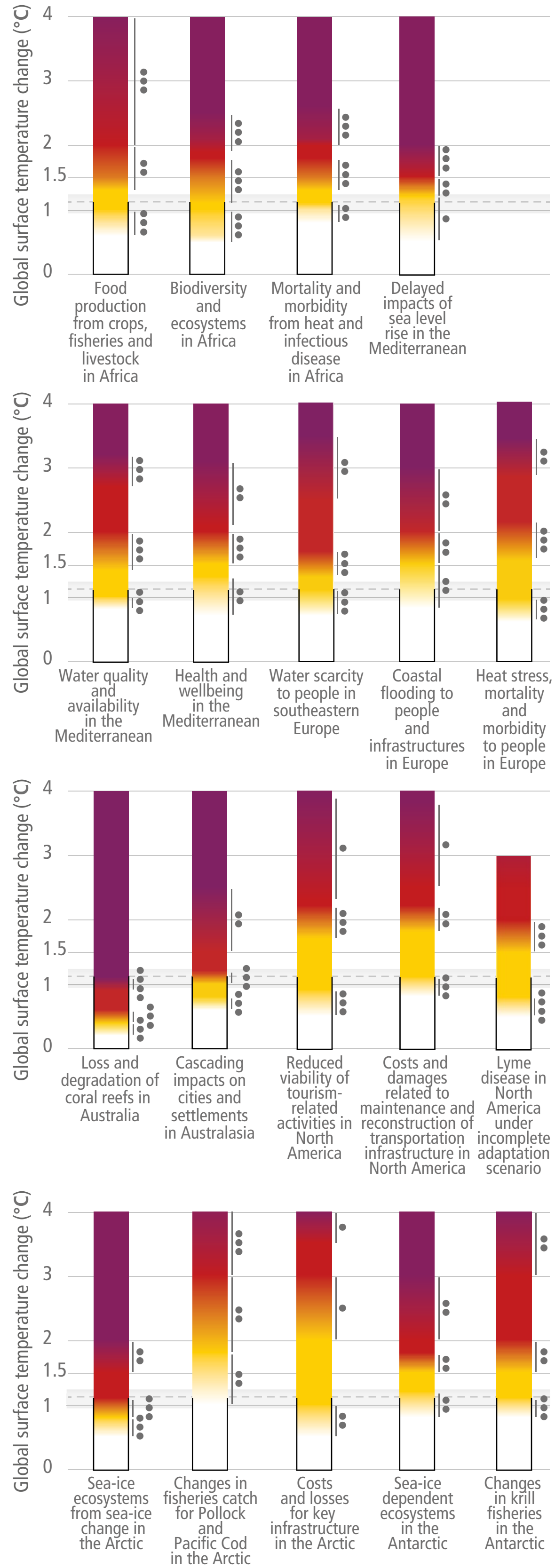


Figure SPM.3 | Synthetic diagrams of global and sectoral assessments and examples of regional key risks. Diagrams show the change in the levels of impacts and risks assessed for global warming of 0–5°C global surface temperature change relative to pre-industrial period (1850–1900) over the range.

(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 SPM.1). 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 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 socioeconomic 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 SPM.1) {Figure TS.4, 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}

Complex, Compound and Cascading Risks

B.5 Climate change impacts and risks are becoming increasingly complex and more difficult to manage. Multiple climate hazards will occur simultaneously, and multiple climatic and non-climatic risks will interact, resulting in compounding overall risk and risks cascading across sectors and regions. Some responses to climate change result in new impacts and risks. (*high confidence*) {1.3, 2.4, Box 2.2, Box 9.5, 11.5, 13.5, 14.6, Box 15.1, CCP1.2, CCP2.2, CCB COVID, CCB DISASTER, CCB INTEREG, CCB SRM, }

B.5.1 Concurrent and repeated climate hazards occur in all regions, increasing impacts and risks to health, ecosystems, infrastructure, livelihoods and food (*high confidence*). Multiple risks interact, generating new sources of vulnerability to climate hazards, and compounding overall risk (*high confidence*). Increasing concurrence of heat and drought events are causing crop production losses and tree mortality (*high confidence*). Above 1.5°C global warming increasing concurrent climate extremes will increase risk of simultaneous crop losses of maize in major food-producing regions, with this risk increasing further with higher global warming levels (*medium confidence*). Future sea level rise combined with storm surge and heavy rainfall will increase compound flood risks (*high confidence*). Risks to health and food production will be made more severe from the interaction of sudden food production losses from heat and drought, exacerbated by heat-induced labour productivity losses (*high confidence*). These interacting impacts will increase food prices, reduce household incomes, and lead to health risks of malnutrition and climate-related mortality with no or low levels of adaptation, especially in tropical regions (*high confidence*). Risks to food safety from climate change will further compound the risks to health by increasing food contamination of crops from mycotoxins and contamination of seafood from harmful algal blooms, mycotoxins, and chemical contaminants (*high confidence*). {Figure TS.10c, 5.2, 5.4, 5.8, 5.9, 5.11, 5.12, 7.2, 7.3, 9.8, 9.11, 10.4, 11.3, 11.5, 12.3, 13.5, 14.5, 15.3, Box 15.1, 16.6, CCP1.2, CCP6.2, , WGI AR6 SPM A.3.1, WGI AR6 SPM A.3.2, WGI AR6 SPM C.2.7}

B.5.2 Adverse impacts from climate hazards and resulting risks are cascading across sectors and regions (*high confidence*), propagating impacts along coasts and urban centres (*medium confidence*) and in mountain regions (*high confidence*). These hazards and cascading risks also trigger tipping points in sensitive ecosystems and in significantly and rapidly changing social-ecological systems impacted by ice melt, permafrost thaw and changing hydrology in polar regions (*high confidence*). Wildfires, in many regions, have affected ecosystems and species, people and their built assets, economic activity, and health (*medium to high confidence*). In cities and settlements, climate impacts to key infrastructure are leading to losses and damages across water and food systems, and affect economic activity, with impacts extending beyond the area directly impacted by the climate hazard (*high confidence*). In Amazonia, and in some mountain regions, cascading impacts from climatic (e.g., heat) and non-climatic stressors (e.g., land use change) will result in irreversible and severe losses of ecosystem services and biodiversity at 2°C global warming level and beyond (*medium confidence*). Unavoidable sea level rise will bring cascading and compounding impacts resulting in losses of coastal ecosystems and ecosystem services, groundwater salinisation, flooding and damages to coastal infrastructure that cascade into risks to livelihoods, settlements, health, well-being, food and water security, and cultural values in the near to long-term (*high confidence*). (Figure SPM.3) {Figure TS.10, 2.5, 3.4, 3.5, Box 7.3, Box 8.7, Box 9.4, 11.5, Box 11.1, 12.3, 13.9, 14.6, 15.3, 16.5, 16.6, CCP1.2, CCP2.2, CCP5.2, CCP5.3, CCP6.2, CCP6.3, Box CCP6.1, Box CCP6.2, CCB EXTREMES, WGI AR6 Figure SPM.8d}

B.5.3 Weather and climate extremes are causing economic and societal impacts across national boundaries through supply-chains, markets, and natural resource flows, with increasing transboundary risks projected across the water, energy and food sectors (*high confidence*). Supply chains that rely on specialized commodities and key infrastructure can be disrupted by weather and climate extreme events. Climate change causes the redistribution of marine fish stocks, increasing risk of transboundary management conflicts among fisheries users, and negatively affecting equitable distribution of food provisioning services as fish stocks shift from lower to higher latitude regions, thereby increasing the need for climate-informed transboundary management and cooperation (*high confidence*). Precipitation and water availability changes increases the risk of planned infrastructure projects, such as hydropower in some regions, having reduced productivity for food and energy sectors including across countries that share river basins (*medium confidence*). {Figure TS.10e-f, 3.4, 3.5, 4.5, 5.8, 5.13, 6.2, 9.4, Box 9.5,14.5, Box 14.5, Box 14.6, CCP5.3, CCB DISASTER, CCB EXTREMES, CCB INTEREG, CCB MOVING PLATE}

B.5.4 Risks arise from some responses that are intended to reduce the risks of climate change, including risks from maladaptation and adverse side effects of some emissions reduction and carbon dioxide removal measures (*high confidence*). Deployment of afforestation of naturally unforested land, or poorly implemented bioenergy, with or without carbon capture and storage, can compound climate-related risks to biodiversity, water and food security, and livelihoods, especially if implemented at large scales, especially in regions with insecure land tenure (*high confidence*). {Box 2.2, 4.1, 4.7, 5.13, Table 5.18, Box 9.3, Box 13.2, CCB NATURAL, CWGB BIOECONOMY}

B.5.5 Solar radiation modification approaches, if they were to be implemented, introduce a widespread range of new risks to people and ecosystems, which are not well understood (*high confidence*). Solar radiation modification approaches have potential to offset warming and ameliorate some climate hazards, but substantial residual climate change or overcompensating change would occur at regional scales and seasonal timescales (*high confidence*). Large uncertainties and knowledge gaps are associated with the potential of solar radiation modification approaches to reduce climate change risks. Solar radiation modification would not stop atmospheric CO_2 concentrations from increasing or reduce resulting ocean acidification under continued anthropogenic emissions (*high confidence*). {CWGB SRM}

Impacts of Temporary Overshoot

B.6 If global warming transiently exceeds 1.5°C in the coming decades or later (overshoot)[37], then many human and natural systems will face additional severe risks, compared to remaining below 1.5°C (*high confidence*). Depending on the magnitude and duration of overshoot, some impacts will cause release of additional greenhouse gases (*medium confidence*) and some will be irreversible, even if global warming is reduced (*high confidence*). (Box SPM.1, Figure SPM.3) {2.5, 3.4, 12.3, 16.6, CCB DEEP, CCB SLR}

B.6.1 While model-based assessments of the impacts of overshoot pathways are limited, observations and current understanding of processes permit assessment of impacts from overshoot. Additional warming, e.g., above 1.5°C during an overshoot period this century, will result in irreversible impacts on certain ecosystems with low resilience, such as polar, mountain, and coastal ecosystems, impacted by ice-sheet, glacier melt, or by accelerating and higher committed sea level rise (*high confidence*).[38] Risks to human systems will increase, including those to infrastructure, low-lying coastal settlements, some ecosystem-based adaptation measures, and associated livelihoods (*high confidence*), cultural and spiritual values (*medium confidence*). Projected impacts are less severe with shorter duration and lower levels of overshoot (*medium confidence*). {2.5, 3.4, 12.3, 13.2, 16.5, 16.6, CCP1.2, CCP2.2, CCP5.3, CCP6.1, CCP6.2, CCB SLR, WGI AR6 SPM B.5, WGI AR6 SPM C.3, SROCC 2.3, SROCC 5.4}

37 In this report, overshoot pathways exceed 1.5°C global warming and then return to that level, or below, after several decades.

38 Despite limited evidence specifically on the impacts of a temporary overshoot of 1.5°C, a much broader evidence base from process understanding and the impacts of higher global warming levels allows a high confidence statement on the irreversibility of some impacts that would be incurred following such an overshoot.

B.6.2 Risk of severe impacts increase with every additional increment of global warming during overshoot (*high confidence*). In high-carbon ecosystems (currently storing 3,000 to 4,000 GtC)[39] such impacts are already observed and are projected to increase with every additional increment of global warming, such as increased wildfires, mass mortality of trees, drying of peatlands, and thawing of permafrost, weakening natural land carbon sinks and increasing releases of greenhouse gases (*medium confidence*). The resulting contribution to a potential amplification of global warming indicates that a return to a given global warming level or below would be more challenging (*medium confidence*). {2.4, 2.5, CCP4.2, WGI AR6 SPM B.4.3, SROCC 5.4}

C: Adaptation Measures and Enabling Conditions

Adaptation, in response to current climate change, is reducing climate risks and vulnerability mostly via adjustment of existing systems. Many adaptation options exist and are used to help manage projected climate change impacts, but their implementation depends upon the capacity and effectiveness of governance and decision-making processes. These and other enabling conditions can also support climate resilient development (Section D).

Current Adaptation and its Benefits

C.1 Progress in adaptation planning and implementation has been observed across all sectors and regions, generating multiple benefits (*very high confidence*). However, adaptation progress is unevenly distributed with observed adaptation gaps[40] (*high confidence*). Many initiatives prioritize immediate and near-term climate risk reduction which reduces the opportunity for transformational adaptation (*high confidence*). {2.6, 5.14, 7.4, 10.4, 12.5, 13.11, 14.7, 16.3, 17.3, CCP5.2, CCP5.4}

C.1.1 Adaptation planning and implementation have continued to increase across all regions (*very high confidence*). Growing public and political awareness of climate impacts and risks has resulted in at least 170 countries and many cities including adaptation in their climate policies and planning processes (*high confidence*). Decision support tools and climate services are increasingly being used (*very high confidence*). Pilot projects and local experiments are being implemented in different sectors (*high confidence*). Adaptation can generate multiple additional benefits such as improving agricultural productivity, innovation, health and well-being, food security, livelihood, and biodiversity conservation as well as reduction of risks and damages (*very high confidence*). {1.4, 2.6, 3.5, 3.6, 4.7, 4.8, 5.4, 5.6, 5.10, 6.4, 7.4, 8.5, 9.3, 9.6, 10.4, 12.5, 13.11, 15.5, 16.3, 17.2, 17.3, 17.5, CCP5.4, CCB ADAPT, CCB NATURAL}

C.1.2 Despite progress, adaptation gaps exist between current levels of adaptation and levels needed to respond to impacts and reduce climate risks (*high confidence*). Most observed adaptation is fragmented, small in scale, incremental, sector-specific, designed to respond to current impacts or near-term risks, and focused more on planning rather than implementation (*high confidence*). Observed adaptation is unequally distributed across regions *(high confidence)*, and gaps are partially driven by widening disparities between the estimated costs of adaptation and documented finance allocated to adaptation (*high confidence*). The largest adaptation gaps exist among lower income population groups (*high confidence*). At current rates of adaptation planning and implementation the adaptation gap will continue to grow (*high confidence*). As adaptation options often have long implementation times, long-term planning and accelerated implementation, particularly in the next decade, is important to close adaptation gaps, recognising that constraints remain for some regions (*high confidence*). {1.1, 1.4, 5.6, 6.3, Figure 6.4, 7.4, 8.3, 10.4, 11.3, 11.7, 13.11, Box 13.1, 15.2, 15.5, 16.3, 16.5, Box 16.1, Figure 16.4, Figure 16.5, 17.4, 18.2, CCP2.4, CCP5.4, CCB FINANCE, CCB SLR}

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39 At the global scale, terrestrial ecosystems currently remove more carbon from the atmosphere (-3.4 ± 0.9 Gt yr^{-1}) than they emit ($+1.6 \pm 0.7$ Gt yr^{-1}), a net sink of -1.9 ± 1.1 Gt yr^{-1}. However, recent climate change has shifted some systems in some regions from being net carbon sinks to net carbon sources.

40 Adaptation gaps are defined as the difference between actually implemented adaptation and a societally set goal, determined largely by preferences related to tolerated climate change impacts and reflecting resource limitations and competing priorities.

Future Adaptation Options and their Feasibility

C.2 There are feasible[41] and effective[42] adaptation options which can reduce risks to people and nature. The feasibility of implementing adaptation options in the near-term differs across sectors and regions (*very high confidence*). The effectiveness of adaptation to reduce climate risk is documented for specific contexts, sectors and regions (*high confidence*) and will decrease with increasing warming (*high confidence*). Integrated, multi-sectoral solutions that address social inequities, differentiate responses based on climate risk and cut across systems, increase the feasibility and effectiveness of adaptation in multiple sectors (*high confidence*). (Figure SPM.4) {Figure TS.6e, 1.4, 3.6, 4.7, 5.12, 6.3, 7.4, 11.3, 11.7, 13.2, 15.5, 17.6, CCP2.3, CCB FEASIB}

Land, Ocean and Ecosystems Transition

C.2.1 Adaptation to water-related risks and impacts make up the majority of all documented adaptation (*high confidence*). For inland flooding, combinations of non-structural measures like early warning systems and structural measures like levees have reduced loss of lives (*medium confidence*). Enhancing natural water retention such as by restoring wetlands and rivers, land use planning such as no build zones or upstream forest management, can further reduce flood risk (*medium confidence*). On-farm water management, water storage, soil moisture conservation and irrigation are some of the most common adaptation responses and provide economic, institutional or ecological benefits and reduce vulnerability (*high confidence*). Irrigation is effective in reducing drought risk and climate impacts in many regions and has several livelihood benefits, but needs appropriate management to avoid potential adverse outcomes, which can include accelerated depletion of groundwater and other water sources and increased soil salinization (*medium confidence*). Large scale irrigation can also alter local to regional temperature and precipitation patterns (*high confidence*), including both alleviating and exacerbating temperature extremes (*medium confidence*). The effectiveness of most water-related adaptation options to reduce projected risks declines with increasing warming (*high confidence*). {4.1, 4.6, 4.7, Box 4.3, Box 4.6, Box 4.7, Figure 4.22, Figure 4.28, Figure 4.29, Table 4.9, 9.3, 9.7, 11.3, 12.5, 13.1, 13.2, 16.3, CCP5.4}

C.2.2 Effective adaptation options, together with supportive public policies enhance food availability and stability and reduce climate risk for food systems while increasing their sustainability (*medium confidence*). Effective options include cultivar improvements, agroforestry, community-based adaptation, farm and landscape diversification, and urban agriculture (*high confidence*). Institutional feasibility, adaptation limits of crops and cost effectiveness also influence the effectiveness of the adaptation options (*limited evidence*, *medium agreement*). Agroecological principles and practices, ecosystem-based management in fisheries and aquaculture, and other approaches that work with natural processes support food security, nutrition, health and well-being, livelihoods and biodiversity, sustainability and ecosystem services (*high confidence*). These services include pest control, pollination, buffering of temperature extremes, and carbon sequestration and storage (*high confidence*). Trade-offs and barriers associated with such approaches include costs of establishment, access to inputs and viable markets, new knowledge and management (*high confidence*) and their potential effectiveness varies by socioeconomic context, ecosystem zone, species combinations and institutional support (*medium confidence*). Integrated, multi-sectoral solutions that address social inequities and differentiate responses based on climate risk and local situation will enhance food security and nutrition (*high confidence*). Adaptation strategies which reduce food loss and waste or support balanced diets[33] (as described in the IPCC Special Report on Climate Change and Land) contribute to nutrition, health, biodiversity and other environmental benefits (*high confidence*). {3.2, 4.7, 4.6, Box 4.3, 5.4, 5.5, 5.6, 5.8, 5.9, 5.10, 5.11, 5.12, 5.13, 5.14, Box 5.10, Box 5.13, 6.3, 7.4, 10.4, 12.5, 13.5, 13.10, 14.5, CCP5.4, CCB FEASIB, CCB HEALTH, CCB MOVING PLATE, CCB NATURAL, CWGB BIOECONOMY}

C.2.3 Adaptation for natural forests[43] includes conservation, protection and restoration measures. In managed forests[43], adaptation options include sustainable forest management, diversifying and adjusting tree species compositions to build resilience, and managing increased risks from pests and diseases and wildfires. Restoring natural forests and drained peatlands and improving sustainability of managed forests, generally enhances the resilience of carbon stocks and sinks. Cooperation, and inclusive decision making, with local communities and Indigenous Peoples, as well as recognition of inherent rights of Indigenous Peoples, is integral to successful forest adaptation in many areas. (*high confidence*) {2.6, Box 2.2, 5.6, 5.13, Table 5.23, 11.4, 12.5, 13.5, Box 14.1, Box 14.2, CCP7.5, Box CCP7.1, CCB FEASIB, CCB INDIG, CCB NATURAL}

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41 In this report, feasibility refers to the potential for a mitigation or adaptation option to be implemented. Factors influencing feasibility are context-dependent, temporally dynamic, and may vary between different groups and actors. Feasibility depends on geophysical, environmental-ecological, technological, economic, socio-cultural and institutional factors that enable or constrain the implementation of an option. The feasibility of options may change when different options are combined and increase when enabling conditions are strengthened.

42 Effectiveness refers to the extent to which an adaptation option is anticipated or observed to reduce climate-related risk.

43 In this report, the term natural forests describes those which are subject to little or no direct human intervention, whereas the term managed forests describes those where planting or other management activities take place, including those managed for commodity production.

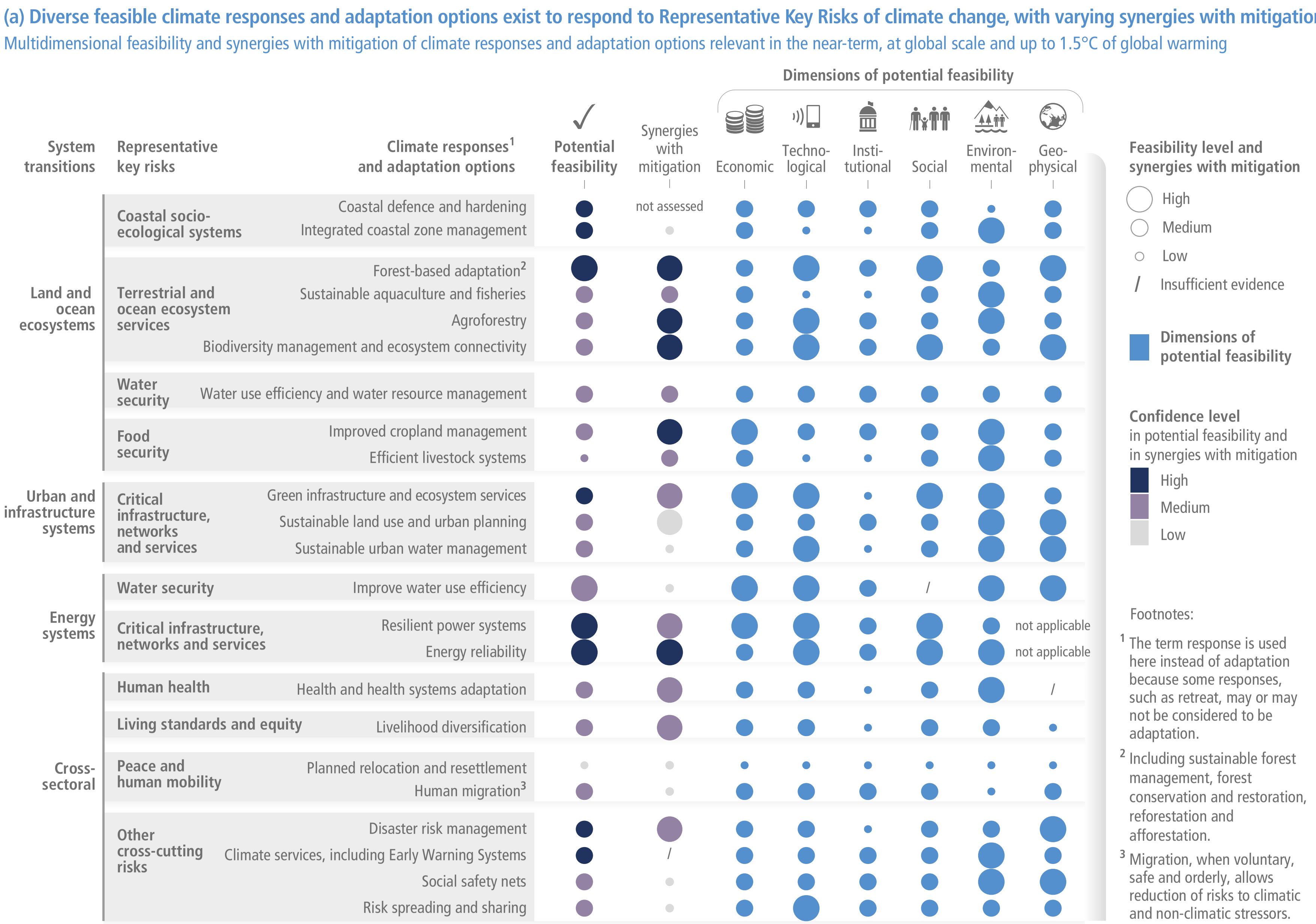

Figure SPM.4 | (a) Climate responses and adaptation options, organized by System Transitions and Representative Key Risks (RKRs), are assessed for their multidimensional feasibility at global scale, in the near term and up to 1.5°C global warming. As literature above 1.5°C is limited, feasibility at 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 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

System transitions	Climate responses[1] and adaptation options	Observed relation with sectors and groups at risk: Ecosystems and their services	Ethnic groups	Gender equity	Low-income groups	Relation with Sustainable Development Goals[4, 5]: 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	Coastal defence and hardening	–	/	–	–			+						+	–	•		■	•	•		
	Integrated coastal zone management	•	/	•	/	+		+	+	+			+			+		■	+	+	+	+
Land and ocean ecosystems	Forest-based adaptation[2]	not assessed				+	•	+		+	+	+	+	+	+	+	+	■		+		
	Sustainable aquaculture and fisheries	+	+	+	+	+	+	+		+	+		+	+	+	+	+	■	+	+		
	Agroforestry	not assessed				+	+	+		+	+	+	+		+	+	+	■		+		+
	Biodiversity management and ecosystem connectivity	+	/	/	–			+			+					+	+	■		+		
	Water use efficiency and water resource management	+	•	•	•			+		•	+	•			•	+	+	■		+	•	
	Improved cropland management	+	+	+	+	+	+	+		+	+	+	+	+	•		+	■		+	+	+
	Efficient livestock systems	not assessed				+	+	+		•			+	+			+	■		+		
Urban and infrastructure systems	Green infrastructure and ecosystem services	+	/	+	+			+			+		+	+	+	+	+	■				
	Sustainable land use and urban planning	+	•	•	•			+			+		+	+	+	+		■				
	Sustainable urban water management	not assessed						+			+		+	+	+	+		■				
Energy systems	Improve water use efficiency	+	/	•	•	+	+	+	+	+	+	+			+			■		+		
	Resilient power systems	not assessed				+	+	+	+	+	+	+			+			■				
	Energy reliability	not assessed				+	+	+	+	+	+	+			+			■				
Cross-sectoral	Health and health systems adaptation	•	•	+	+	+	+	+	+	+	+	+	+		+	+	+	■	+	+	+	+
	Livelihood diversification	+	/	•	•	+	+	+	+	•	•	•	•	•	–	–	•	■		•		
	Planned relocation and resettlement	+	•	•	•													■			•	
	Human migration[3]	+	•	•	•	•	•	•	+	•			+		•	•		■			•	
	Disaster risk management	not assessed				+	+	+	+	•	+			•	+	+		■			+	
	Climate services, including Early Warning Systems	+	/	–	+	+	+	+		•				•	•	+		■		+	+	+
	Social safety nets	•	+	+	+	+	+	+	+				+		+	+		■				
	Risk spreading and sharing	–	–	•	•	+	+	+					•	+			•	■		•		

Types of relation

- \+ With benefits
- – With dis-benefits
- • Not clear or mixed
- / Insufficient evidence

Confidence level in type of relation with sectors and groups at risk

- High
- Medium
- Low

■ **Related Sustainable Development Goals**

1: No Poverty
2: Zero Hunger
3: Good Health and Well-being
4: Quality Education
5: Gender Equality
6: Clean Water and Sanitation
7: Affordable and Clean Energy
8: Decent Work and Economic Growth
9: Industry, Innovation and Infrastructure
10: Reducing Inequality
11: Sustainable Cities and Communities
12: Responsible Consumption and Production
13: Climate Action
14: Life Below Water
15: Life On Land
16: Peace, Justice, and Strong Institutions
17: Partnerships for the Goals

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 SPM.4 | (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}

C.2.4 Conservation, protection and restoration of terrestrial, freshwater, coastal and ocean ecosystems, together with targeted management to adapt to unavoidable impacts of climate change, reduces the vulnerability of biodiversity to climate change (*high confidence*). The resilience of species, biological communities and ecosystem processes increases with size of natural area, by restoration of degraded areas and by reducing non-climatic stressors (*high confidence*). To be effective, conservation and restoration actions will increasingly need to be responsive, as appropriate, to ongoing changes at various scales, and plan for future changes in ecosystem structure, community composition and species' distributions, especially as 1.5°C global warming is approached and even more so if it is exceeded (*high confidence*). Adaptation options, where circumstances allow, include facilitating the movement of species to new ecologically appropriate locations, particularly through increasing connectivity between conserved or protected areas, targeted intensive management for vulnerable species and protecting refugial areas where species can survive locally (*medium confidence*). {2.3, 2,6, Figure 2.1, Table 2.6, 3.3, 3.6, Box 3.4, 4.6, Box 4.6, Box 11.2, 12.3, 12.5, 13.4, 14.7, CCP5.4, CCB FEASIB}

C.2.5 Effective Ecosystem-based Adaptation[44] reduces a range of climate change risks to people, biodiversity and ecosystem services with multiple co-benefits (*high confidence*). Ecosystem-based Adaptation is vulnerable to climate change impacts, with effectiveness declining with increasing global warming (*high confidence*). Urban greening using trees and other vegetation can provide local cooling (*very high confidence*). Natural river systems, wetlands and upstream forest ecosystems reduce flood risk by storing water and slowing water flow, in most circumstances (*high confidence*). Coastal wetlands protect against coastal erosion and flooding associated with storms and sea level rise where sufficient space and adequate habitats are available until rates of sea level rise exceeds natural adaptive capacity to build sediment (*very high confidence*). {2.4, 2.5, 2.6, Table 2.7, 3.4, 3.5, 3.6, Figure 3.26, 4.6, Box 4.6, Box 4.7, 5.5, 5.14, Box 5.11, 6.3, 6.4, Figure 6.6, 7.4, 8.5, 8.6, 9.6, 9.8, 9.9, 10.2, 11.3, 12.5, 13.3, 13.4, 13.5, 14.5, Box 14.7, 16.3, 18.3, CCP5.4, CCB FEASIB.3, CCB HEALTH, CCB MOVING PLATE, CCB NATURAL, CWGB BIOECONOMY}

Urban, Rural and Infrastructure Transition

C.2.6 Considering climate change impacts and risks in the design and planning of urban and rural settlements and infrastructure is critical for resilience and enhancing human well-being (*high confidence*). The urgent provision of basic services, infrastructure, livelihood diversification and employment, strengthening of local and regional food systems and community-based adaptation enhance lives and livelihoods, particularly of low-income and marginalised groups (*high confidence*). Inclusive, integrated and long-term planning at local, municipal, sub-national and national scales, together with effective regulation and monitoring systems and financial and technological resources and capabilities foster urban and rural system transition (*high confidence*). Effective partnerships between governments, civil society, and private sector organizations, across scales provide infrastructure and services in ways that enhance the adaptive capacity of vulnerable people (*medium* to *high confidence*). {5.12, 5.13, 5.14, 6.3, 6.4, Box 6.3, Box 6.6, Table 6.6, 7.4, 12.5, 13.6, 14.5, Box 14.4, Box 17.4, CCP2.3, CCP2.4, CCP5.4, CCB FEASIB}

C.2.7 An increasing number of adaptation responses exist for urban systems, but their feasibility and effectiveness is constrained by institutional, financial, and technological access and capacity, and depends on coordinated and contextually appropriate responses across physical, natural and social infrastructure (*high confidence*). Globally, more financing is directed at physical infrastructure than natural and social infrastructure (*medium confidence*) and there is *limited evidence* of investment in the informal settlements hosting the most vulnerable urban residents (*medium* to *high confidence*). Ecosystem-based adaptation (e.g., urban agriculture and forestry, river restoration) has increasingly been applied in urban areas (*high confidence*). Combined ecosystem-based and structural adaptation responses are being developed, and there is growing evidence of their potential to reduce adaptation costs and contribute to flood control, sanitation, water resources management, landslide prevention and coastal protection (*medium confidence*). {3.6, Box 4.6, 5.12, 6.3, 6.4, Table 6.8, 7.4, 9.7, 9.9, 10.4, Table 10.3, 11.3, 11.7, Box 11.6, 12.5, 13.2, 13.3, 13.6, 14.5, 15.5, 17.2, Box 17.4, CCP2.3, CCP 3.2, CCP5.4, CCB FEASIB, CCB SLR, SROCC SPM}

44 Ecosystem based Adaptation (EbA) is recognised internationally under the Convention on Biological Diversity (CBD14/5). A related concept is Nature-based Solutions (NbS), which includes a broader range of approaches with safeguards, including those that contribute to adaptation and mitigation. The term 'Nature-based Solutions' is widely but not universally used in the scientific literature. The term is the subject of ongoing debate, with concerns that it may lead to the misunderstanding that NbS on its own can provide a global solution to climate change.

C.2.8 Sea level rise poses a distinctive and severe adaptation challenge as it implies dealing with slow onset changes and increased frequency and magnitude of extreme sea level events which will escalate in the coming decades (*high confidence*). Such adaptation challenges would occur much earlier under high rates of sea level rise, in particular if low-likelihood, high impact outcomes associated with collapsing ice sheets occur (*high confidence*). Responses to ongoing sea level rise and land subsidence in low-lying coastal cities and settlements and small islands include protection, accommodation, advance and planned relocation (*high confidence*)[45]. These responses are more effective if combined and/or sequenced, planned well ahead, aligned with sociocultural values and development priorities, and underpinned by inclusive community engagement processes (*high confidence*). { 6.2, 10.4, 11.7, Box 11.6, 13.2, 14.5, 15.5, CCP2.3, CCB SLR, WGI AR6 SPM B.5, WGI AR6 SPM C.3, SROCC SPM C3.2}

C.2.9 Approximately 3.4 billion people globally live in rural areas around the world, and many are highly vulnerable to climate change. Integrating climate adaptation into social protection programs, including cash transfers and public works programmes, is highly feasible and increases resilience to climate change, especially when supported by basic services and infrastructure. Social safety nets are increasingly being reconfigured to build adaptive capacities of the most vulnerable in rural and also urban communities. Social safety nets that support climate change adaptation have strong co-benefits with development goals such as education, poverty alleviation, gender inclusion and food security. (*high confidence*) {5.14, 9.4, 9.10, 9.11, 12.5, 14.5, CCP5.4, CCB FEASIB, CCB GENDER}

Energy System Transition

C.2.10 Within energy system transitions, the most feasible adaptation options support infrastructure resilience, reliable power systems and efficient water use for existing and new energy generation systems (*very high confidence*). Energy generation diversification, including with renewable energy resources and generation that can be decentralised depending on context (e.g., wind, solar, small scale hydroelectric) and demand side management (e.g., storage, and energy efficiency improvements) can reduce vulnerabilities to climate change, especially in rural populations (*high confidence*). Adaptations for hydropower and thermo-electric power generation are effective in most regions up to 1.5°C to 2°C, with decreasing effectiveness at higher levels of warming (*medium confidence*). Climate responsive energy markets, updated design standards on energy assets according to current and projected climate change, smart-grid technologies, robust transmission systems and improved capacity to respond to supply deficits have high feasibility in the medium- to long-term, with mitigation co-benefits (*very high confidence*). {4.6, 4.7, Figure 4.28, Figure 4.29, 10.4, Table 11.8, 13.6, Figure 13.16, Figure 13.19, 18.3,CCP5.2, CCP5.4, CCB FEASIB, CWGB BIOECONOMY}

Cross-cutting Options

C.2.11 Strengthening the climate resiliency of health systems will protect and promote human health and well-being (*high confidence*). There are multiple opportunities for targeted investments and finance to protect against exposure to climate hazards, particularly for those at highest risk. Heat Health Action Plans that include early warning and response systems are effective adaptation options for extreme heat (*high confidence*). Effective adaptation options for water-borne and food-borne diseases include improving access to potable water, reducing exposure of water and sanitation systems to flooding and extreme weather events, and improved early warning systems (*very high confidence*). For vector-borne diseases, effective adaptation options include surveillance, early warning systems, and vaccine development (*very high confidence*). Effective adaptation options for reducing mental health risks under climate change include improving surveillance, access to mental health care, and monitoring of psychosocial impacts from extreme weather events (*high confidence*). Health and well-being would benefit from integrated adaptation approaches that mainstream health into food, livelihoods, social protection, infrastructure, water and sanitation policies requiring collaboration and coordination at all scales of governance (*very high confidence*). {5.12, 6.3, 7.4, 9.10, Box 9.7, 11.3, 12.5, 13.7, 14.5, CCB COVID, CCB FEASIB, CCB ILLNESS }

C.2.12 Increasing adaptive capacities minimises the negative impacts of climate-related displacement and involuntary migration for migrants and sending and receiving areas (*high confidence*). This improves the degree of choice under which migration decisions are made, ensuring safe and orderly movements of people within and between countries (*high confidence*). Some development reduces underlying vulnerabilities associated with conflict, and adaptation contributes by reducing the impacts of climate change on climate sensitive drivers of conflict (*high confidence*). Risks to peace are reduced, for example, by supporting people in climate-sensitive economic activities (*medium confidence*) and advancing women's empowerment (*high confidence*). {7.4, Box 9.8, Box 10.2, 12.5, CCB FEASIB, CCB MIGRATE}

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

C.2.13 There are a range of adaptation options, such as disaster risk management, early warning systems, climate services and risk spreading and sharing that have broad applicability across sectors and provide greater benefits to other adaptation options when combined (*high confidence*). For example, climate services that are inclusive of different users and providers can improve agricultural practices, inform better water use and efficiency, and enable resilient infrastructure planning (*high confidence*). {2.6, 3.6, 4.7, 5.4, 5.5, 5.6, 5.8, 5.9, 5.12, 5.14, 9.4, 9.8, 10.4, 12.5, 13.11, CCP5.4, CCB FEASIB, CCB MOVING PLATE}

Limits to Adaptation

C.3 Soft limits to some human adaptation have been reached, but can be overcome by addressing a range of constraints, primarily financial, governance, institutional and policy constraints (*high confidence*). Hard limits to adaptation have been reached in some ecosystems (*high confidence*). With increasing global warming, losses and damages will increase and additional human and natural systems will reach adaptation limits (*high confidence*). {Figure TS.7, 1.4, 2.4, 2.5, 2.6, 3.4, 3.6, 4.7, Figure 4.30, 5.5, Table 8.6, Box 10.7, 11.7, Table 11.16, 12.5, 13.2, 13.5, 13.6, 13.10, 13.11, Figure 13.21, 14.5, 15.6, 16.4, Figure 16.8, Table 16.3, Table 16.4, CCP1.2, CCP1.3, CCP2.3, CCP3.3, CCP5.2, CCP5.4, CCP6.3, CCP7.3, CCB SLR}

C.3.1 Soft limits to some human adaptation have been reached, but can be overcome by addressing a range of constraints, which primarily consist of financial, governance, institutional and policy constraints (*high confidence*). For example, individuals and households in low-lying coastal areas in Australasia and Small Islands and smallholder farmers in Central and South America, Africa, Europe and Asia have reached soft limits (*medium confidence*). Inequity and poverty also constrain adaptation, leading to soft limits and resulting in disproportionate exposure and impacts for most vulnerable groups (*high confidence*). Lack of climate literacy[46] at all levels and limited availability of information and data pose further constraints to adaptation planning and implementation (*medium confidence*). {1.4, 4.7, 5.4, 8.4, Table 8.6, 9.1, 9.4, 9.5, 9.8, 11.7, 12.5 13.5, 15.3, 15.5, 15.6, 16.4, Box 16.1, Figure 16.8, CCP5.2, CCP5.4, CCP6.3}

C.3.2 Financial constraints are important determinants of soft limits to adaptation across sectors and all regions (*high confidence*). Although global tracked climate finance has shown an upward trend since AR5, current global financial flows for adaptation, including from public and private finance sources, are insufficient for and constrain implementation of adaptation options especially in developing countries (*high confidence*). The overwhelming majority of global tracked climate finance was targeted to mitigation while a small proportion was targeted to adaptation (*very high confidence*). Adaptation finance has come predominantly from public sources (*very high confidence*). Adverse climate impacts can reduce the availability of financial resources by incurring losses and damages and through impeding national economic growth, thereby further increasing financial constraints for adaptation, particularly for developing and least developed countries (*medium confidence*). {Figure TS.7, 1.4, 2.6, 3.6, 4.7, Figure 4.30, 5.14, 7.4, 8.4, Table 8.6, 9.4, 9.9, 9.11, 10.5, 12.5, 13.3, 13.11, Box 14.4, 15.6, 16.2, 16.4, Figure 16.8, Table 16.4, 17.4, 18.1, CCP2.4, CCP5.4, CCP6.3, CCB FINANCE}

C.3.3 Many natural systems are near the hard limits of their natural adaptation capacity and additional systems will reach limits with increasing global warming (*high confidence*). Ecosystems already reaching or surpassing hard adaptation limits include some warm-water coral reefs, some coastal wetlands, some rainforests, and some polar and mountain ecosystems (*high confidence*). Above 1.5°C global warming level, some Ecosystem-based Adaptation measures will lose their effectiveness in providing benefits to people as these ecosystems will reach hard adaptation limits (*high confidence*). (Figure SPM.4) {1.4, 2.4, 2.6, 3.4, 3.6, 9.6, Box 11.2, 13.4, 14.5, 15.5, 16.4, 16.6, 17.2, CCP1.2, CCP5.2, CCP6.3, CCP7.3, CCB SLR}

C.3.4 In human systems, some coastal settlements face soft adaptation limits due to technical and financial difficulties of implementing coastal protection (*high confidence*). Above 1.5°C global warming level, limited freshwater resources pose potential hard limits for Small Islands and for regions dependent on glacier and snow-melt (*medium confidence*). By 2°C global warming level, soft limits are projected for multiple staple crops in many growing areas, particularly in tropical regions (*high confidence*). By 3°C global warming level, soft limits are projected for some water management measures for many regions, with hard limits projected for parts of Europe (*medium confidence*). Transitioning from incremental to transformational adaptation can help overcome soft adaptation limits (*high confidence*). {1.4, 4.7, 5.4, 5.8, 7.2, 7.3, 8.4, Table 8.6, 9.8, 10.4, 12.5, 13.2, 13.6, 16.4, 17.2, CCP1.3. Box CCP1.1, CCP2.3, CCP3.3, CCP4.4, CCP5.3, CCB SLR}

C.3.5 Adaptation does not prevent all losses and damages, even with effective adaptation and before reaching soft and hard limits. Losses and damages are unequally distributed across systems, regions and sectors and are not comprehensively addressed by current financial, governance and institutional arrangements, particularly in vulnerable developing countries. With increasing global warming, losses and damages increase and become increasingly difficult to avoid, while strongly concentrated among the poorest vulnerable populations. (*high confidence*) {1.4, 2.6, 3.4, 3.6, 6.3, Figure 6.4, 8.4, 13.2, 13.7, 13.10, 17.2, CCP2.3, CCP4.4, CCB LOSS, CCB SLR, CWGB ECONOMIC}

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46 Climate literacy encompasses being aware of climate change, its anthropogenic causes and implications.

Avoiding Maladaptation

C.4 There is increased evidence of maladaptation[15] across many sectors and regions since the AR5. Maladaptive responses to climate change can create lock-ins of vulnerability, exposure and risks that are difficult and expensive to change and exacerbate existing inequalities. Maladaptation can be avoided by flexible, multi-sectoral, inclusive and long-term planning and implementation of adaptation actions with benefits to many sectors and systems. (*high confidence*) {1.3, 1.4, 2.6, Box 2.2, 3.2, 3.6, 4.6, 4.7, Box 4.3, Box 4.5, Figure 4.29, 5.6, 5.13, 8.2, 8.3, 8.4, 8.6, 9.6, 9.7, 9.8, 9.9, 9.10, 9.11, Box 9.5, Box 9.8, Box 9.9, Box 11.6, 13.11, 13.3, 13.4, 13.5, 14.5, 15.5, 15.6, 16.3, 17.2, 17.3, 17.4, 17.5, 17.6, CCP2.3, CCP2.3, CCP5.4, CCB DEEP, CCB NATURAL, CCB SLR, CWGB BIOECONOMY}

C.4.1 Actions that focus on sectors and risks in isolation and on short-term gains often lead to maladaptation if long-term impacts of the adaptation option and long-term adaptation commitment are not taken into account (*high confidence*). The implementation of these maladaptive actions can result in infrastructure and institutions that are inflexible and/or expensive to change (*high confidence*). For example, seawalls effectively reduce impacts to people and assets in the short-term but can also result in lock-ins and increase exposure to climate risks in the long-term unless they are integrated into a long-term adaptive plan (*high confidence*). Adaptation integrated with development reduces lock-ins and creates opportunities (e.g., infrastructure upgrading) (*medium confidence*). {1.4, 3.4, 3.6, 10.4, 11.7, Box 11.6, 13.2, 17.2, 17.5, 17.6, CCP 2.3, CCB DEEP, CCB SLR}

C.4.2 Biodiversity and ecosystem resilience to climate change are decreased by maladaptive actions, which also constrain ecosystem services. Examples of these maladaptive actions for ecosystems include fire suppression in naturally fire-adapted ecosystems or hard defences against flooding. These actions reduce space for natural processes and represent a severe form of maladaptation for the ecosystems they degrade, replace or fragment, thereby reducing their resilience to climate change and the ability to provide ecosystem services for adaptation. Considering biodiversity and autonomous adaptation in long-term planning processes reduces the risk of maladaptation. (*high confidence*) {2.4, 2.6, Table 2.7, 3.4, 3.6, 4.7, 5.6, 5.13, Table 5.21, Table 5.23, Box 11.2, 13.2, Box 13.2, 17.2, 17.5, CCP5.4}

C.4.3 Maladaptation especially affects marginalised and vulnerable groups adversely (e.g., Indigenous Peoples, ethnic minorities, low-income households, informal settlements), reinforcing and entrenching existing inequities. Adaptation planning and implementation that do not consider adverse outcomes for different groups can lead to maladaptation, increasing exposure to risks, marginalising people from certain socioeconomic or livelihood groups, and exacerbating inequity. Inclusive planning initiatives informed by cultural values, Indigenous knowledge, local knowledge, and scientific knowledge can help prevent maladaptation. (*high confidence*) (Figure SPM.4) {2.6, 3.6, 4.3, 4.6, 4.8, 5.12, 5.13, 5.14, 6.1, Box 7.1, 8.4, 11.4, 12.5, Box 13.2, 14.4, Box 14.1, 17.2, 17.5, 18.2, 17.2, CCP2.4}

C.4.4 To minimize maladaptation, multi-sectoral, multi-actor and inclusive planning with flexible pathways encourages low-regret[47] and timely actions that keep options open, ensure benefits in multiple sectors and systems and indicate the available solution space for adapting to long-term climate change (*very high confidence*). Maladaptation is also minimized by planning that accounts for the time it takes to adapt (*high confidence*), the uncertainty about the rate and magnitude of climate risk (*medium confidence*) and a wide range of potentially adverse consequences of adaptation actions (*high confidence*). {1.4, 3.6, 5.12, 5.13, 5.14, 11.6, 11.7, 17.3, 17.6, CCP2.3, CCP2.4, CCP5.4, CCB DEEP, CCB SLR}

Enabling Conditions

C.5 Enabling conditions are key for implementing, accelerating and sustaining adaptation in human systems and ecosystems. These include political commitment and follow-through, institutional frameworks, policies and instruments with clear goals and priorities, enhanced knowledge on impacts and solutions, mobilization of and access to adequate financial resources, monitoring and evaluation, and inclusive governance processes. (*high confidence*) {1.4, 2.6, 3.6, 4.8, 6.4, 7.4, 8.5, 9.4, 10.5, 11.4, 11.7, 12.5, 13.11, 14.7, 15.6, 17.4, 18.4, CCP2.4, CCP5.4, CCB FINANCE, CCB INDIG}

C.5.1 Political commitment and follow-through across all levels of government accelerate the implementation of adaptation actions (*high confidence*). Implementing actions can require large upfront investments of human, financial and technological resources (*high confidence*), whilst some benefits could only become visible in the next decade or beyond (*medium confidence*). Accelerating commitment and follow-through is promoted by rising public awareness, building business cases for adaptation, accountability and transparency mechanisms, monitoring and evaluation of adaptation progress, social movements, and climate-related litigation in some regions (*medium confidence*). {3.6, 4.8, 5.8, 6.4, 8.5, 9.4, 11.7, 12.5, 13.11, 17.4, 17.5, 18.4, CCP2.4, CCB COVID}

47 From AR5, an option *that would generate net social and/or economic benefits under current climate change and a range of future climate change scenarios*, and represent one example of robust strategies.

C.5.2 Institutional frameworks, policies and instruments that set clear adaptation goals and define responsibilities and commitments and that are coordinated amongst actors and governance levels, strengthen and sustain adaptation actions (*very high confidence*). Sustained adaptation actions are strengthened by mainstreaming adaptation into institutional budget and policy planning cycles, statutory planning, monitoring and evaluation frameworks and into recovery efforts from disaster events (*high confidence*). Instruments that incorporate adaptation such as policy and legal frameworks, behavioural incentives, and economic instruments that address market failures, such as climate risk disclosure, inclusive and deliberative processes strengthen adaptation actions by public and private actors (*medium confidence*). {1.4, 3.6, 4.8, 5.14, 6.3, 6.4, 7.4, 9.4, 10.4, 11.7, Box 11.6, Table 11.17, 13.10, 13.11, 14.7, 15.6, 17.3, 17.4, 17.5, 17.6, 18.4, CCP2.4, CCP5.4, CCP6.3, CCB DEEP}

C.5.3 Enhancing knowledge on risks, impacts, and their consequences, and available adaptation options promotes societal and policy responses (*high confidence*). A wide range of top-down, bottom-up and co-produced processes and sources can deepen climate knowledge and sharing, including capacity building at all scales, educational and information programmes, using the arts, participatory modelling and climate services, Indigenous knowledge and local knowledge and citizen science (*high confidence*). These measures can facilitate awareness, heighten risk perception and influence behaviours (*high confidence*). {1.3, 3.6, 4.8, 5.9, 5.14, 6.4, Table 6.8, 7.4, 9.4, 10.5, 11.1, 11.7, 12.5, 13.9, 13.11, 14.3, 15.6, 15.6, 17.4, 18.4, CCP2.4.1, CCB INDIG}

C.5.4 With adaptation finance needs estimated to be higher than those presented in AR5, enhanced mobilization of and access to financial resources are essential for implementation of adaptation and to reduce adaptation gaps (*high confidence*). Building capacity and removing some barriers to accessing finance is fundamental to accelerate adaptation, especially for vulnerable groups, regions and sectors (*high confidence*). Public and private finance instruments include inter alia grants, guarantee, equity, concessional debt, market debt, and internal budget allocation as well as savings in households and insurance. Public finance is an important enabler of adaptation (*high confidence*). Public mechanisms and finance can leverage private sector finance for adaptation by addressing real and perceived regulatory, cost and market barriers, for example via public-private partnerships (*high confidence*). Financial and technological resources enable effective and ongoing implementation of adaptation, especially when supported by institutions with a strong understanding of adaptation needs and capacity (*high confidence*). {4.8, 5.14, 6.4, Table 6.10, 7.4, 9.4, Table 11.17, 12.5, 13.11, 15.6, 17.4, 18.4, Box 18.9, CCP5.4, CCB FINANCE}

C.5.5 Monitoring and evaluation (M&E) of adaptation are critical for tracking progress and enabling effective adaptation (*high confidence*). M&E implementation is currently limited (*high confidence*) but has increased since AR5 at local and national levels. Although most of the monitoring of adaptation is focused towards planning and implementation, the monitoring of outcomes is critical for tracking the effectiveness and progress of adaptation *(high confidence).* M&E facilitates learning on successful and effective adaptation measures, and signals when and where additional action may be needed. M&E systems are most effective when supported by capacities and resources and embedded in enabling governance systems (*high confidence*). {1.4, 2.6, 6.4, 7.4, 11.7, 11.8, 13.2, 13.11, 17.5, 18.4, CCP2.4, CCB DEEP, CCB ILLNESS, CCB NATURAL, CCB PROGRESS}

C.5.6 Inclusive governance that prioritises equity and justice in adaptation planning and implementation leads to more effective and sustainable adaptation outcomes (*high confidence*). Vulnerabilities and climate risks are often reduced through carefully designed and implemented laws, policies, processes, and interventions that address context specific inequities such as based on gender, ethnicity, disability, age, location and income (*high confidence*). These approaches, which include multi-stakeholder co-learning platforms, transboundary collaborations, community-based adaptation and participatory scenario planning, focus on capacity-building, and meaningful participation of the most vulnerable and marginalised groups, and their access to key resources to adapt (*high confidence*). {1.4, 2.6, 3.6, 4.8, 5.4, 5.8, 5.9, 5.13, 6.4, 7.4, 8.5, 11.8, 12.5, 13.11, 14.7, 15.5, 15.7, 17.3, 17.5, 18.4, CCP2.4, CCP5.4, CCP6.4, CCB GENDER, CCB HEALTH, CCB INDIG}

D: Climate Resilient Development

Climate resilient development integrates adaptation measures and their enabling conditions (Section C) with mitigation to advance sustainable development for all. Climate resilient development involves questions of equity and system transitions in land, ocean and ecosystems; urban and infrastructure; energy; industry; and society and includes adaptations for human, ecosystem and planetary health. Pursuing climate resilient development focuses on both where people and ecosystems are co-located as well as the protection and maintenance of ecosystem function at the planetary scale. Pathways for advancing climate resilient development are development trajectories that successfully integrate mitigation and adaptation actions to advance sustainable development. Climate resilient development pathways may be temporarily coincident with any RCP and SSP scenario used throughout AR6, but do not follow any particular scenario in all places and over all time.

Conditions for Climate Resilient Development

D.1 Evidence of observed impacts, projected risks, levels and trends in vulnerability, and adaptation limits, demonstrate that worldwide climate resilient development action is more urgent than previously assessed in AR5. Comprehensive, effective, and innovative responses can harness synergies and reduce trade-offs between adaptation and mitigation to advance sustainable development. (*very high confidence*) {2.6, 3.4, 3.6, 4.2, 4.6, 7.2, 7.4, 8.3, 8.4, 9.3, 10.6, 13.3, 13.8, 13.10, 14.7, 17.2, 18.3, Box 18.1, Figure 18.1, Table 18.5}

D.1.1 There is a rapidly narrowing window of opportunity to enable climate resilient development. Multiple climate resilient development pathways are still possible by which communities, the private sector, governments, nations and the world can pursue climate resilient development – each involving and resulting from different societal choices influenced by different contexts and opportunities and constraints on system transitions. Climate resilient development pathways are progressively constrained by every increment of warming, in particular beyond 1.5°C, social and economic inequalities, the balance between adaptation and mitigation varying by national, regional and local circumstances and geographies, according to capabilities including resources, vulnerability, culture and values, past development choices leading to past emissions and future warming scenarios, bounding the climate resilient development pathways remaining, and the ways in which development trajectories are shaped by equity, and social and climate justice. (*very high confidence*) {Figure TS.14d, 2.6, 4.7, 4.8, 5.14, 6.4, 7.4, 8.3, 9.4, 9.3, 9.4, 9.5, 10.6, 11.8, 12.5, 13.10, 14.7, 15.3, 18.5, CCP2.3, CCP3.4, CCP4.4, CCP5.3, CCP5.4, Table CCP5.2, CCP6.3, CCP7.5}

D.1.2 Opportunities for climate resilient development are not equitably distributed around the world (*very high confidence*). Climate impacts and risks exacerbate vulnerability and social and economic inequities and consequently increase persistent and acute development challenges, especially in developing regions and sub-regions, and in particularly exposed sites, including coasts, small islands, deserts, mountains and polar regions. This in turn undermines efforts to achieve sustainable development, particularly for vulnerable and marginalized communities (*very high confidence*). {2.5, 4.4, 4.7, 6.3, Box 6.4, Figure 6.5, 9.4, Table 18.5, CCP2.2, CCP3.2, CCP3.3, CCP5.4, CCP6.2, CCB HEALTH, CWGB URBAN}

D.1.3 Embedding effective and equitable adaptation and mitigation in development planning can reduce vulnerability, conserve and restore ecosystems, and enable climate resilient development. This is especially challenging in localities with persistent development gaps and limited resources (*high confidence*). Dynamic trade-offs and competing priorities exist between mitigation, adaptation, and development. Integrated and inclusive system-oriented solutions based on equity and social and climate justice reduce risks and enable climate resilient development (*high confidence*). {1.4, 2.6, Box 2.2, 3.6, 4.7, 4.8, Box 4.5, Box 4.8, 5.13, 7.4, 8.5, 9.4, Box 9.3, 10.6, 12.5, 12.6, 13.3, 13.4, 13.10, 13.11, 14.7, 18.4, CCB DEEP, CCP2, CCP5.4, CCB HEALTH, SRCCL}

Enabling Climate Resilient Development

D.2 Climate resilient development is enabled when governments, civil society and the private sector make inclusive development choices that prioritise risk reduction, equity and justice, and when decision-making processes, finance and actions are integrated across governance levels, sectors and timeframes (*very high confidence*). Climate resilient development is facilitated by international cooperation and by governments at all levels working with communities, civil society, educational bodies, scientific and other institutions, media, investors and businesses; and by developing partnerships with traditionally marginalised groups, including women, youth, Indigenous Peoples, local communities and ethnic minorities (*high confidence*). These partnerships are most effective when supported by enabling political leadership, institutions, resources, including finance, as well as climate services, information and decision support tools (*high confidence*). (Figure SPM.5) {1.3, 1.4, 1.5, 2.7, 3.6, 4.8, 5.14, 6.4, 7.4, 8.5, 8.6, 9.4, 10.6, 11.8, 12.5, 13.11, 14.7, 15.6, 15.7, 17.4, 17.6, 18.4, 18.5, CCP2.4, CCP3.4, CCP4.4, CCP5.4, CCP6.4, CCP7.6, CCB DEEP, CCB GENDER, CCB HEALTH, CCB INDIG, CCB NATURAL, CCB SLR}

D.2.1 Climate resilient development is advanced when actors work in equitable, just and enabling ways to reconcile divergent interests, values and worldviews, toward equitable and just outcomes (*high confidence*). These practices build on diverse knowledges about climate risk and chosen development pathways account for local, regional and global climate impacts, risks, barriers and opportunities (*high confidence*). Structural vulnerabilities to climate change can be reduced through carefully designed and implemented legal, policy, and process interventions from the local to global that address inequities based on gender, ethnicity, disability, age, location and income (*very high confidence*). This includes rights-based approaches that focus on capacity-building, meaningful participation of the most vulnerable groups, and their access to key resources, including financing, to reduce risk and adapt (*high confidence*). Evidence shows that climate resilient development processes link scientific, Indigenous, local, practitioner and other forms of knowledge, and are more effective and sustainable because they are locally appropriate and lead to more legitimate, relevant and effective actions (*high confidence*).

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

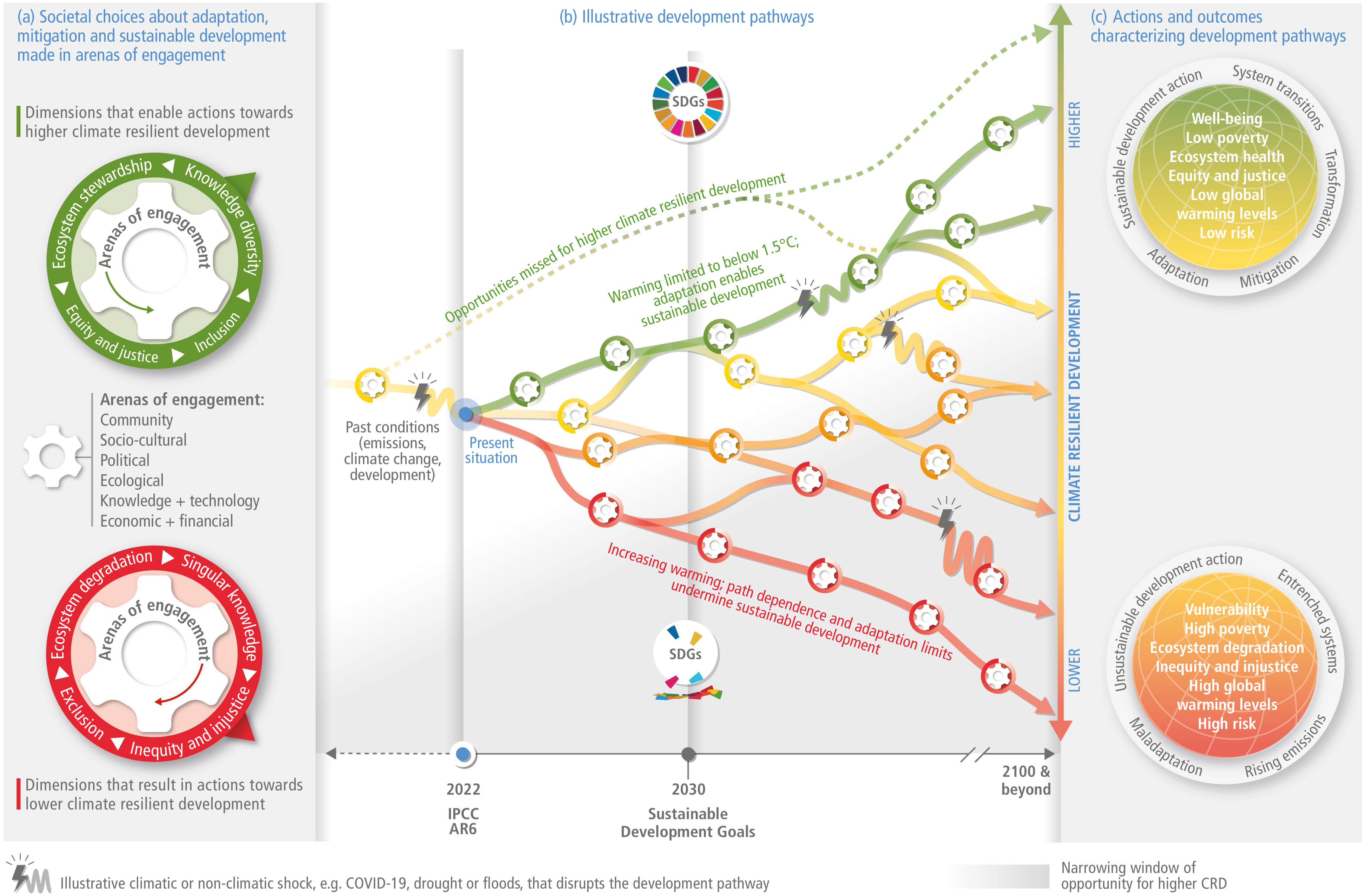

Figure SPM.5 | Climate resilient development (CRD) is the process of implementing greenhouse gas mitigation and adaptation measures to support sustainable development. This figure builds on Figure SPM.9 in AR5 WGII (depicting climate resilient pathways) by describing how CRD pathways are the result of cumulative societal choices and actions within multiple arenas.

Panel (a) Societal choices towards higher CRD **(green cog)** or lower CRD **(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 CRD **(dashed green line)**.

Panel (c) Higher CRD 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 SPM.2, Figure SPM.3) {Figure TS.14b, 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}

Pathways towards climate resilient development overcome jurisdictional and organizational barriers, and are founded on societal choices that accelerate and deepen key system transitions (*very high confidence*). Planning processes and decision analysis tools can help identify 'low regrets' options[47] that enable mitigation and adaptation in the face of change, complexity, deep uncertainty and divergent views (*medium confidence*). {1.3, 1.4, 1.5, 2.7, 3.6, 4.8, 5.14, 6.4, 7.4, 8.5, 8.6, Box 8.7, 9.4, Box 9.2, 10.6, 11.8, 12.5, 13.11, 14.7, 15.6, 15.7, 17.2–17.6, 18.2–18.4, CCP2.3–2.4, CCP3.4, CCP4.4, CCP5.4, CCP6.4, CCP7.6, CCB DEEP, CCB HEALTH, CCB INDIG, CCB NATURAL, CCB SLR}

D.2.2 Inclusive governance contributes to more effective and enduring adaptation outcomes and enables climate resilient development (*high confidence*). Inclusive processes strengthen the ability of governments and other stakeholders to jointly consider factors such as the rate and magnitude of change and uncertainties, associated impacts, and timescales of different climate resilient development pathways given past development choices leading to past emissions and scenarios of future global warming (*high confidence*). Associated societal choices are made continuously through interactions in arenas of engagement from local to international levels. The quality and outcome of these interactions helps determine whether development pathways shift towards or away from climate resilient development (*medium confidence*). (Figure SPM.5) {2.7, 3.6, 4.8, 5.14, 6.4, 7.4, 8.5, 8.6, 9.4, 10.6, 11.8, 12.5, 13.11, 14.7, 15.6, 15.7, 17.2–17.6, 18.2, 18.4, CCP2.3–2.4, CCP3.4, CCP4.4, CCP5.4, CCP6.4, CCP7.6, CCB GENDER, CCB HEALTH, CCB INDIG}

D.2.3 Governance for climate resilient development is most effective when supported by formal and informal institutions and practices that are well-aligned across scales, sectors, policy domains and timeframes. Governance efforts that advance climate resilient development account for the dynamic, uncertain and context-specific nature of climate-related risk, and its interconnections with non-climate risks. Institutions[48] that enable climate resilient development are flexible and responsive to emergent risks and facilitate sustained and timely action. Governance for climate resilient development is enabled by adequate and appropriate human and technological resources, information, capacities and finance. (*high confidence*) {2.7, 3.6, 4.8, 5.14, 6.3, 6.4, 7.4, 8.5, 8.6, 9.4, 10.6, 11.8, 12.5, 13.11, 14.7, 15.6, 15.7, 17.2-17.6, 18.2, 18.4, CCP2.3–2.4, CCP3.4, CCP4.4, CCP5.4, CCP6.4, CCP7.6, CCB DEEP, CCB GENDER, CCB HEALTH, CCB INDIG, CCB NATURAL, CCB SLR}

Climate Resilient Development for Natural and Human Systems

D.3 **Interactions between changing urban form, exposure and vulnerability can create climate change-induced risks and losses for cities and settlements. However, the global trend of urbanisation also offers a critical opportunity in the near-term, to advance climate resilient development (*high confidence*). Integrated, inclusive planning and investment in everyday decision-making about urban infrastructure, including social, ecological and grey/physical infrastructures, can significantly increase the adaptive capacity of urban and rural settlements. Equitable outcomes contributes to multiple benefits for health and well-being and ecosystem services, including for Indigenous Peoples, marginalised and vulnerable communities (*high confidence*). Climate resilient development in urban areas also supports adaptive capacity in more rural places through maintaining peri-urban supply chains of goods and services and financial flows (*medium confidence*). Coastal cities and settlements play an especially important role in advancing climate resilient development (*high confidence*). {6.2, 6.3, Table 6.6, 7.4, 8.6, Box 9.8, 18.3, CCP2.1. CCP2.2, CCP6.2, CWGB URBAN}**

48 Institutions: Rules, norms and conventions that guide, constrain or enable human behaviours and practices. Institutions can be formally established, for instance through laws and regulations, or informally established, for instance by traditions or customs. Institutions may spur, hinder, strengthen, weaken or distort the emergence, adoption and implementation of climate action and climate governance.

D.3.1 Taking integrated action for climate resilience to avoid climate risk requires urgent decision making for the new built environment and retrofitting existing urban design, infrastructure and land use. Based on socioeconomic circumstances, adaptation and sustainable development actions will provide multiple benefits including for health and well-being, particularly when supported by national governments, non-governmental organisations and international agencies that work across sectors in partnerships with local communities. Equitable partnerships between local and municipal governments, the private sector, Indigenous Peoples, local communities, and civil society can, including through international cooperation, advance climate resilient development by addressing structural inequalities, insufficient financial resources, cross-city risks and the integration of Indigenous knowledge and local knowledge. (*high confidence*) {6.2, 6.3, 6.4, Table 6.6, 7.4, 8.5, 9.4, 10.5. 12.5, 17.4, Table 17.8, 18.2, Box 18.1, CCP2.4, CCB FINANCE, CCB GENDER, CCB INDIG, CWGB URBAN}

D.3.2 Rapid global urbanisation offers opportunities for climate resilient development in diverse contexts from rural and informal settlements to large metropolitan areas (*high confidence*). Dominant models of energy intensive and market-led urbanisation, insufficient and misaligned finance and a predominant focus on grey infrastructure in the absence of integration with ecological and social approaches, risks missing opportunities for adaptation and locking in maladaptation (*high confidence*). Poor land use planning and siloed approaches to health, ecological and social planning also exacerbates, vulnerability in already marginalised communities (*medium confidence*). Urban climate resilient development is observed to be more effective if it is responsive to regional and local land use development and adaptation gaps, and addresses the underlying drivers of vulnerability (*high confidence*). The greatest gains in well-being can be achieved by prioritizing finance to reduce climate risk for low-income and marginalized residents including people living in informal settlements (*high confidence*). {5.14, 6.1, 6.2, 6.3, 6.4, 6.5, Figure 6.5, Table 6.6, 7.4, 8.5, 8.6, 9.8, 9.9, 10.4, Table 17.8, 18.2, CCP2.2, CCP5.4, CCB HEALTH, CWGB URBAN}

D.3.3 Urban systems are critical, interconnected sites for enabling climate resilient development, especially at the coast. Coastal cities and settlements play a key role in moving toward higher climate resilient development given firstly, almost 11% of the global population – 896 million people – lived within the Low Elevation Coastal Zone[49] in 2020, potentially increasing to beyond 1 billion people by 2050, and these people, and associated development and coastal ecosystems, face escalating climate compounded risks, including sea level rise. Secondly, these coastal cities and settlements make key contributions to climate resilient development through their vital role in national economies and inland communities, global trade supply chains, cultural exchange, and centres of innovation. (*high confidence*) {6.1, 6.2, 6.4, Table 6.6, Box 15.2, SMCCP Table 2.1, CCP2.2, CCP2.4, CCB SLR, XWGB URBAN, SROCC Chapter 4}

D.4 **Safeguarding biodiversity and ecosystems is fundamental to climate resilient development, in light of the threats climate change poses to them and their roles in adaptation and mitigation (*very high confidence*). Recent analyses, drawing on a range of lines of evidence, suggest that maintaining the resilience of biodiversity and ecosystem services at a global scale depends on effective and equitable conservation of approximately 30% to 50% of Earth's land, freshwater and ocean areas, including currently near-natural ecosystems (*high confidence*). {2.4, 2.5, 2.6, 3.4, 3.5, 3.6, Box 3.4, 12.5, 13.3, 13.4, 13.5, 13.10, CCB INDIG, CCB NATURAL}**

D.4.1 Building the resilience of biodiversity and supporting ecosystem integrity[50] can maintain benefits for people, including livelihoods, human health and well-being and the provision of food, fibre and water, as well as contributing to disaster risk reduction and climate change adaptation and mitigation. {2.2, 2.5, 2.6, Table 2.6, Table 2.7, 3.5, 3.6, 5.8, 5.13, 5.14, Box 5.11, 12.5, CCP5.4, CCB COVID, CCB GENDER, CCB ILLNESS, CCB INDIG, CCB MIGRATE, CCB NATURAL}

D.4.2 Protecting and restoring ecosystems is essential for maintaining and enhancing the resilience of the biosphere (*very high confidence*). Degradation and loss of ecosystems is also a cause of greenhouse gas emissions and is at increasing risk of being exacerbated by climate change impacts, including droughts and wildfire *(high confidence).* Climate resilient development avoids adaptation and mitigation measures that damage ecosystems (*high confidence*). Documented examples of adverse impacts of land-based measures intended as mitigation, when poorly implemented, include afforestation of grasslands, savannas and peatlands, and risks from bioenergy crops at large scale to water supply, food security and biodiversity (*high confidence*). {2.4, 2.5, Box 2.2, 3.4, 3.5, Box 3.4, Box 9.3, CCP7.3, CCB NATURAL, CWGB BIOECONOMY}

49 LECZ, coastal areas below 10 m of elevation above sea level that are hydrologically connected to the sea.

50 Ecosystem integrity refers to the ability of ecosystems to maintain key ecological processes, recover from disturbance, and adapt to new conditions.

D.4.3 Biodiversity and ecosystem services have limited capacity to adapt to increasing global warming levels, which will make climate resilient development progressively harder to achieve beyond 1.5°C warming (*very high confidence*). Consequences of current and future global warming for climate resilient development include reduced effectiveness of Ecosystem-based Adaptation and approaches to climate change mitigation based on ecosystems and amplifying feedbacks to the climate system (*high confidence*). {Figure TS.14d, 2.4, 2.5, 2.6, 3.4, Box 3.4, 3.5, 3.6, Table 5.2, 12.5, 13.2, 13.3, 13.10, 14.5, 14.5, Box 14.3, 15.3, 17.3, 17.6, CCP5.3, CCP5.4, CCB EXTREMES, CCB ILLNESS, CCB NATURAL, CCB SLR, SR1.5, SRCCL, SROCC}

Achieving Climate Resilient Development

D.5 **It is unequivocal that climate change has already disrupted human and natural systems. Past and current development trends (past emissions, development and climate change) have not advanced global climate resilient development (*very high confidence*). Societal choices and actions implemented in the next decade determine the extent to which medium- and long-term pathways will deliver higher or lower climate resilient development (*high confidence*). Importantly climate resilient development prospects are increasingly limited if current greenhouse gas emissions do not rapidly decline, especially if 1.5°C global warming is exceeded in the near-term (*high confidence*). These prospects are constrained by past development, emissions and climate change, and enabled by inclusive governance, adequate and appropriate human and technological resources, information, capacities and finance (*high confidence*). {Figure TS.14d, 1.2, 1.4, 1.5, 2.6, 2.7, 3.6, 4.7, 4.8, 5.14, 6.4, 7.4, 8.3, 8.5, 8.6, 9.3, 9.4, 9.5, 10.6, 11.8, 12.5, 13.10, 13.11, 14.7, 15.3, 15.6, 15.7, 16.2, 16.4, 16.5, 16.6, 17.2–17.6, 18.2–18.5, CCP2.3–2.4, CCP3.4, CCP4.4, CCP5.3, CCP5.4, Table CCP5.2, CCP6.3, CCP6.4, CCP7.5, CCP7.6, CCB DEEP, CCB HEALTH, CCB INDIG, CCB NATURAL, CCB SLR}**

D.5.1 Climate resilient development is already challenging at current global warming levels (*high confidence*). The prospects for climate resilient development will be further limited if global warming levels exceeds 1.5°C (*high confidence*) and not be possible in some regions and sub-regions if the global warming level exceeds 2°C (*medium confidence*). Climate resilient development is most constrained in regions/subregions in which climate impacts and risks are already advanced, including low-lying coastal cities and settlements, small islands, deserts, mountains and polar regions (*high confidence*). Regions and subregions with high levels of poverty, water, food and energy insecurity, vulnerable urban environments, degraded ecosystems and rural environments, and/or few enabling conditions, face many non-climate challenges that inhibit climate resilient development which are further exacerbated by climate change (*high confidence*). {Figure TS.14d, 1.2, Box 6.6, 9.3, 9.4, 9.5, 10.6, 11.8, 12.5, 13.10, 14.7, 15.3, CCP2.3, CCP3.4, CCP4.4, CCP5.3, Table CCP5.2, CCP6.3, CCP7.5}

D.5.2 Inclusive governance, investment aligned with climate resilient development, access to appropriate technology and rapidly scaled-up finance, and capacity building of governments at all levels, the private sector and civil society enable climate resilient development. Experience shows that climate resilient development processes are timely, anticipatory, integrative, flexible and action focused. Common goals and social learning build adaptive capacity for climate resilient development. When implementing adaptation and mitigation together, and taking trade-offs into account, multiple benefits and synergies for human well-being as well as ecosystem and planetary health can be realised. Prospects for climate resilient development are increased by inclusive processes involving local knowledge and Indigenous Knowledge as well as processes that coordinate across risks and institutions. Climate resilient development is enabled by increased international cooperation including mobilising and enhancing access to finance, particularly for vulnerable regions, sectors and groups. (*high confidence*) (Figure SPM.5) {2.7, 3.6, 4.8, 5.14, 6.4, 7.4, 8.5, 8.6, 9.4, 10.6, 11.8, 12.5, 13.11, 14.7, 15.6, 15.7, 17.2–17.6, 18.2–18.5, CCP2.3–2.4, CCP3.4, CCP4.4, CCP5.4, CCP6.4, CCP7.6, CCB DEEP, CCB HEALTH, CCB INDIG, CCB NATURAL, CCB SLR}

D.5.3 The cumulative scientific evidence is unequivocal: Climate change is a threat to human well-being and planetary health. Any further delay in concerted anticipatory global action on adaptation and mitigation will miss a brief and rapidly closing window of opportunity to secure a liveable and sustainable future for all. (*very high confidence*) {1.2, 1.4, 1.5, 16.2, Table SM16.24, 16.4, 16.5, 16.6, 17.4, 17.5, 17.6, 18.3, 18.4, 18.5, CCB DEEP, CWGB URBAN, WGI AR6 SPM, SROCC SPM, SRCCL SPM}

Technical Summary

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.

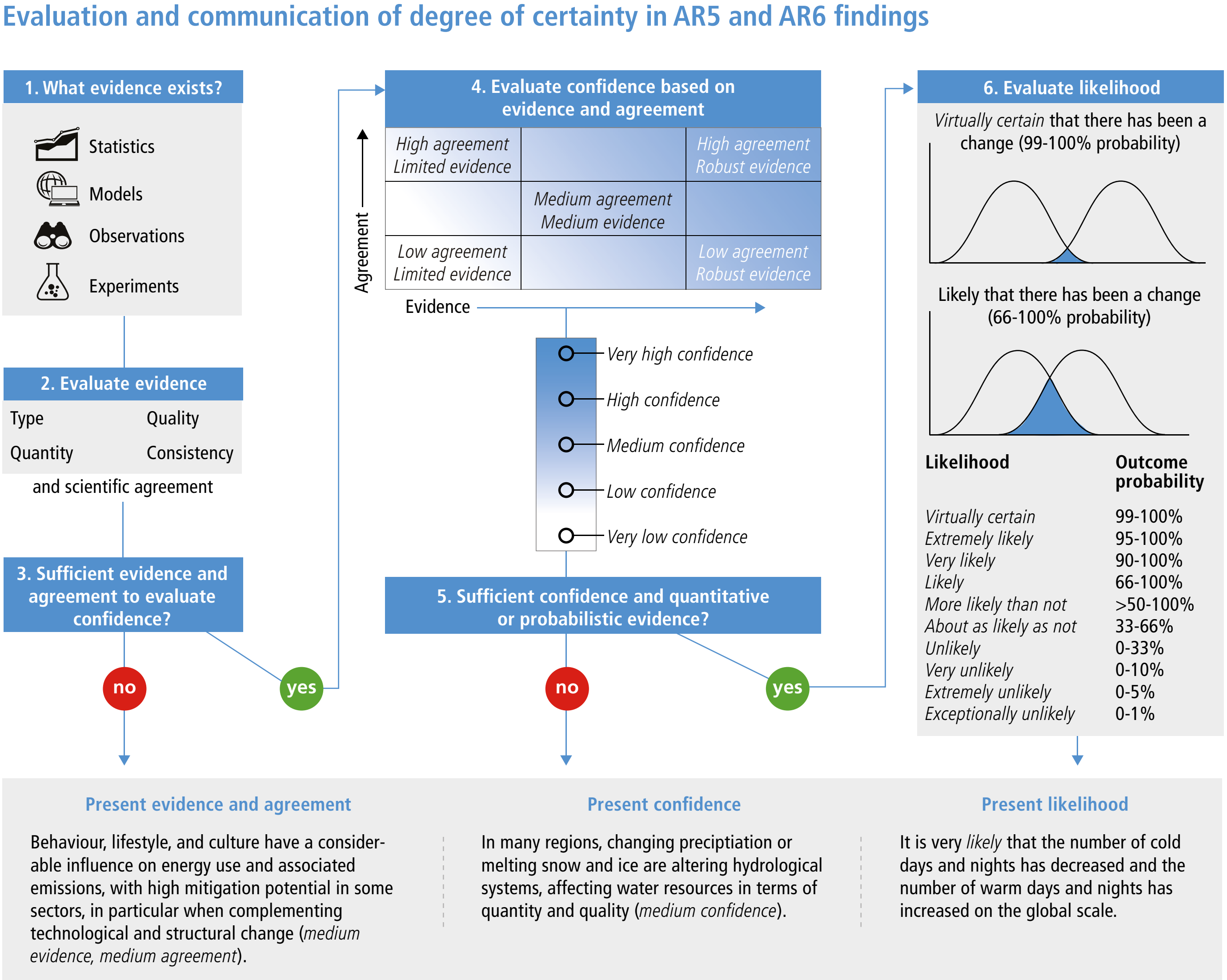

Figure TS.1 | The IPCC AR5 and AR6 framework for applying expert judgement in the evaluation and characterisation of assessment findings. This illustration depicts the process assessment authors apply in evaluating and communicating the current state of knowledge. {Figure 1.6}

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.

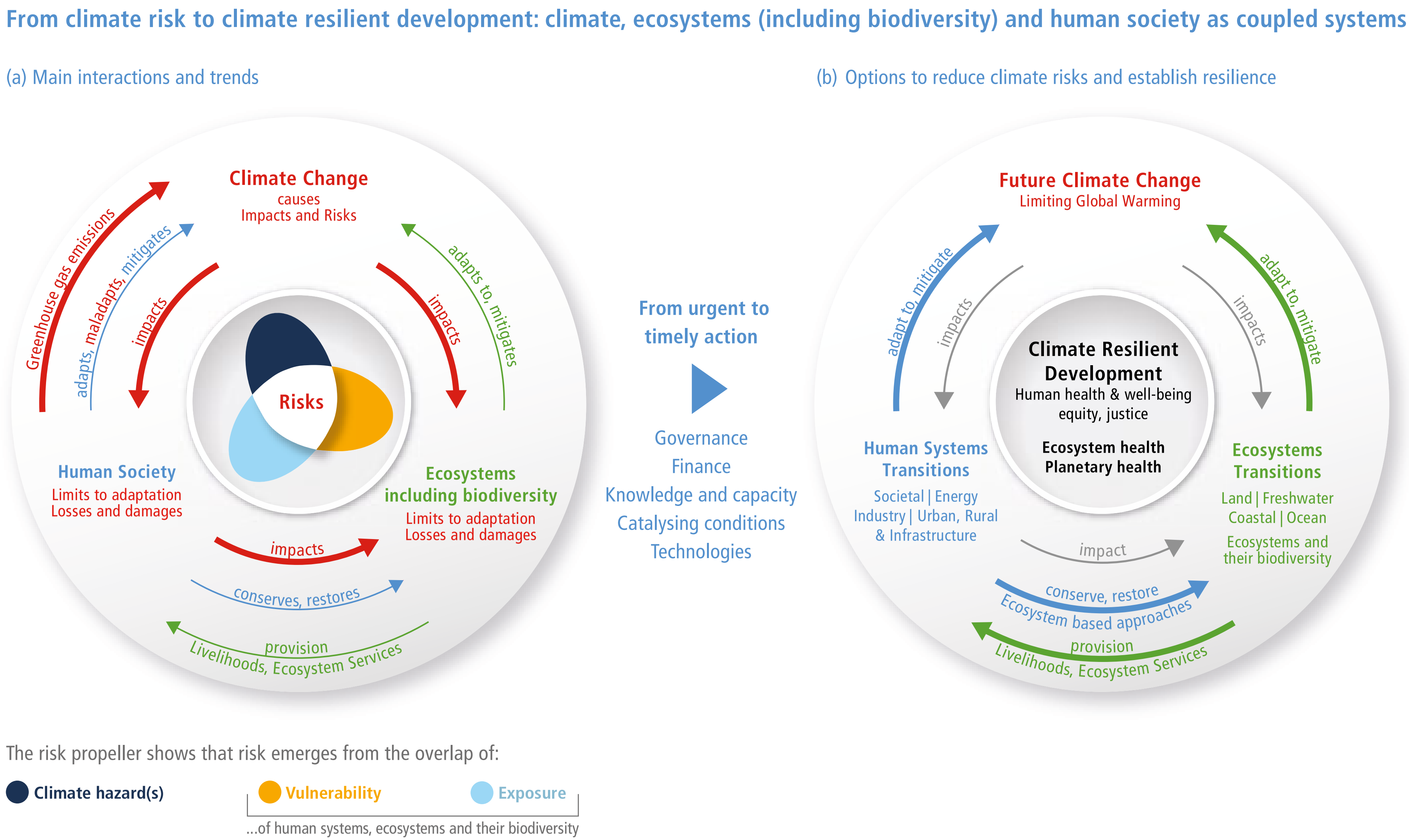

Figure TS.2 | This report has a strong focus on the interactions among the coupled systems climate, ecosystems (including their biodiversity) and human society. These interactions are the basis of emerging risks from climate change, ecosystem degradation and biodiversity loss and, at the same time, offer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

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,

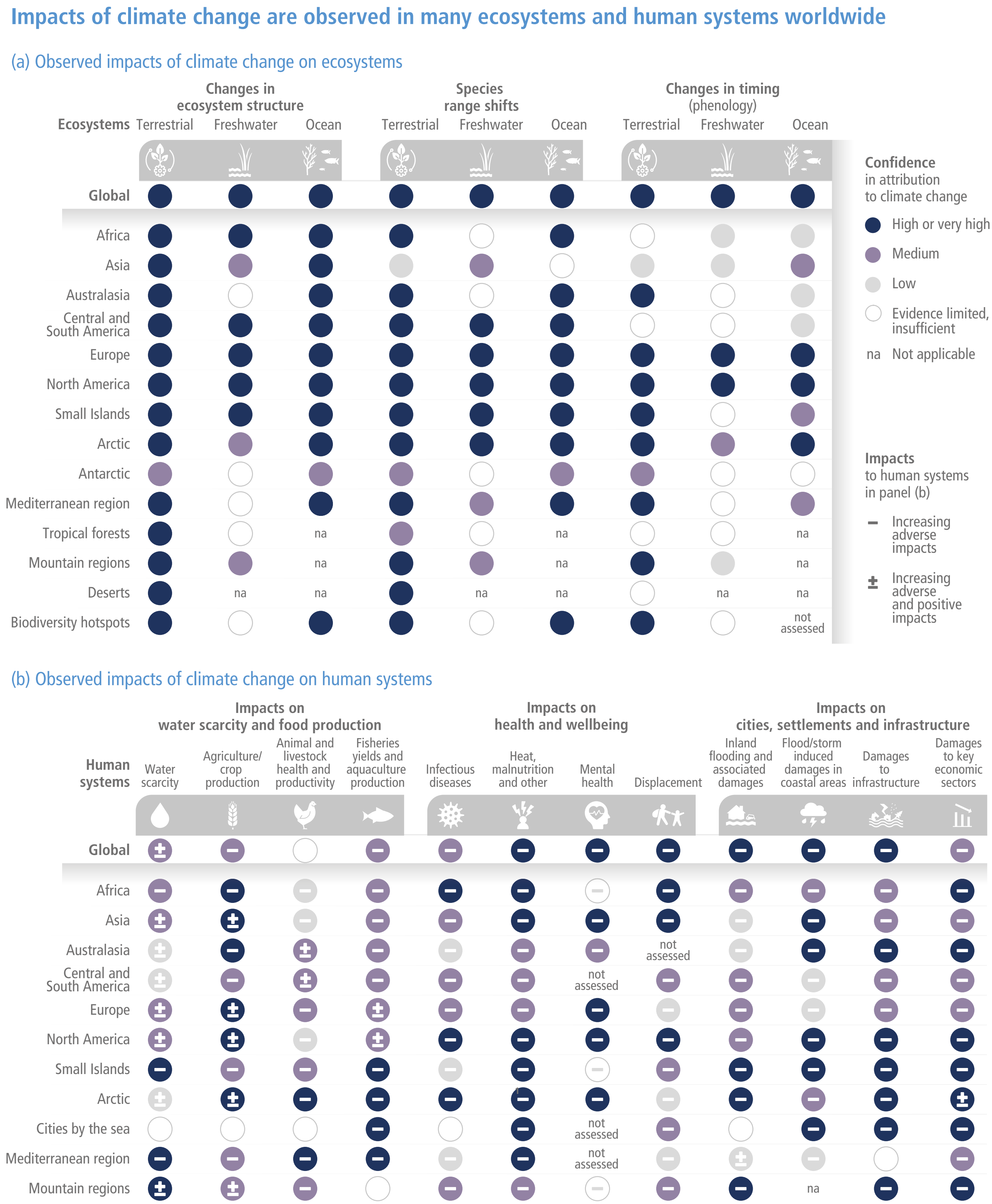

Figure TS.3 | Observed global and regional impacts on ecosystems and human systems attributed to climate change. Confidence levels reflect uncertainty in attribution of the observed impact to climate change. Global assessments focus on large studies, multi-species, meta-analyses and large reviews. For 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.

(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 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}

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}

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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 (*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 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}

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*).

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

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 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 (*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 eco-systems 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* 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}

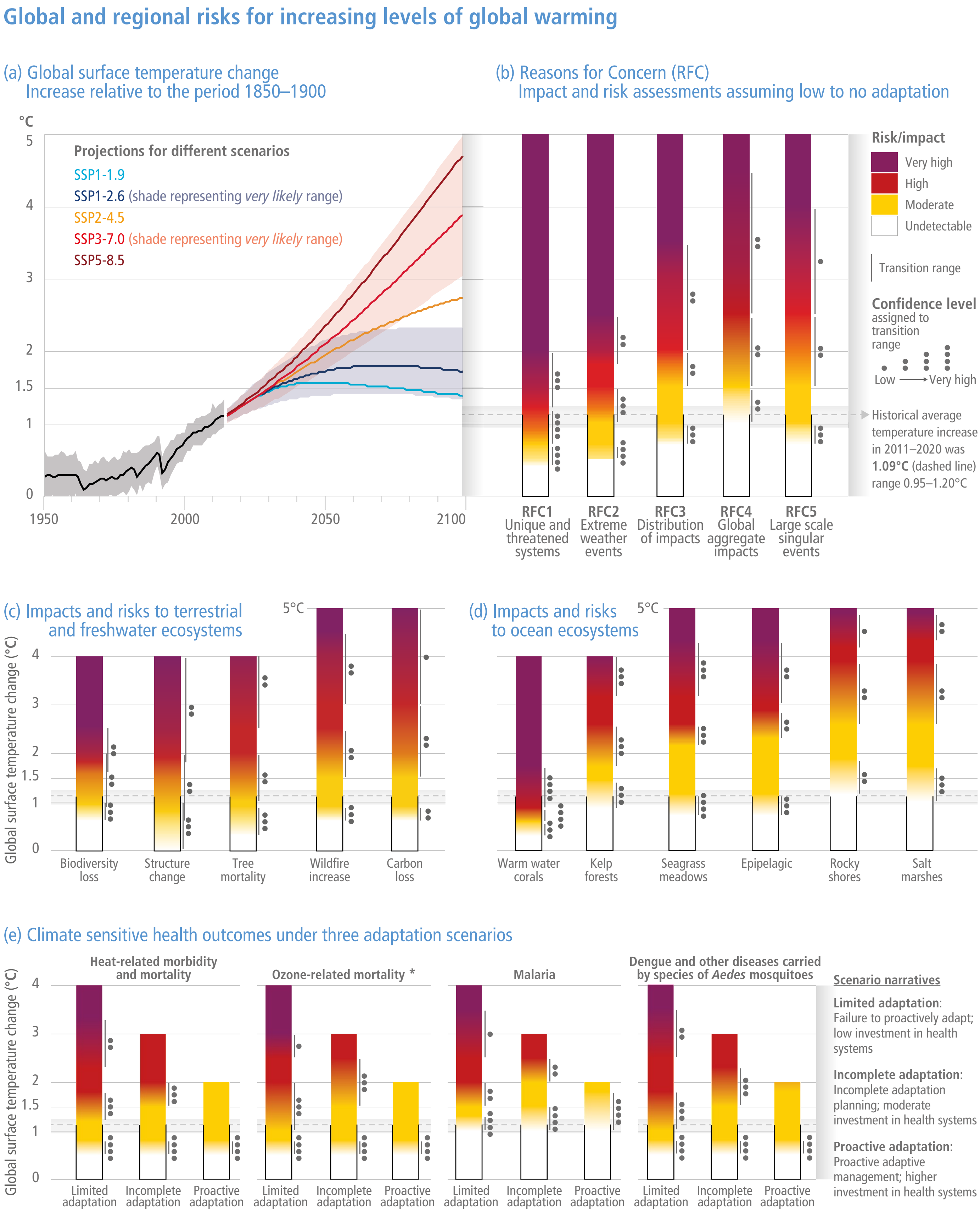
TS.C.2.5 Warming pathways that temporarily increase global mean temperature over 1.5°C above pre-industrial for multi-decadal time spans imply severe risks and irreversible impacts in many ecosystems (*high confidence*). Major risks include loss of coastal ecosystems such as wetlands and marshlands from 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



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

(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

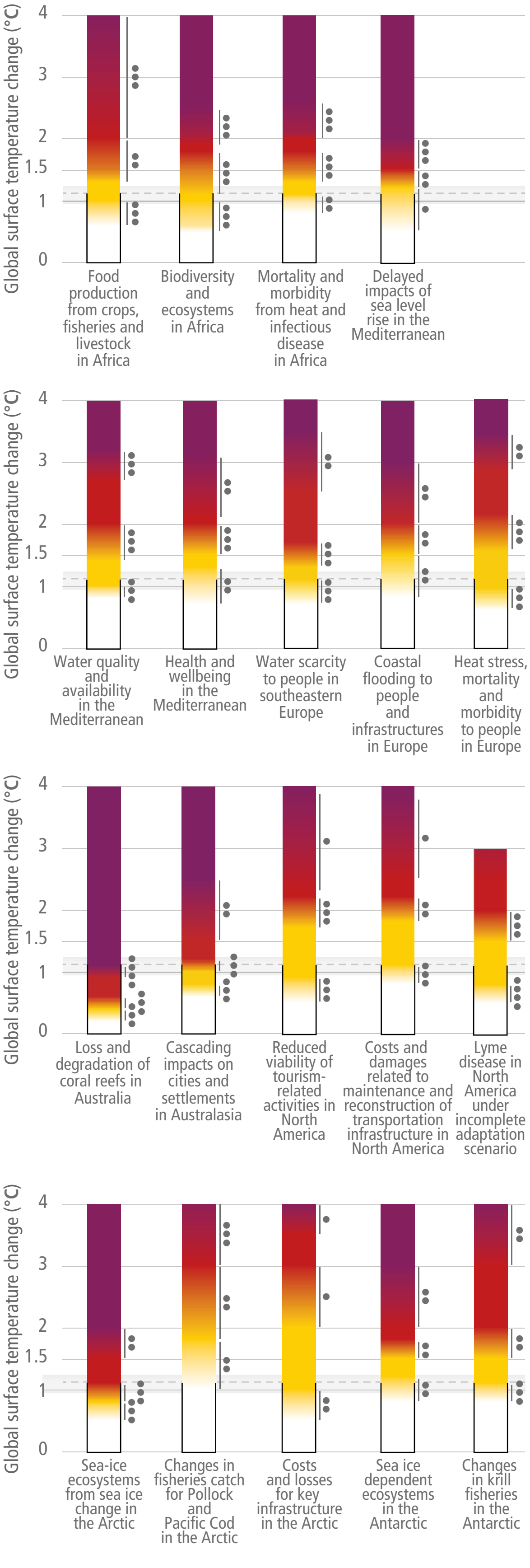


Figure TS.4 | Synthetic diagrams of global and sectoral assessments and examples of regional key risks. Diagrams show the change in the levels of impacts and risks assessed for global warming of 0–5°C global surface temperature change relative to pre-industrial period (1850–1900) over the range.

(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 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 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 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, 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}

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 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,

TS

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, smallholder 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

***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}

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*)

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 warning; 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*)

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}

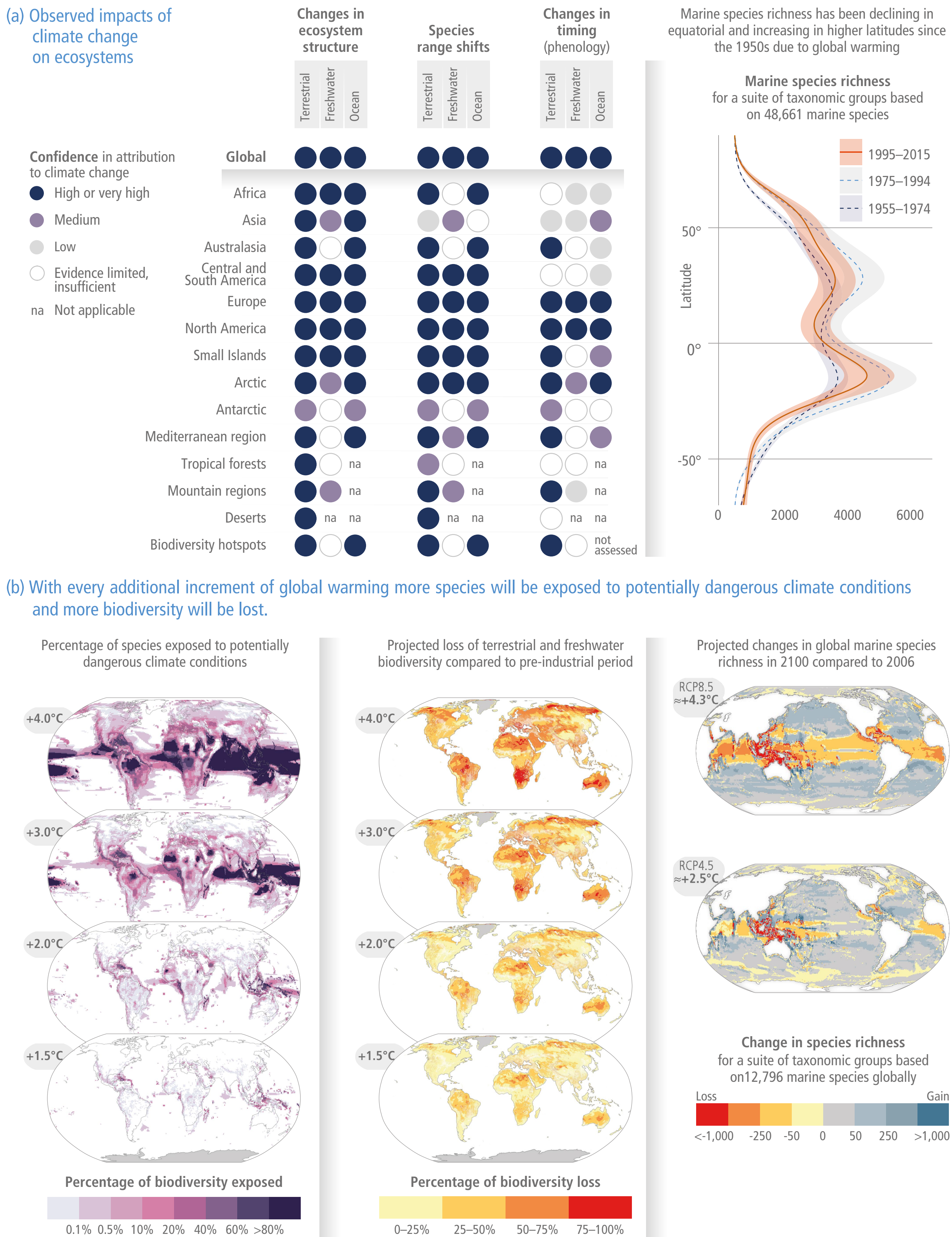
TS.D.1.1 Responses have accelerated in both developed and developing regions since AR5, with some examples of regression (*high confidence*). Growing adaptation knowledge in public and private sectors, increasing numbers of policy and legal frameworks and dedicated spending on adaptation are all clear 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



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

Confidence in its effectiveness in reducing risks of climate change: High, Medium, Low

Terrestrial ecosystems	Confidence	Freshwater ecosystems	Confidence	Ocean ecosystems	Confidence
Conservation of climatic microrefugia	High	Conservation of climatic microrefugia	Low	Conservations of marine climate refugia	Medium
Assisted reintroduction, translocation and migration of species	Medium	Assisted reintroduction, translocation and migration of species	Low	Assisted reintroduction, translocation and migration of species	High
Adjusting conservation strategies and site objectives to reflect changing species distributions and habitat characteristics	High	Adjusting conservation strategies and site objectives to reflect changing species distributions and habitat characteristics	High	Climate-adaptive management*	High
Reducing non-climatic stressors to increase resilience of ecosystems	Medium	Reducing non-climatic stressors to increase resilience of ecosystems	Medium	Sustainable harvesting, reducing the ecological vulnerability of marine ecosystems	High
Restoration of natural ecological communities and processes	Medium	Restoring hydrological processes of wetlands, rivers and catchments	High	Marine habitat restoration, increasing biodiversity	High
Protect, restore or create large areas of natural and semi-natural habitat	High	Protect or restore natural vegetation cover in catchments	Medium	Transboundary marine spatial planning (MSP) and integrated coastal zone management (ICZM)**	Low
Intensive management for vulnerable species	Medium	Intensive management for vulnerable species	Medium	Expansion of marine protected areas (MPAs) and MPA networks	High
Increase habitat connectivity	Medium	Increased connectivity in river systems	Medium	Ecosystem-based management	High

* Considering species distribution shifts and other climate change responses ** Low confidence due to limited evidence

(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).

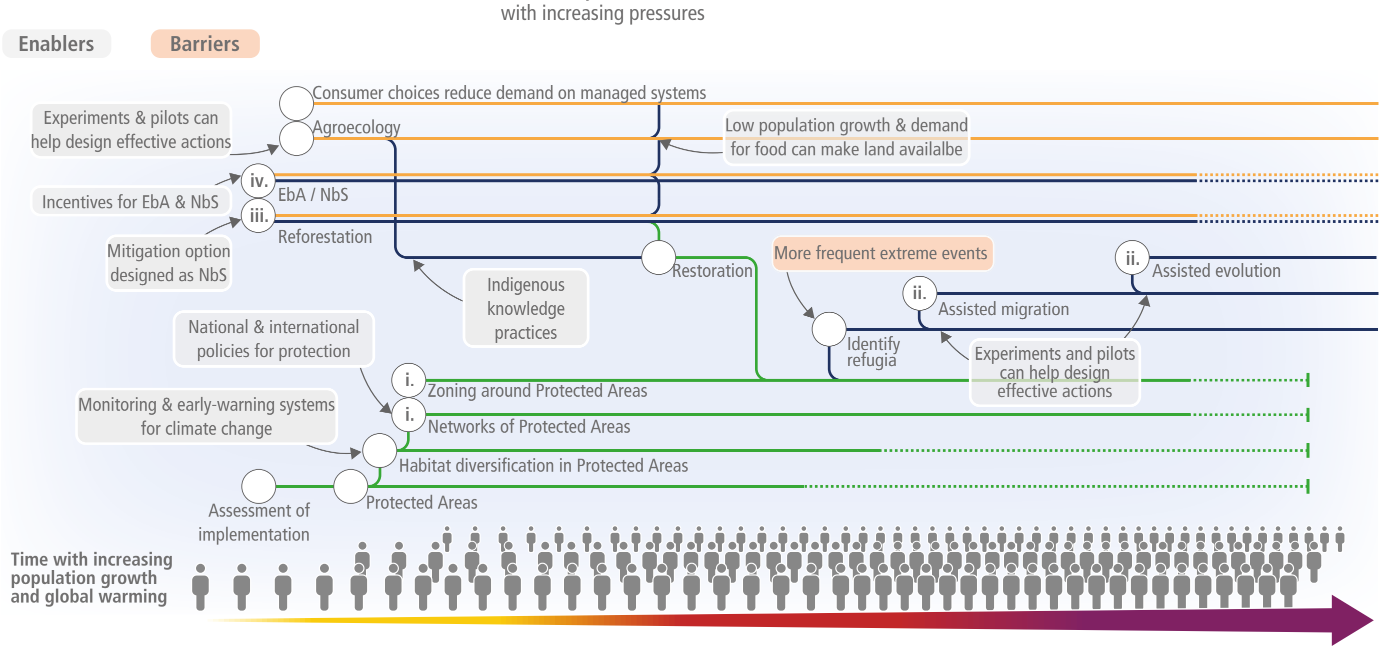


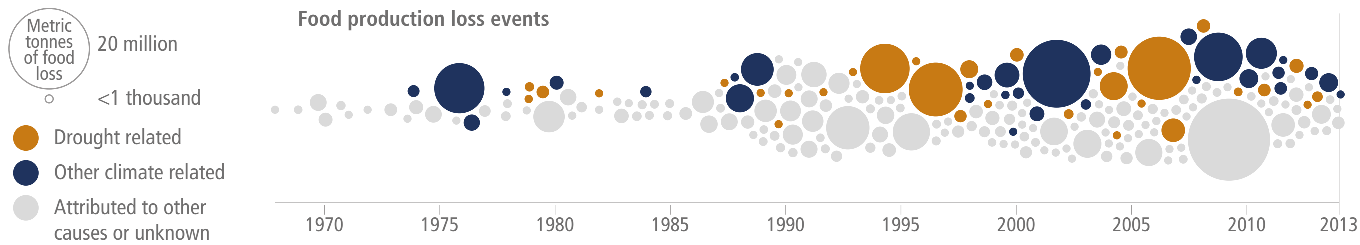
Figure TS.5 ECOSYSTEMS | (a) Left: Observed global and regional impacts on ecosystems and human systems attributed to climate change. Confidence levels reflect uncertainty in attribution of the observed impact to climate change. For more details and line of sight to chapters and cross-chapter papers 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}

TS

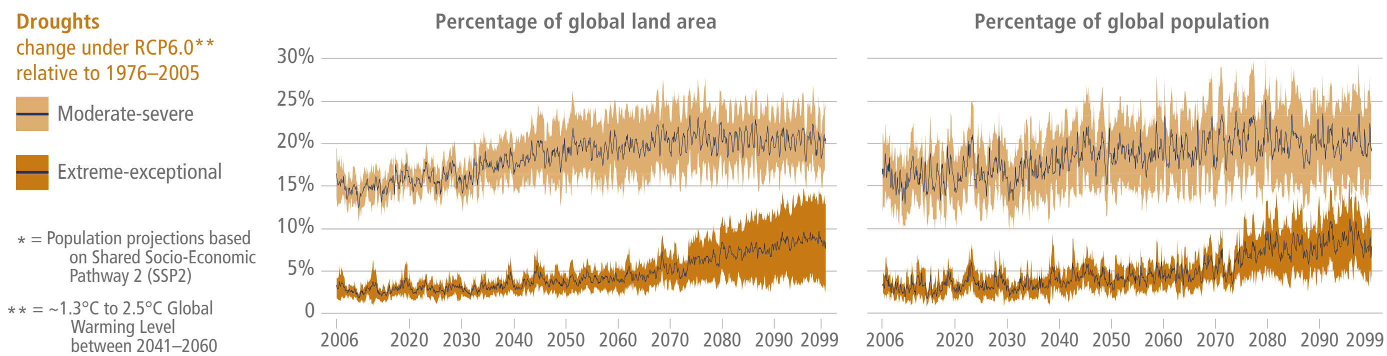
Climate change is affecting food security through pervasive water impacts

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

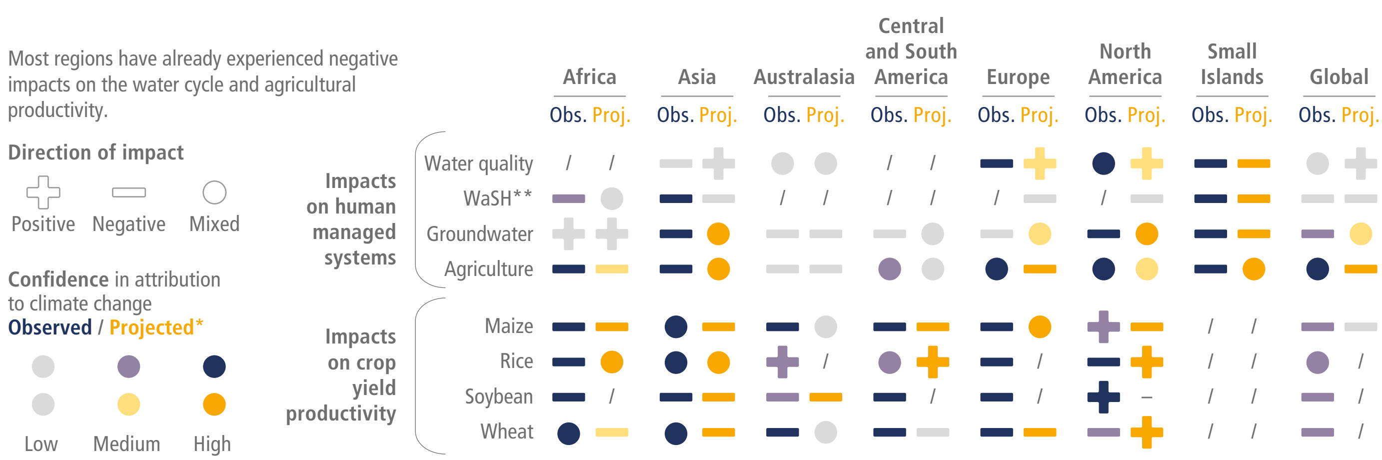
(a) The frequency of climated-related food production losses in crops, livestocks, fisheries and aquacultures has been increasing over the last decades.



(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.

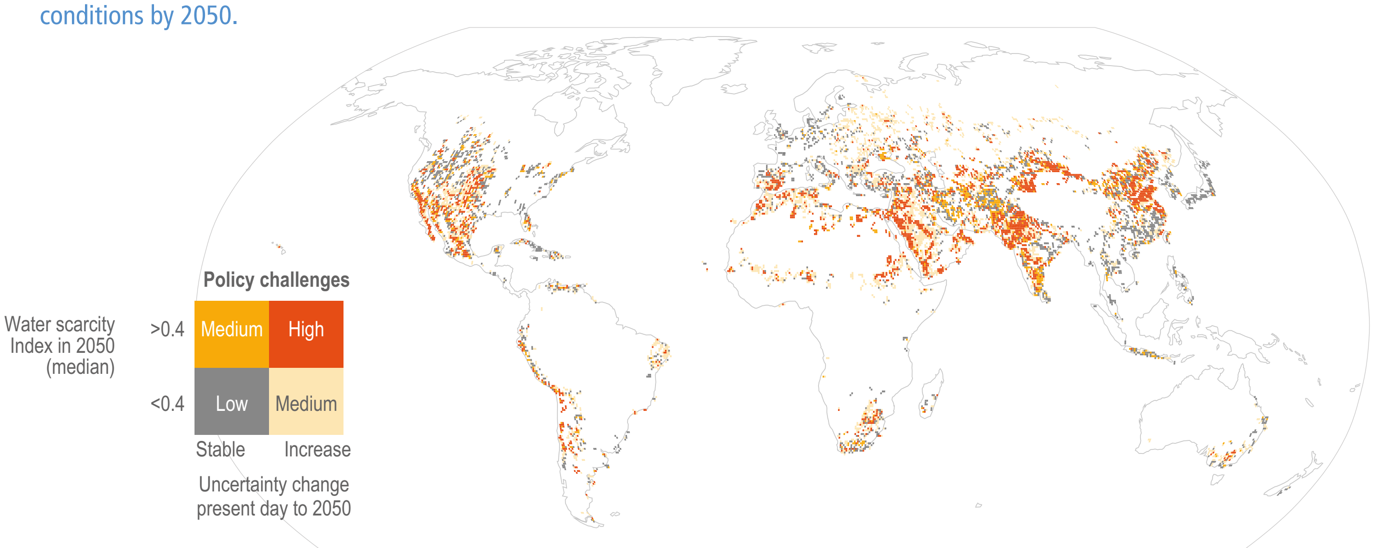


*Mid-century at RCP4.5 (~2°C Global Warming Level)

** = Water, sanitation and hygiene

/ = Not observed or insufficient evidence

(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.

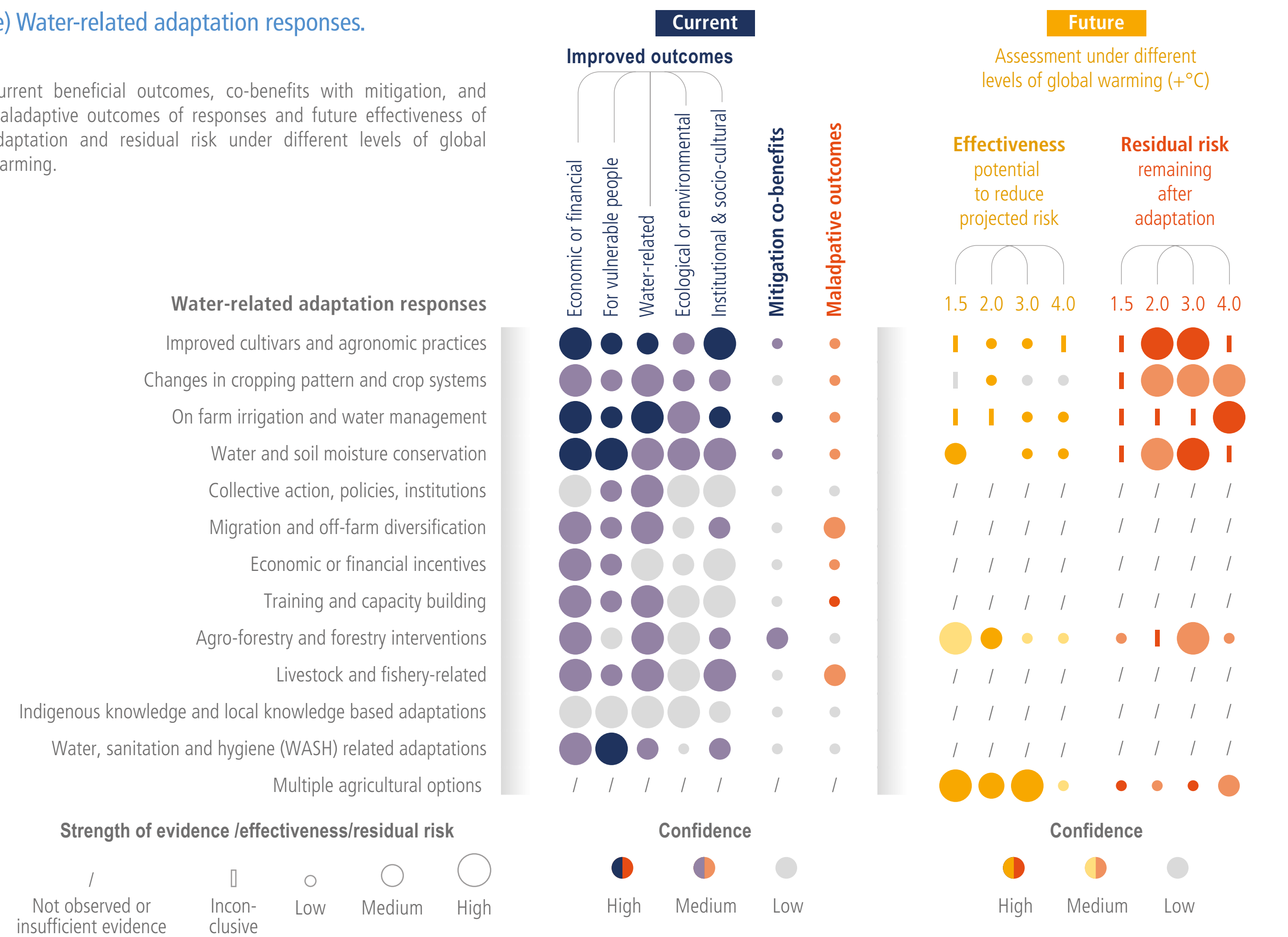
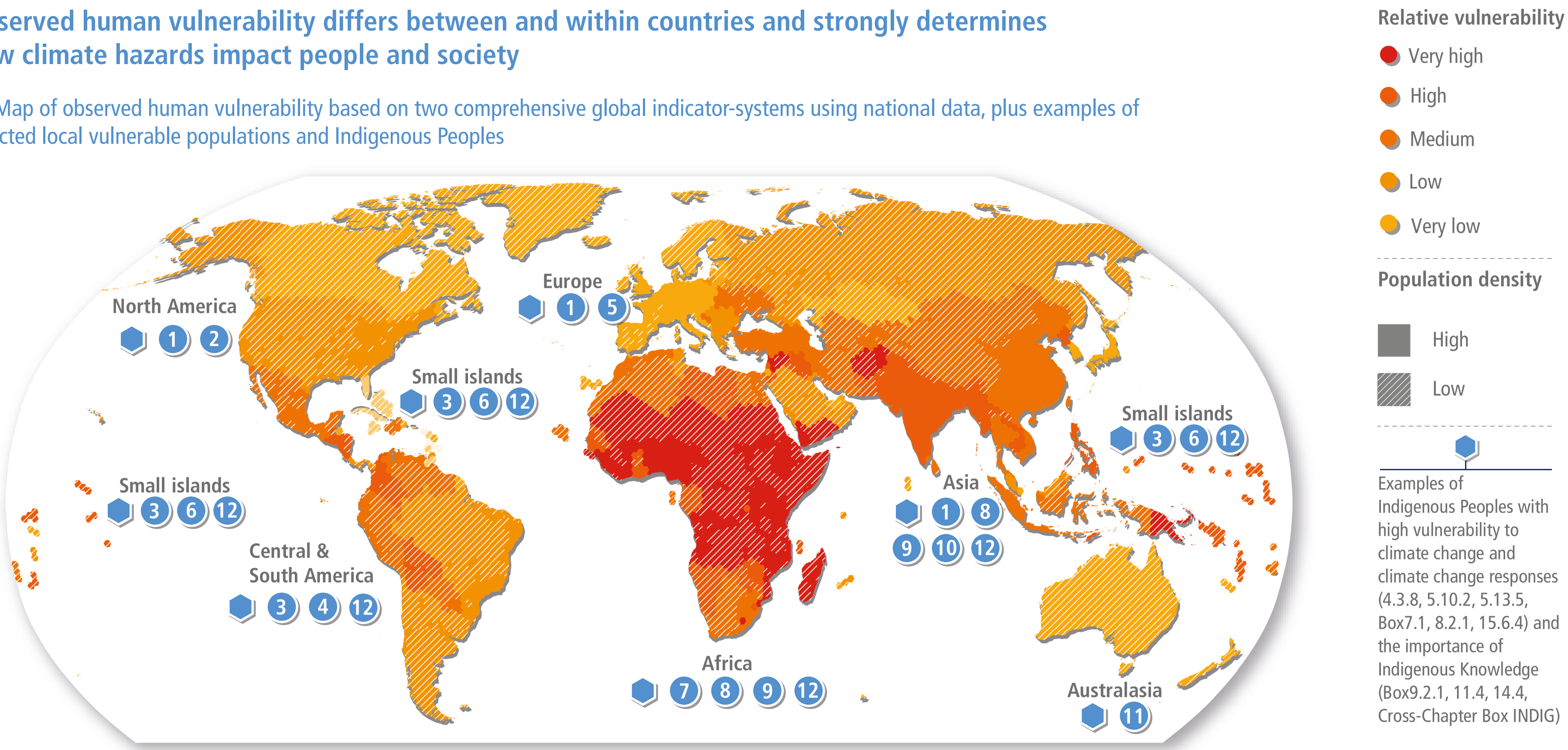


Figure TS.6 FOOD-WATER | (a) {5.4.1.1, Box 5.1, FAQ 5.1, SM5.1, Figure AI.20}. **(b)** Projected increase in the global share of area and population impacted from droughts. Changes are calculated based on the RCP6.0 concentration pathway for Terrestrial Water Storage (TWS) droughts, which can be considered 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}.

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

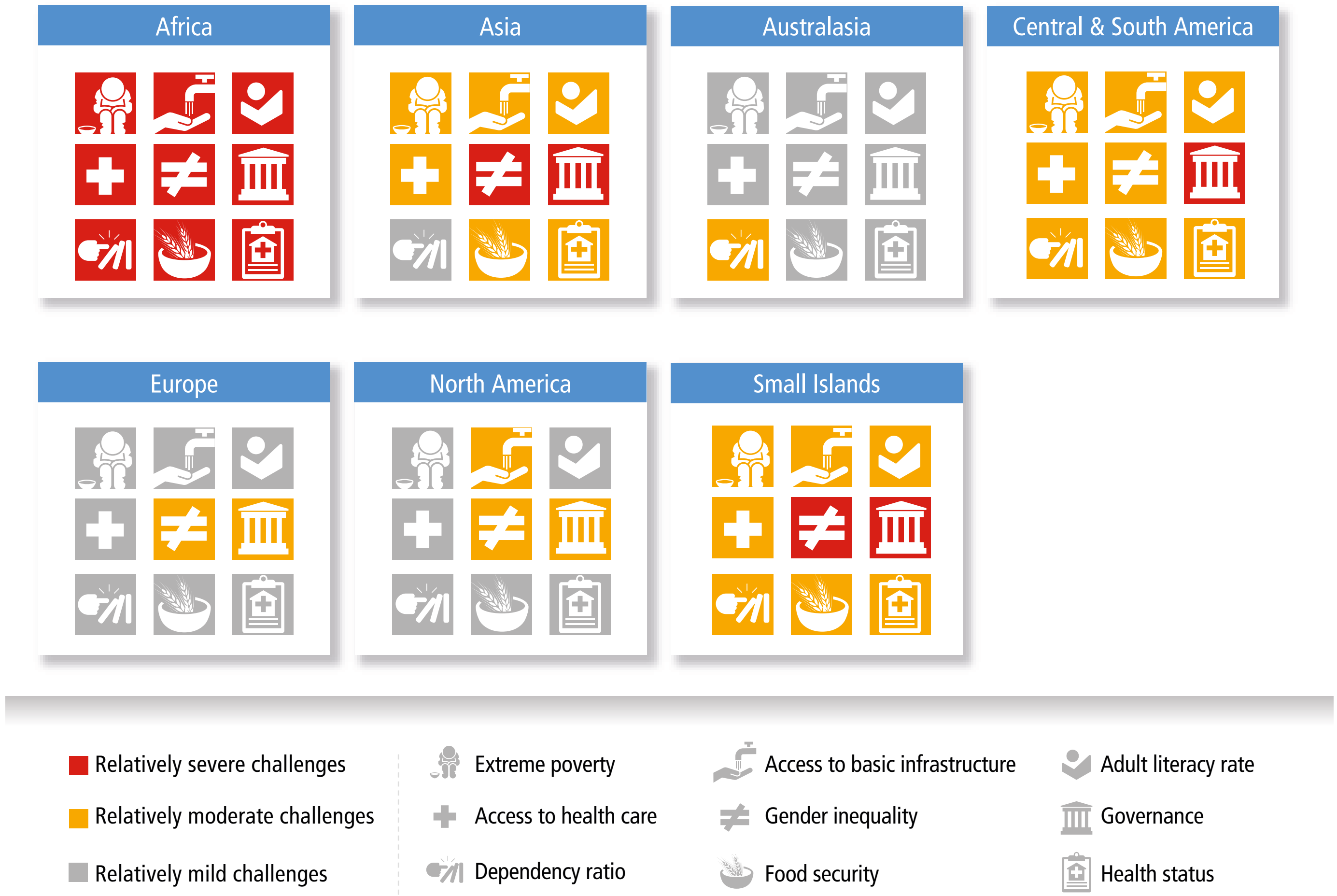
9 | **Women & non-binary** | limited access to & control over resources, e.g. water, land, credit | Box 9.1, CCB-GENDER, 4.8.3, 5.4.2, 10.3.3

10 | **Migrants** | informal status, limited access to health services & shelter, exclusion from decision-making processes | 6.3.6, Box 10.2

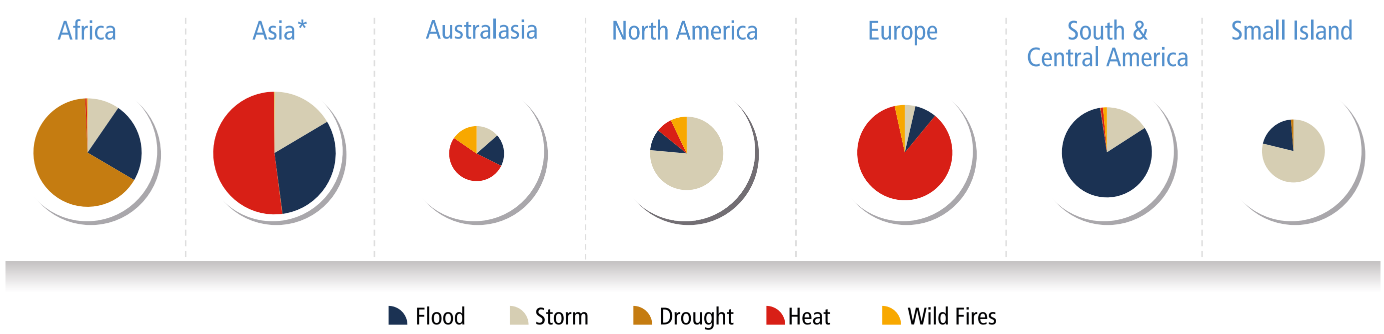
11 | **Aboriginal and Torres Strait Islander Peoples** | poverty, food & housing insecurity, dislocation from community | 11.4.1

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)



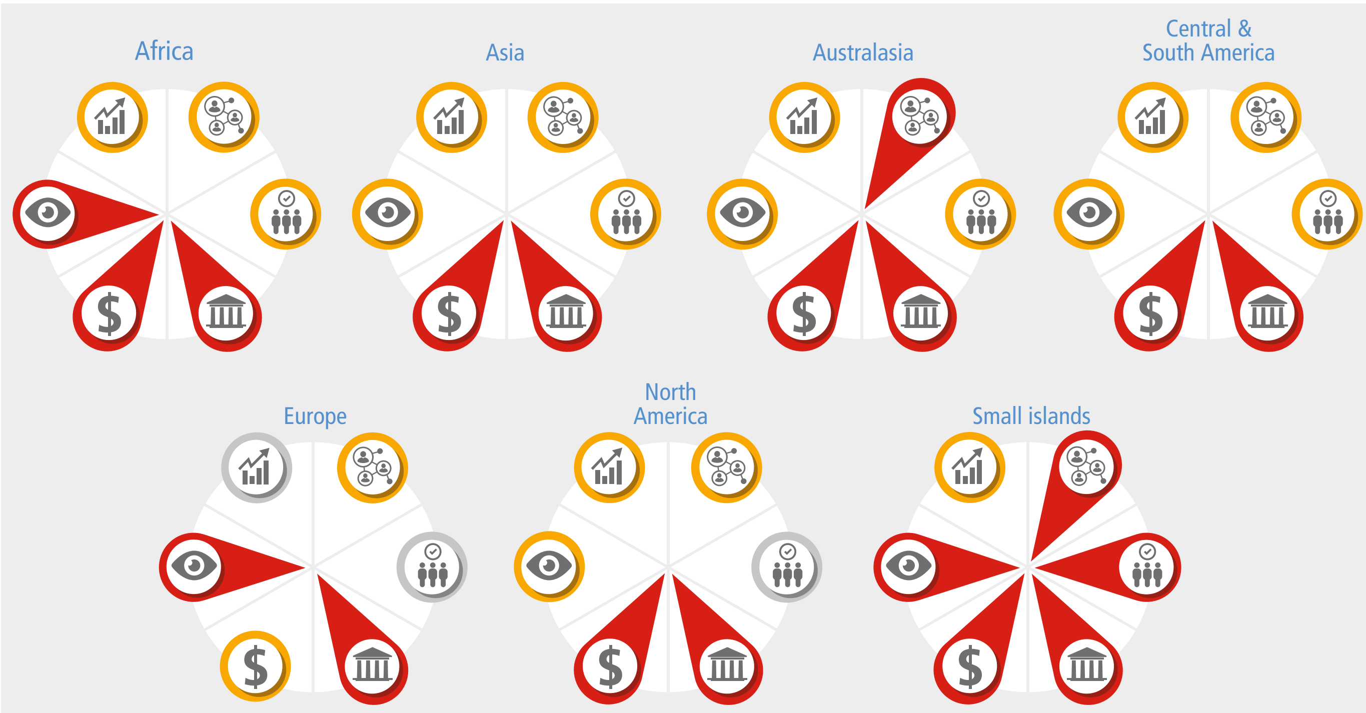
(c) Average mortality per hazard event per region between 2010 and 2020:



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.

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



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

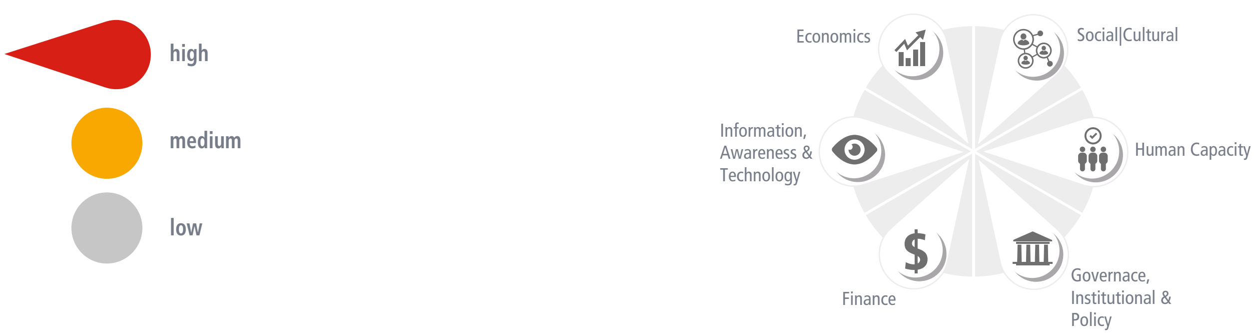


Figure TS.7 VULNERABILITY | (a) The global map of vulnerability is based on two comprehensive global indicator systems, namely INFORM Risk Index and WorldRiskIndex (2019). Climate change hazards and exposure levels are not included in this figure. The relative level of average national vulnerability 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}

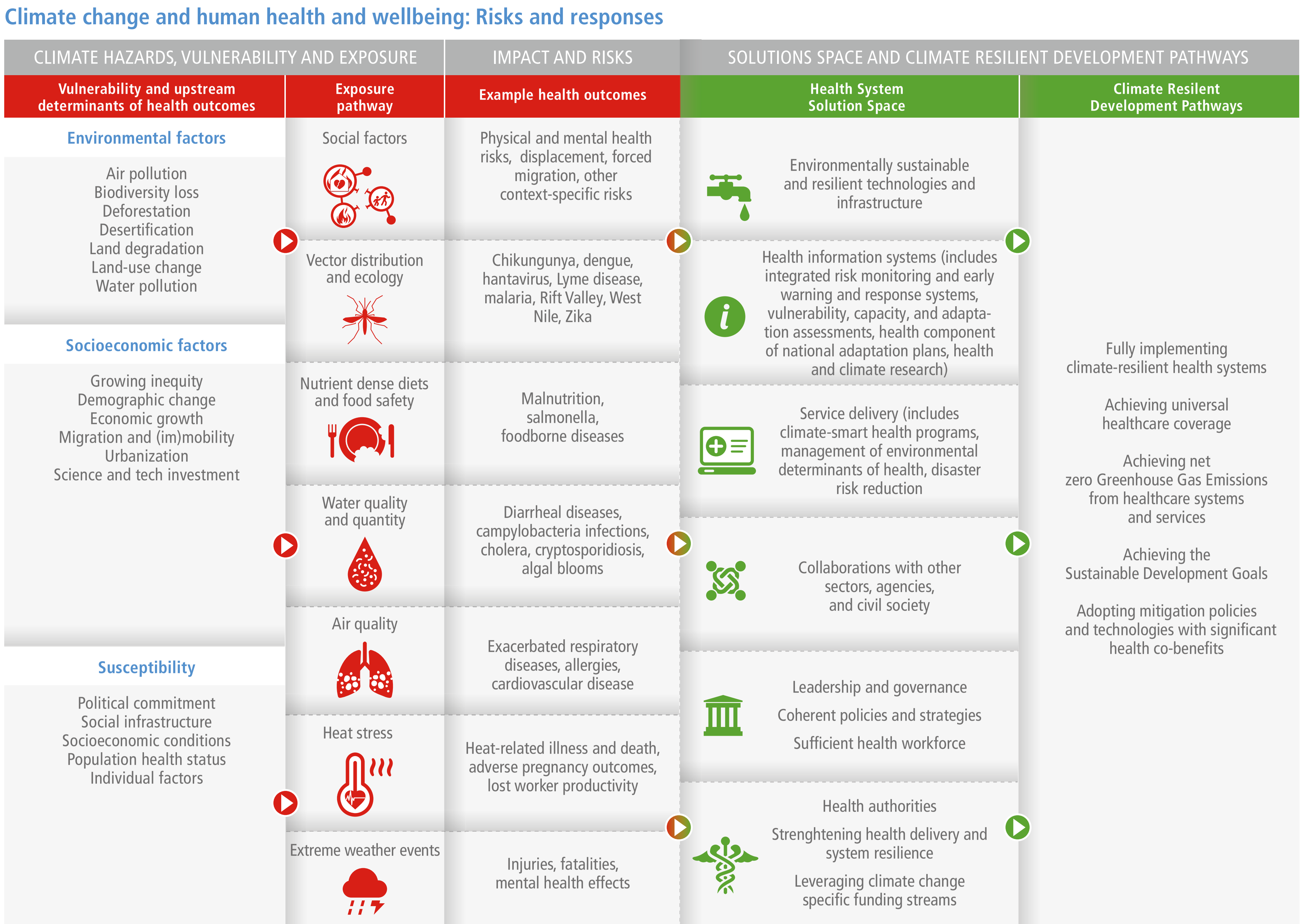
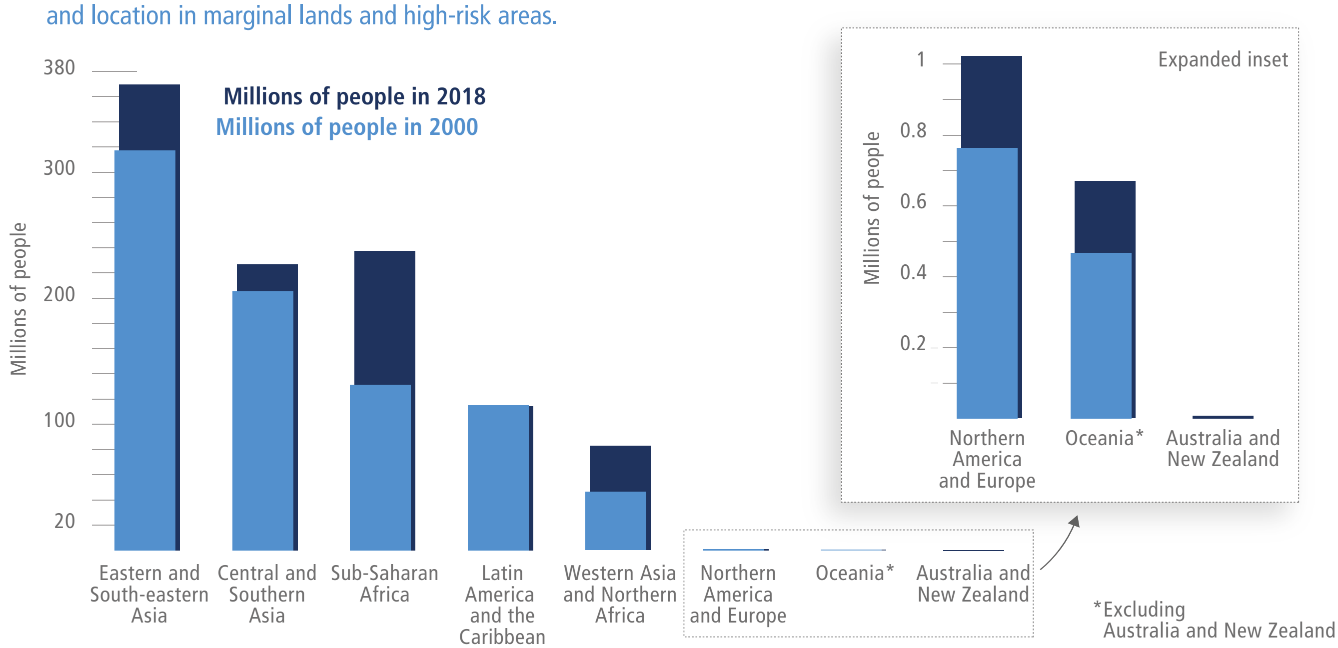


Figure TS.8 HEALTH | Multiple socio-economic and environmental factors interact with climate risks to shape human health and well-being. Achieving climate resilient development requires leveraging opportunities in the solution space within health systems and across other sectors. {7.1.4, 7.1.6, 7.1.7, 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.

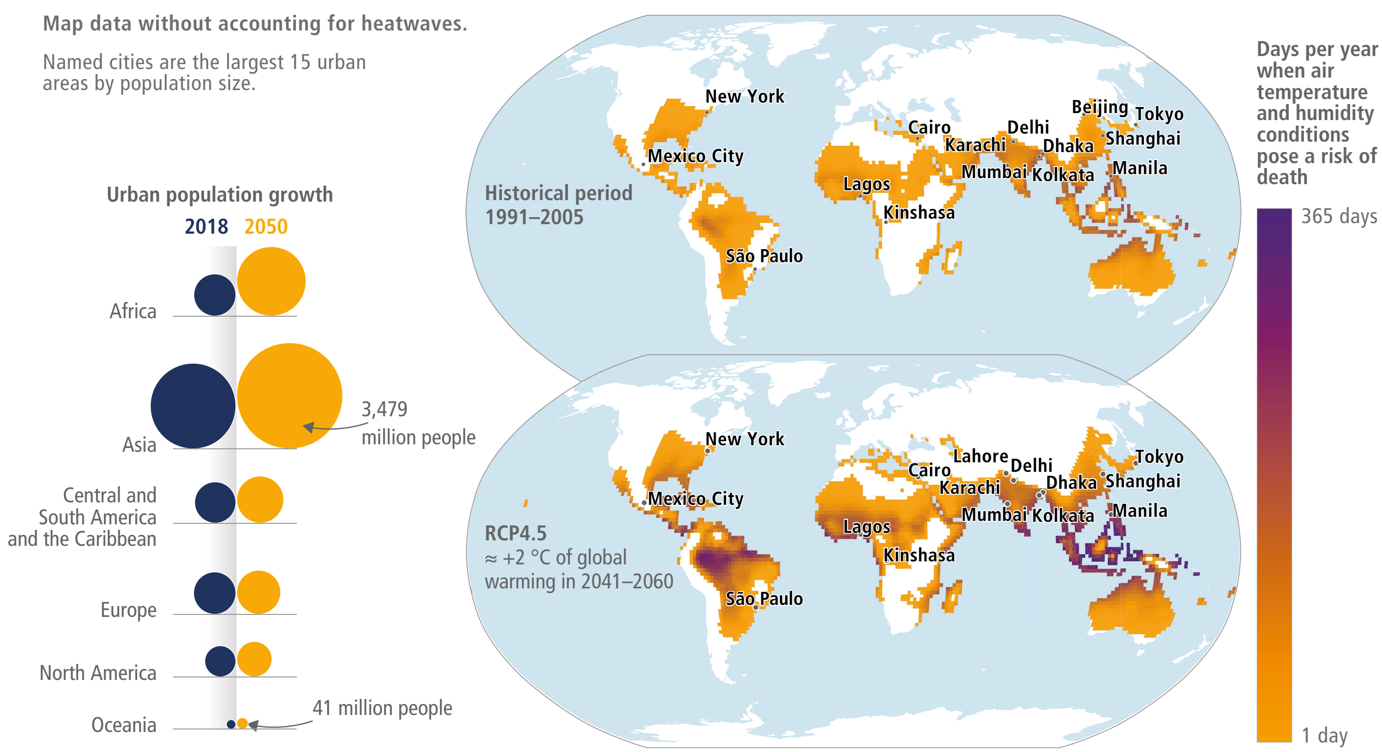
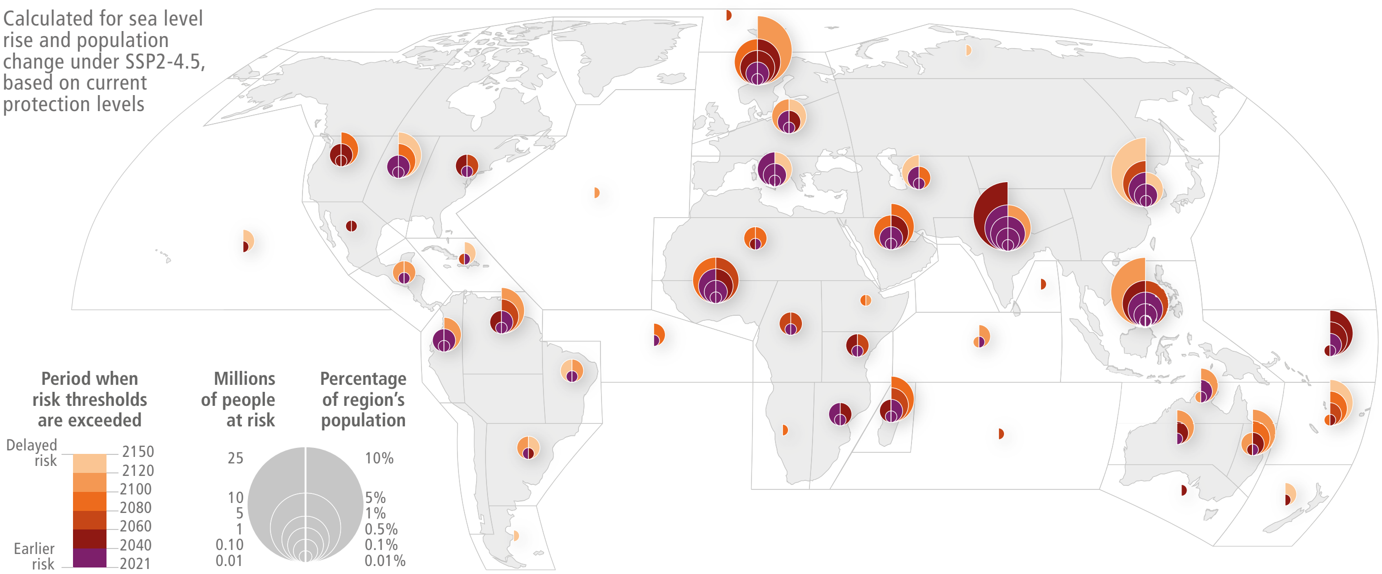


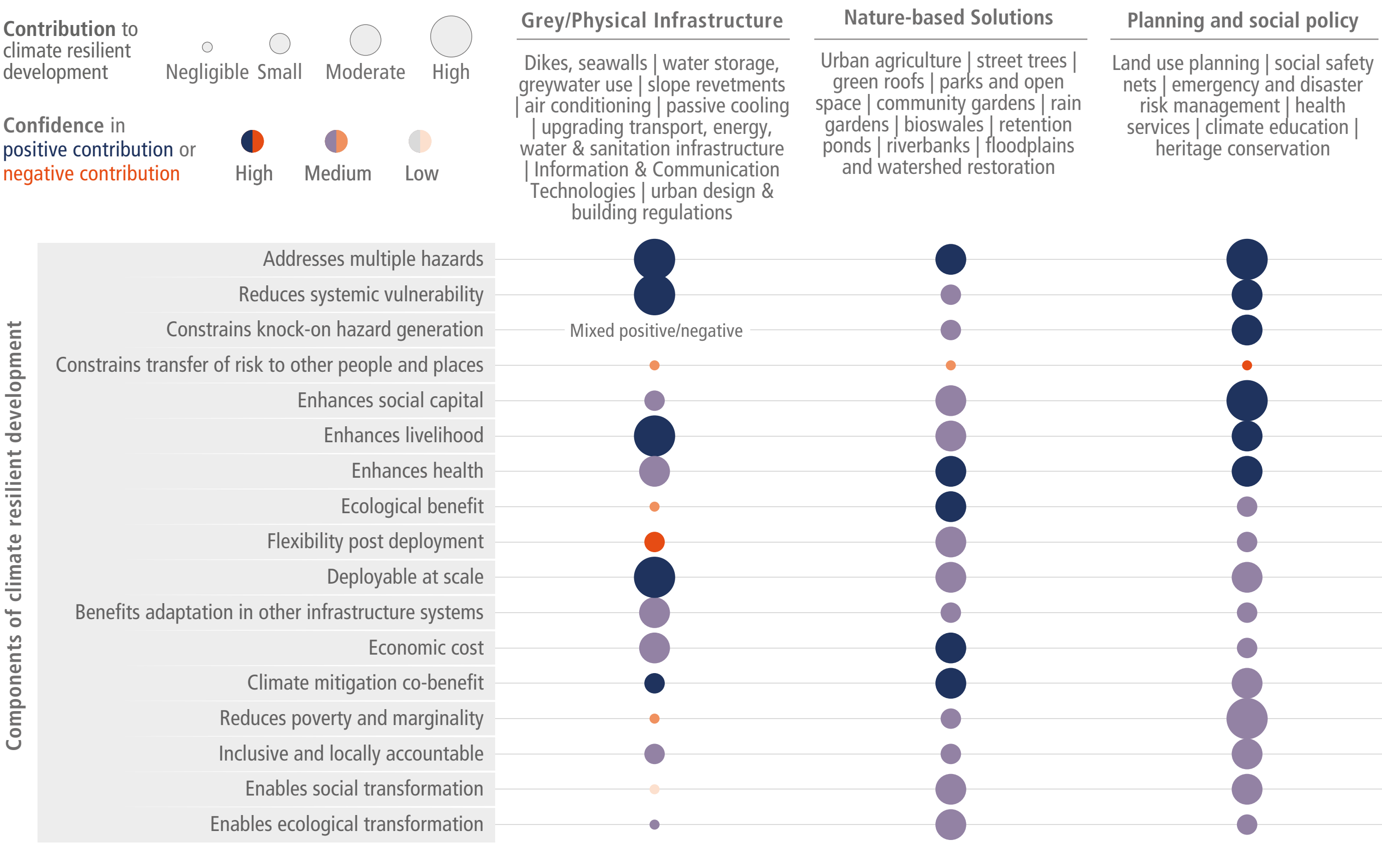
Figure TS.9 URBAN | (a) The regions shown are reflecting the original dataset from UN Habitat and vary from IPCC regions. {6.1.4, 9.9.3, 10.4.6, 12.5.5} **(b)** Heat is a growing health risk due to increasing urbanization and rising temperature extremes. Within cities the urban heat island effect elevates 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}

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



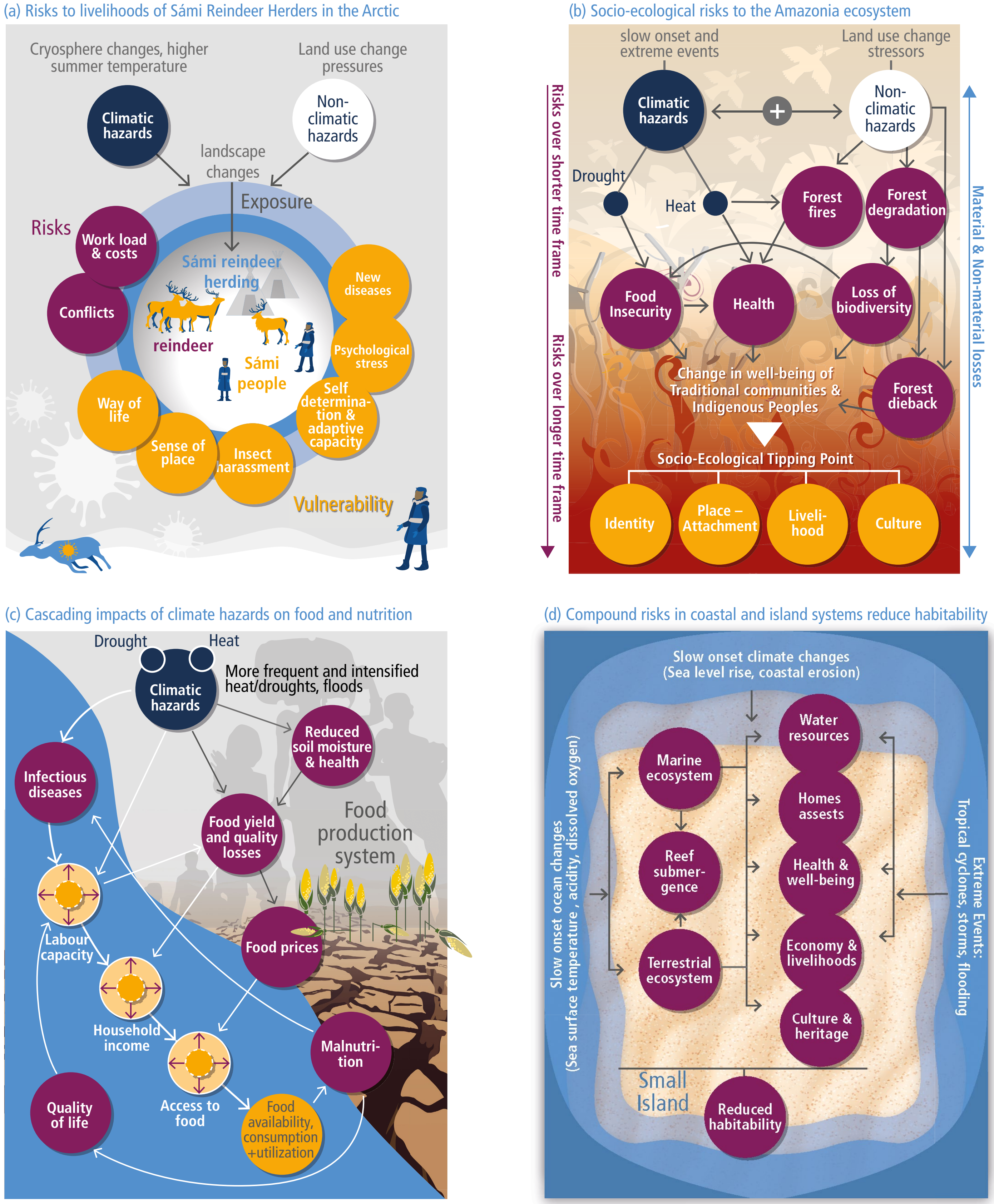
(d) Contributions of urban adaptation options to climate resilient development.

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.

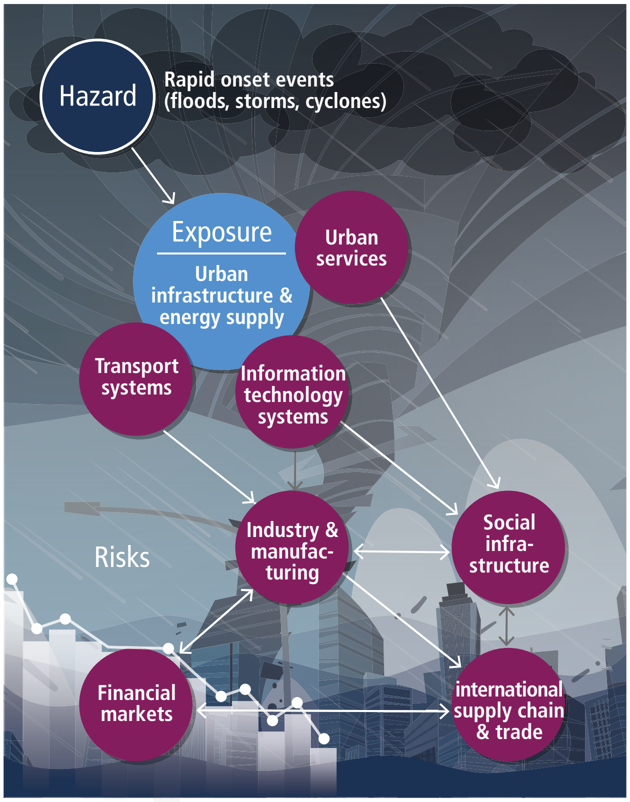


(c) The size of the circle represents the number of people at risk per IPCC region and the colours show the timing of risk based on projected population change and sea level rise under SSP2-4.5. Darker colours indicate earlier in setting risks. The left side of the circles shows absolute projected population 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}

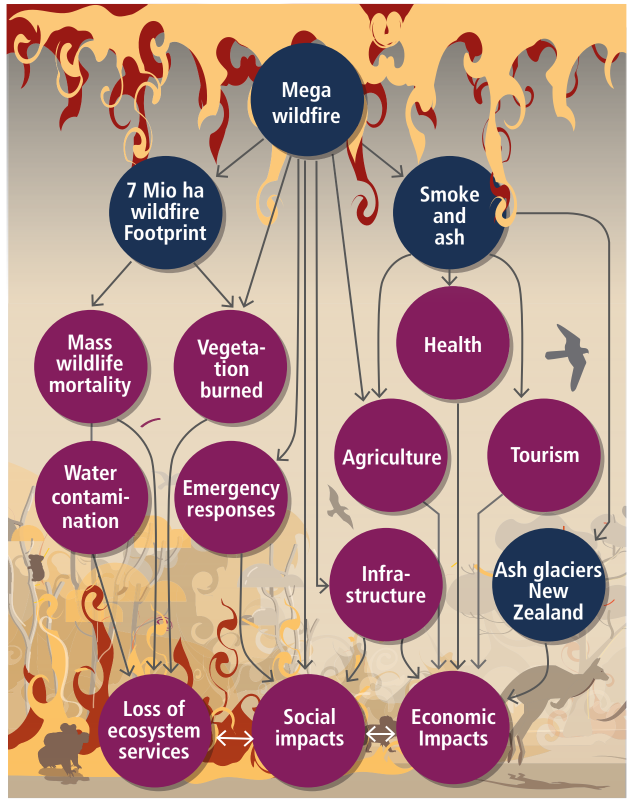
Compound, cascading and transboundary impacts for humans and ecosystems result from the complex interaction of multiple climate hazards, exposures and vulnerabilities



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



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



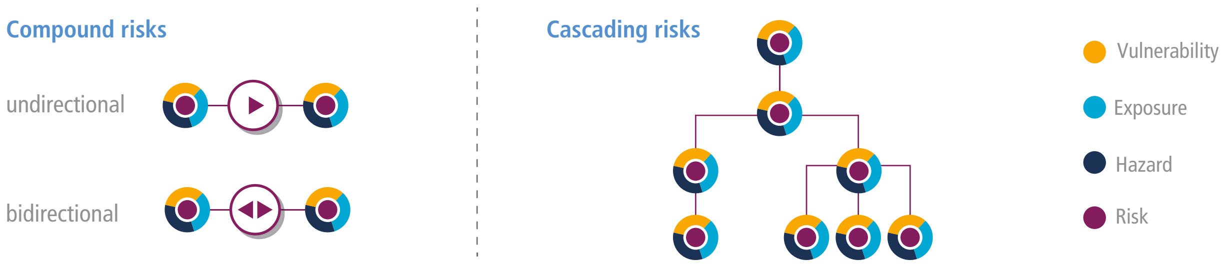


Figure TS.10 COMPLEX RISK | Compound, cascading and transboundary impacts for humans and ecosystems result from exposure to the complex interactions of (1) multiple climatic hazards, including with non-climatic stressors (as seen in panels a, b, c, d), (2) multiple vulnerabilities compounding the effect 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}

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 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

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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}

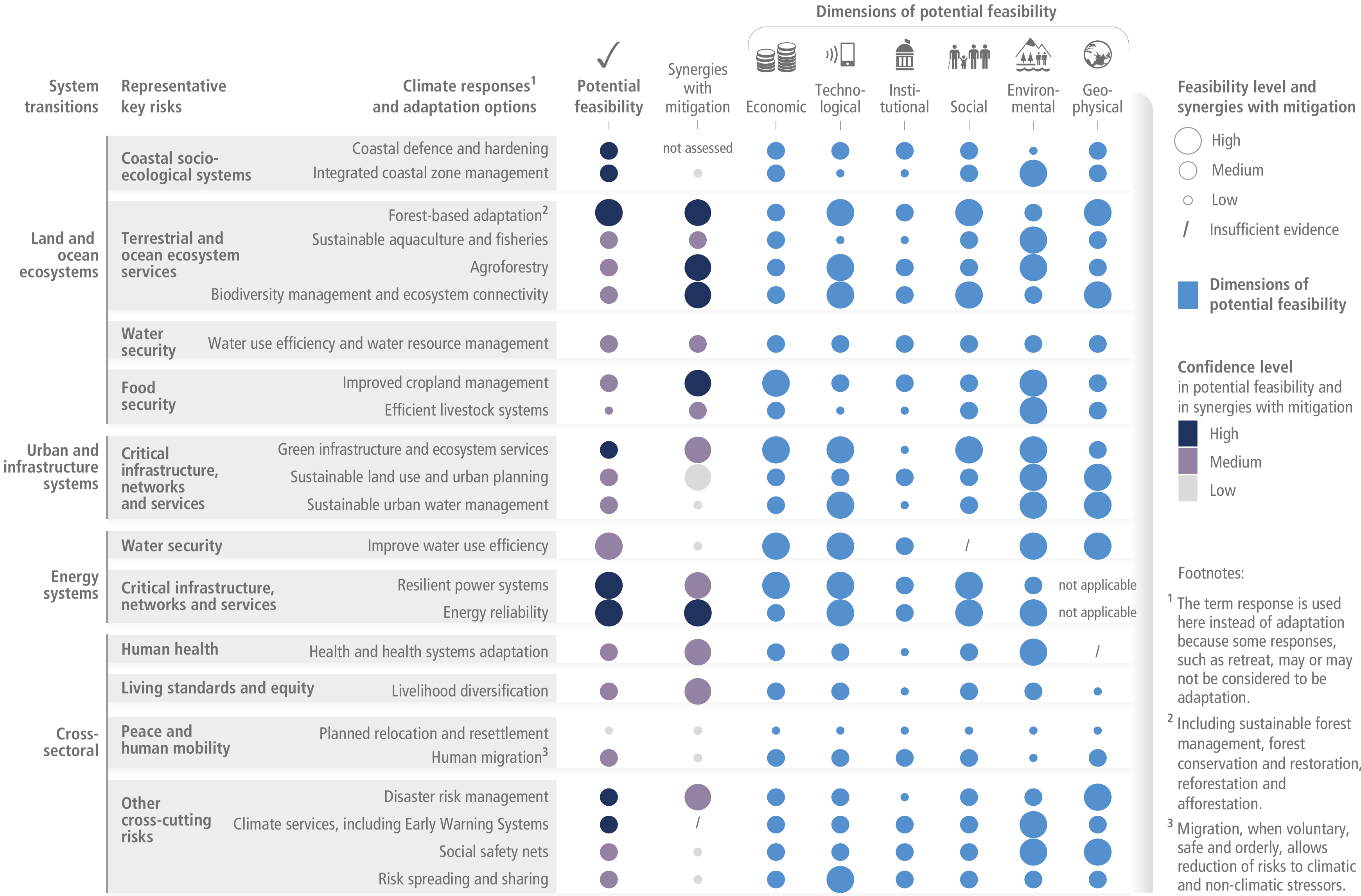
Water and food sectors

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 eco-system-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.

(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



(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

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

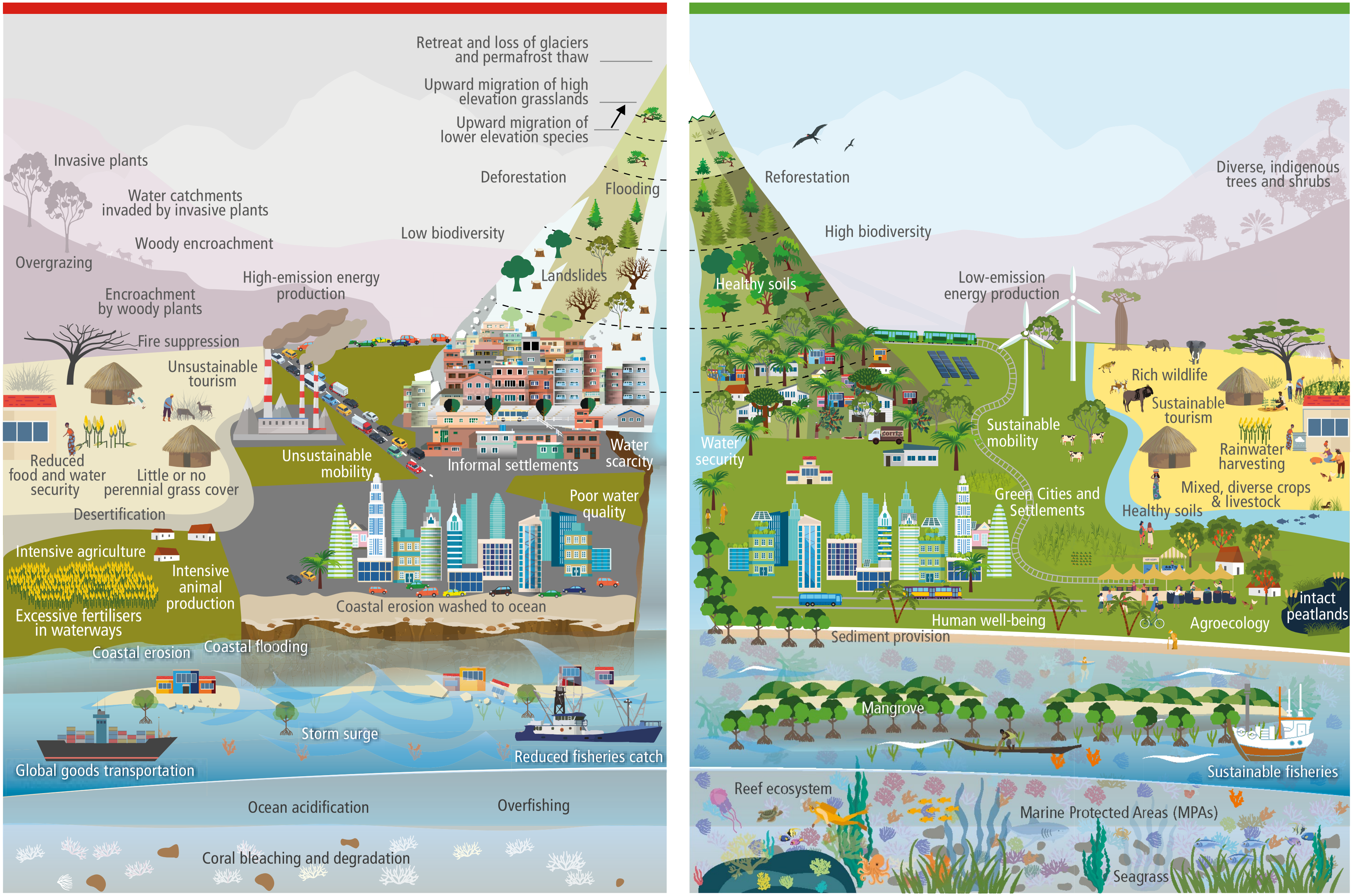


Figure TS.12 | This figure shows the interconnectedness between different ecosystems and system transitions, with human activities in urban, rural and coastal locations embedded in ecosystems. Maintaining biosphere integrity is essential for biodiversity, human and societal health and a precondition 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

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 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, 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

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

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 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}

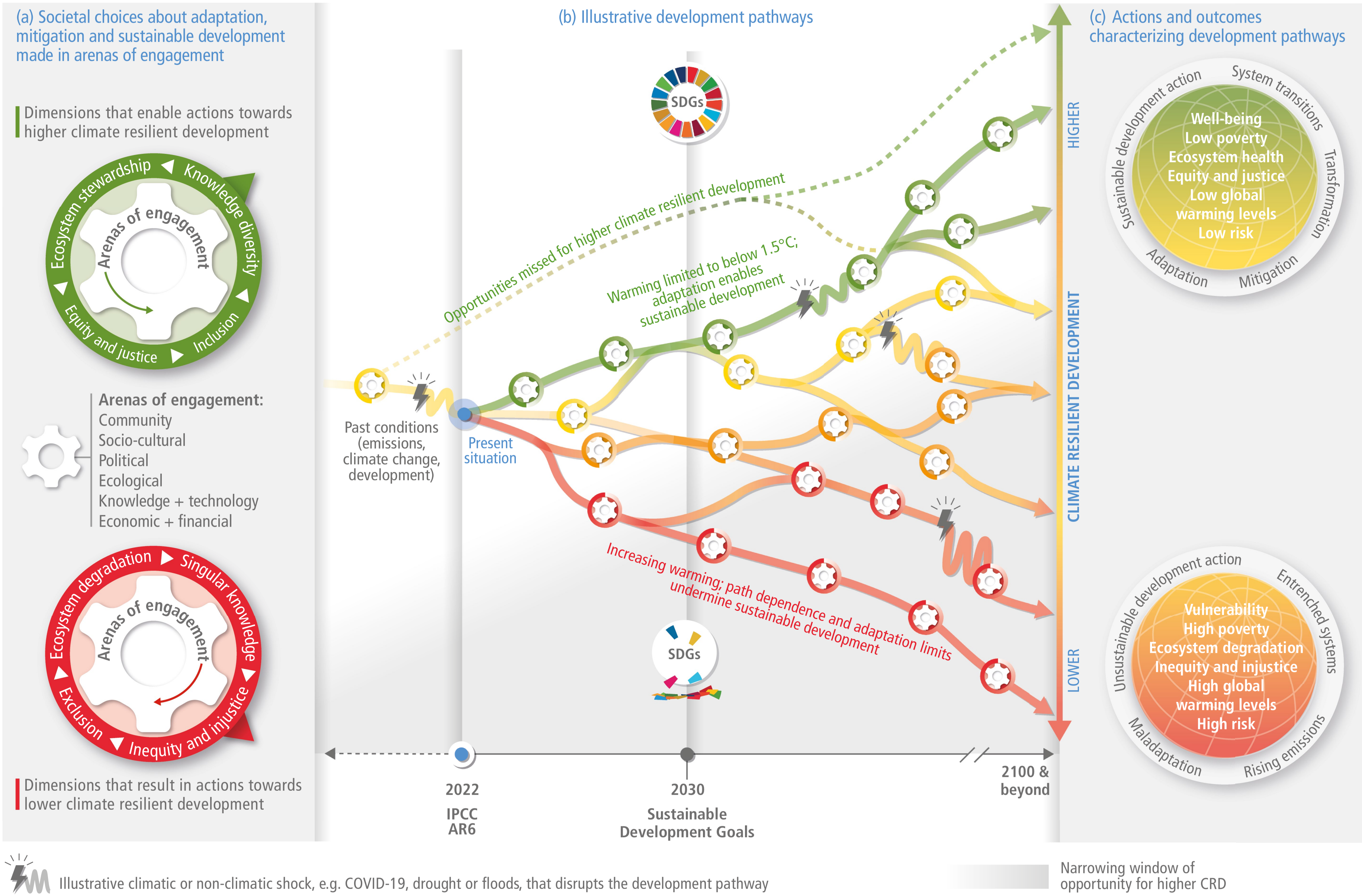
TS.E.2 Climate action and sustainable development are interdependent. Pursued in an inclusive and integrated manner, they enhance human and ecological well-being. Sustainable development is fundamental to capacity for climate action, including reductions in greenhouse gas emissions as well as enhancing 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}

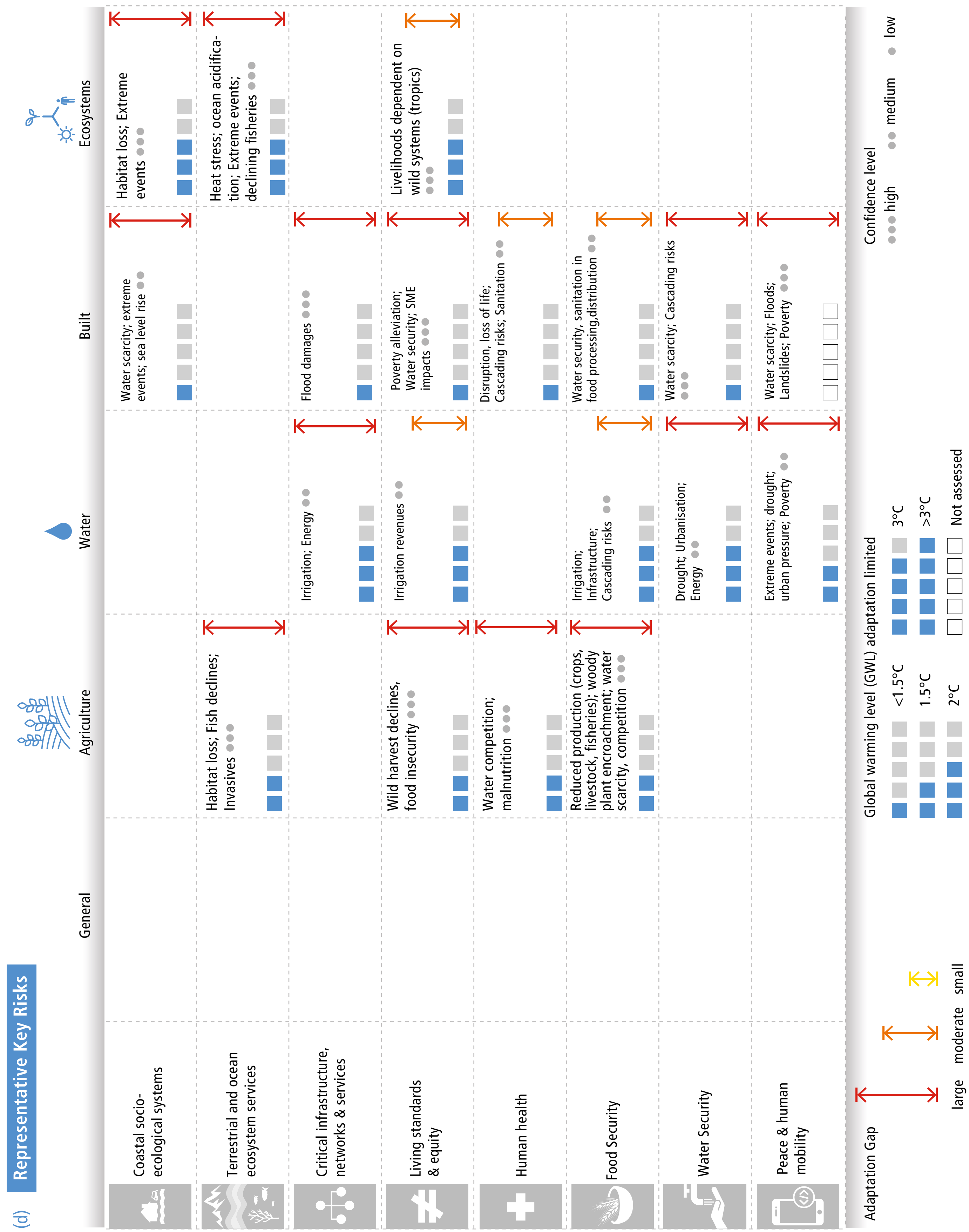
TS.E.2.1 Conditions enabling rapid increases and innovative climate responses include experience of extreme events or climate education influencing perceptions of urgency, together with the actions of catalysing agents such as social movements and technological entrepreneurs. People who have experienced 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}

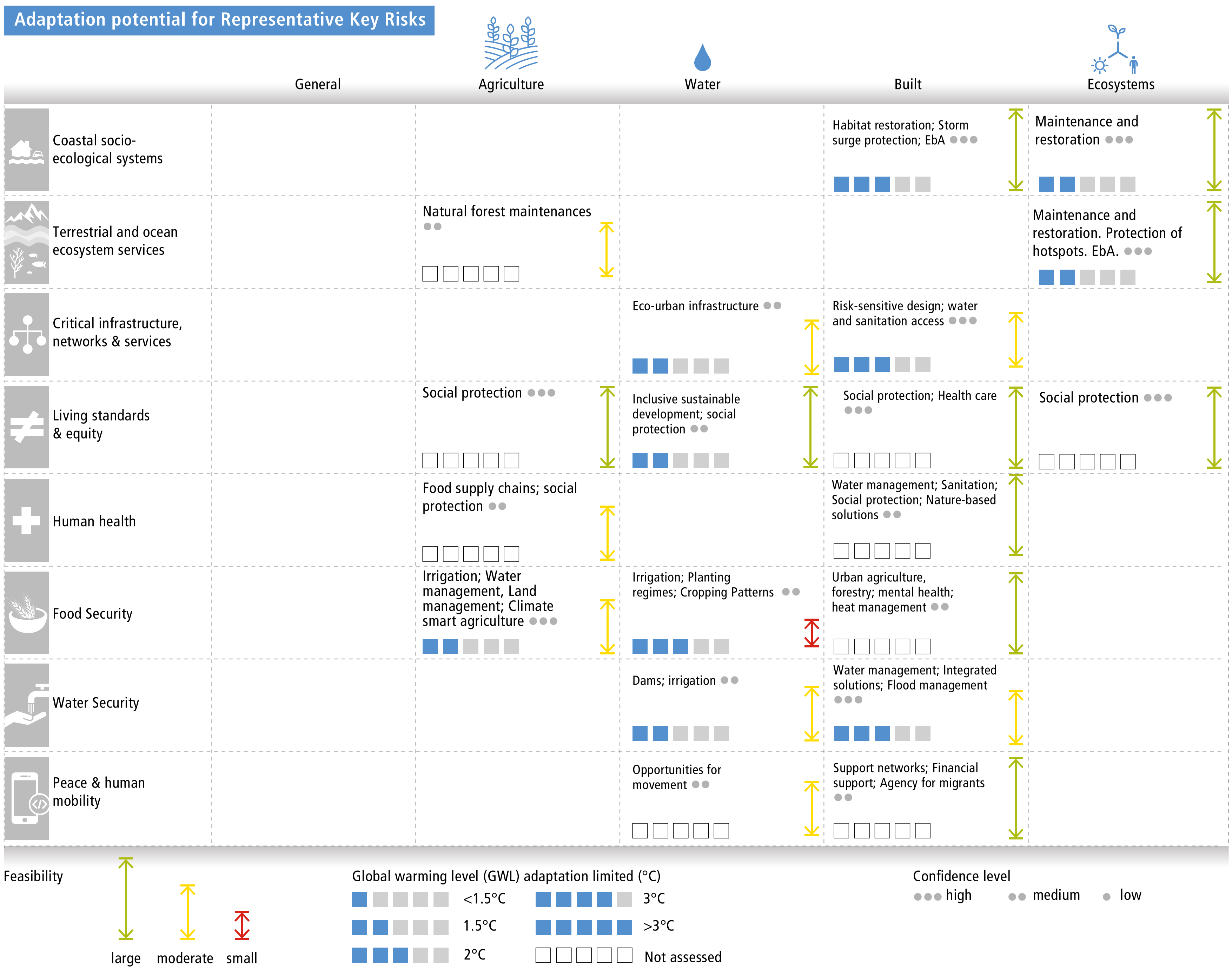
TS.E.2.3 Climate adaptation actions are grounded in local realities so understanding links with SDG 5 on gender equality ensures that adaptive actions do not worsen existing gender and other inequities within society (e.g., leading to maladaptation practices) (*high confidence*). Adaptation actions do 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}

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
Habitat loss; Extreme events
Water scarcity; extreme events; sea level rise
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



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 − +|− +

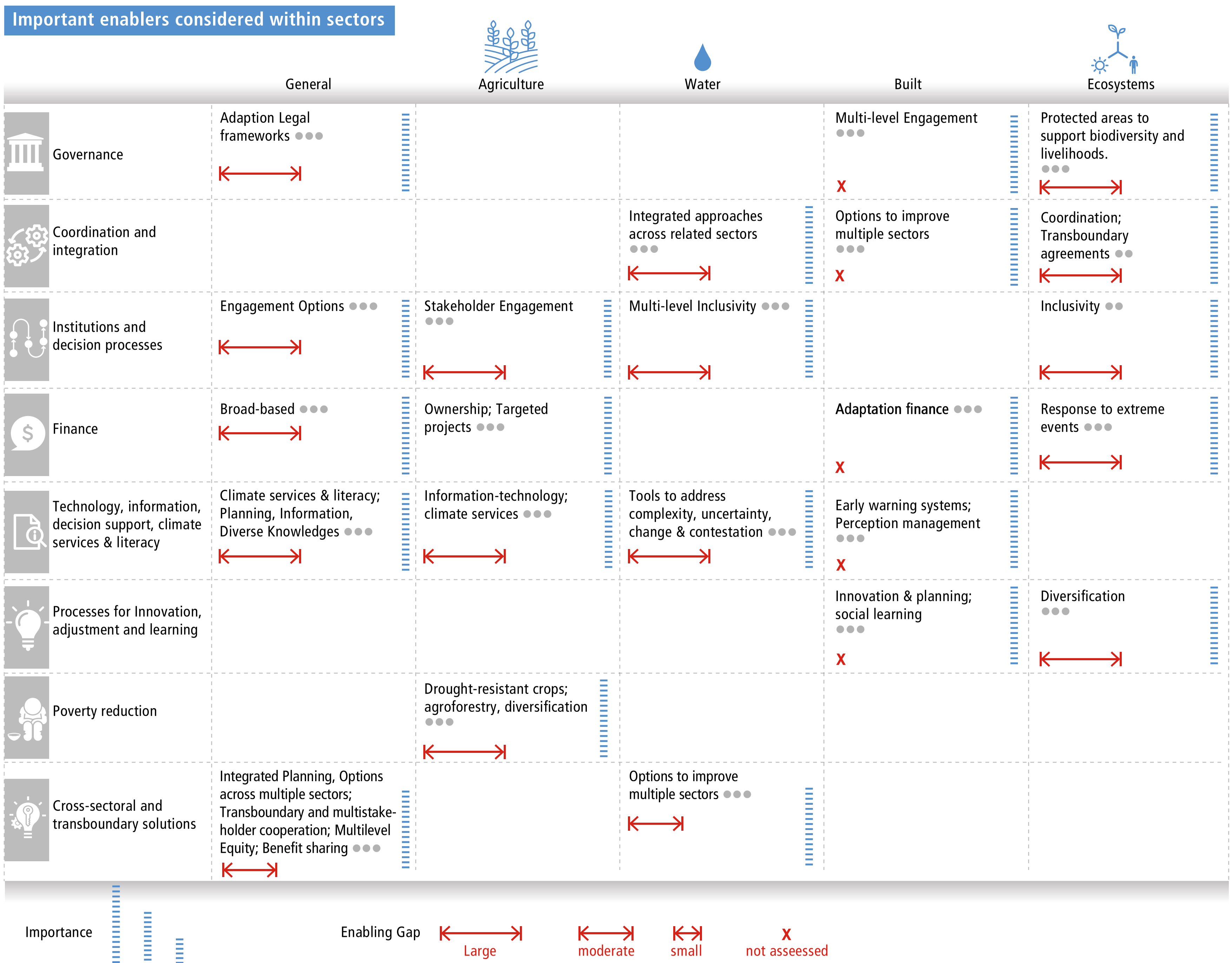

Important enablers considered within sectors
General
Agriculture
Water
Built
Ecosystems
Governance
Adaption Legal frameworks
Multi-level Engagement
Protected areas to support biodiversity and livelihoods.
Coordination and integration
Integrated approaches across related sectors
Options to improve multiple sectors
Coordination; Transboundary agreements
Institutions and decision processes
Engagement Options
Stakeholder Engagement
Multi-level Inclusivity
Inclusivity
Finance
Broad-based
Ownership; Targeted projects
Adaptation finance
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
Processes for Innovation, adjustment and learning
Innovation & planning; social learning
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 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

TS

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

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}

Synthesis of the severity conditions for Representative Key Risks by the end of this century

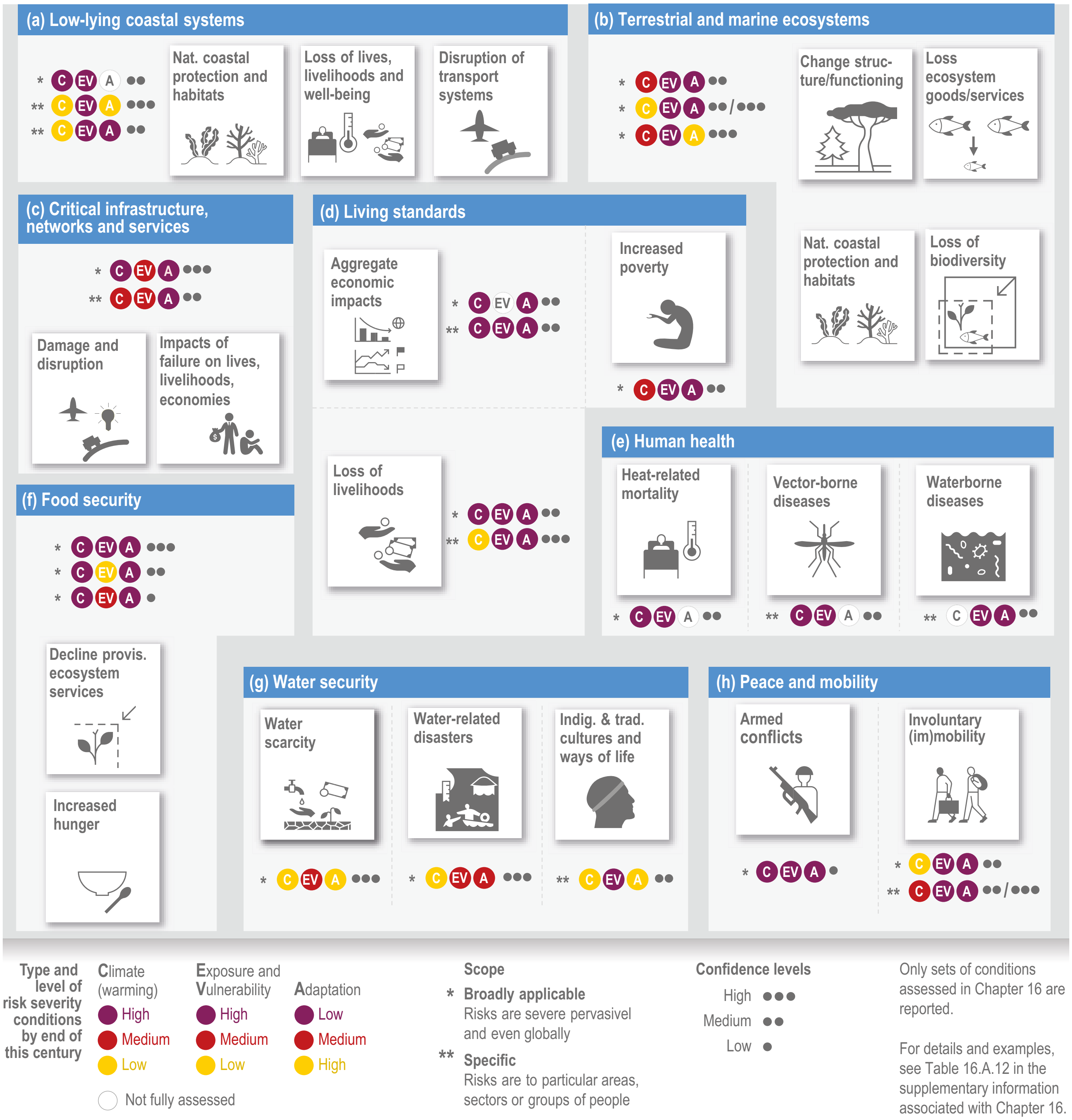


Figure TS.AII.1 | Synthesis of the severity conditions for Representative Key Risks (RKRs) by the end of this century. The figure does not aim to describe severity conditions exhaustively for each RKR, but rather to illustrate the risks highlighted in this report (Sections 16.5.2.3.1 to 16.5.2.3.8). 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}

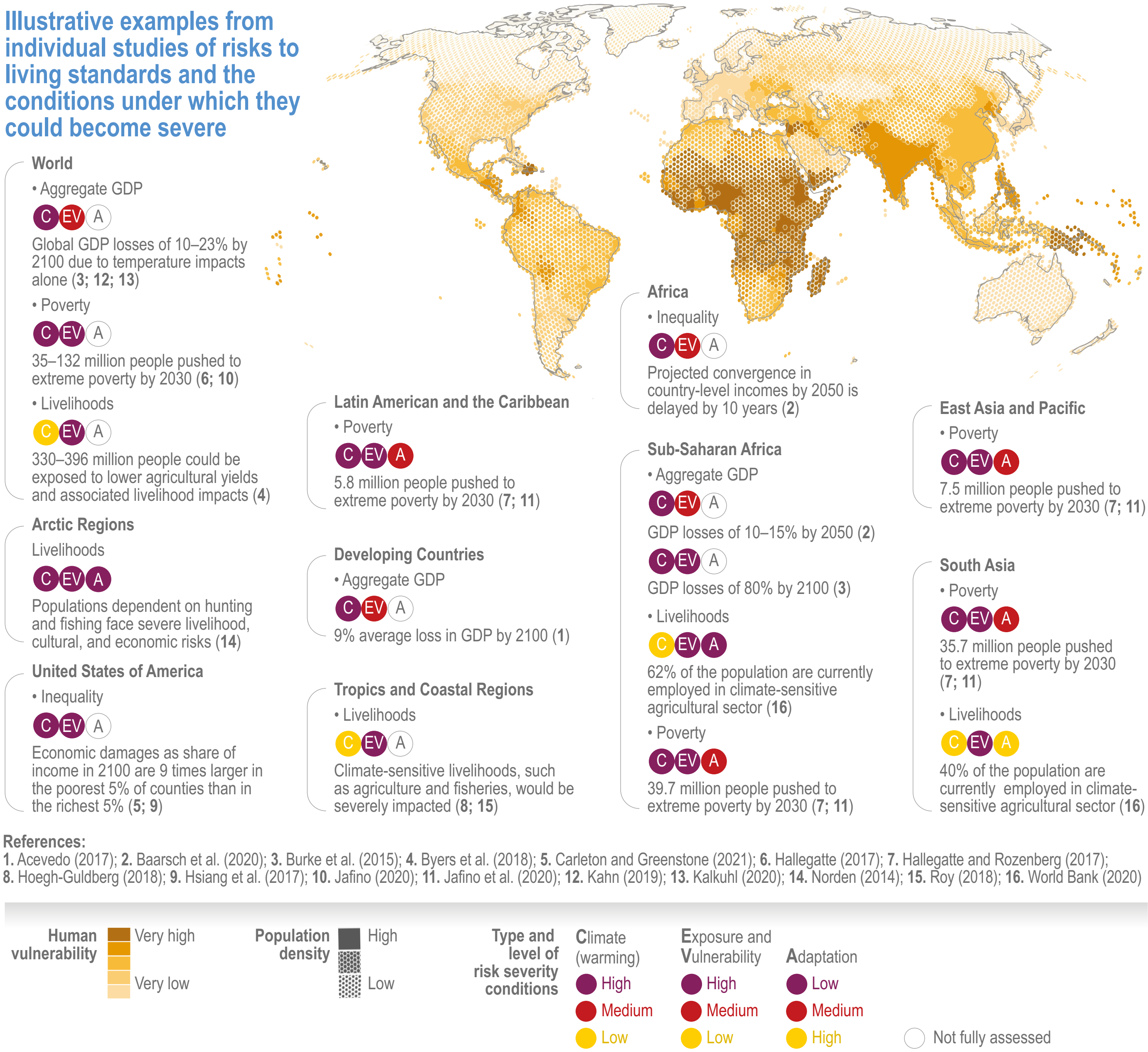


Figure TS.AII.2 | Illustrative examples from individual studies of risks to living standards and the conditions under which they could become severe in terms of aggregate economic output, poverty and livelihoods. High, medium and low levels of warming, exposure/vulnerability and adaptation are defined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

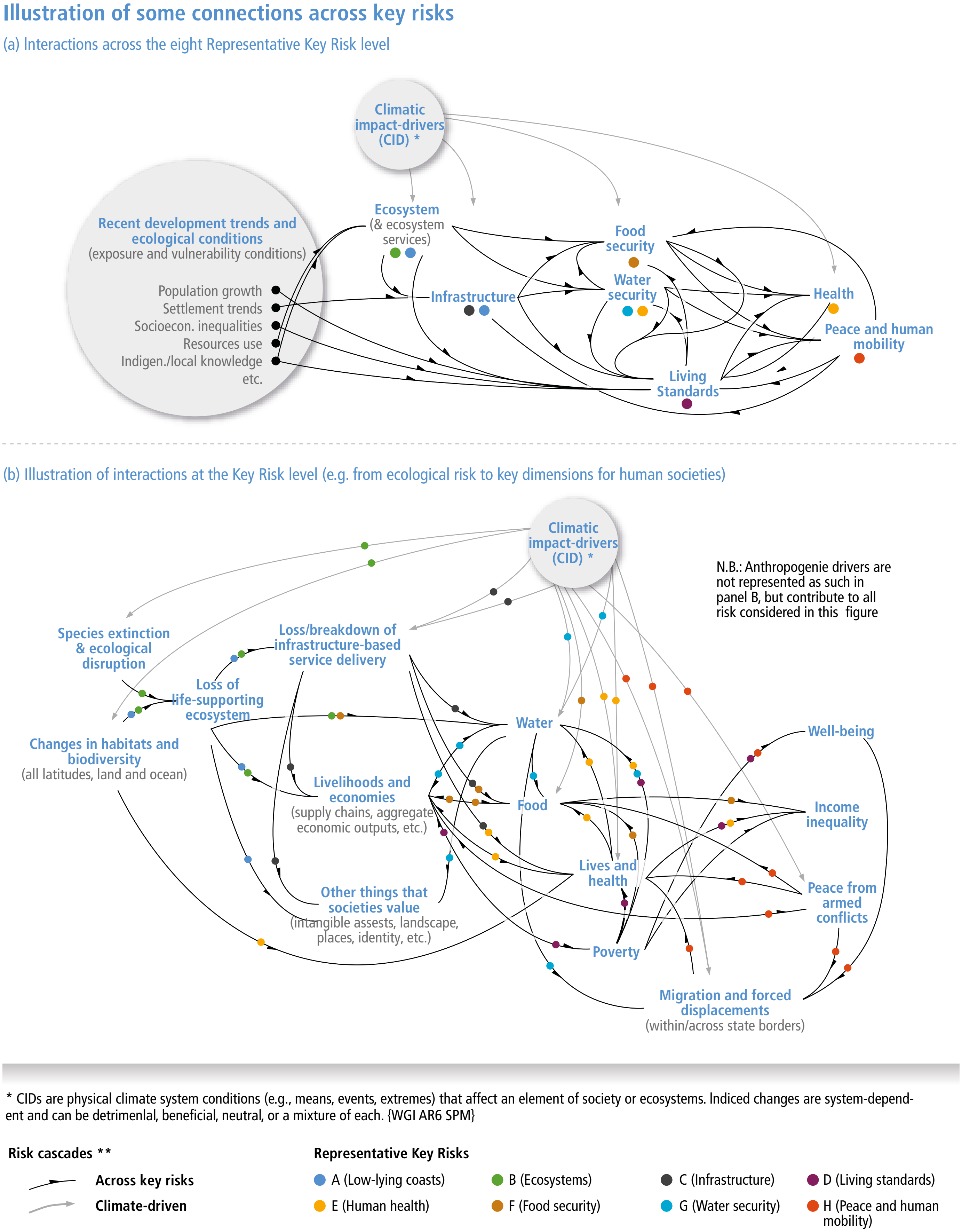


Figure TS.AII.3 | Illustration of some connections across key risks. Panel A describes all the cross-RKR risk cascades that are described in RKR assessments (Sections 16.5.2.3.2 to 16.5.2.3.9). Panel B provides an illustration of such interactions at the key risk level, for example from ecological risk 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

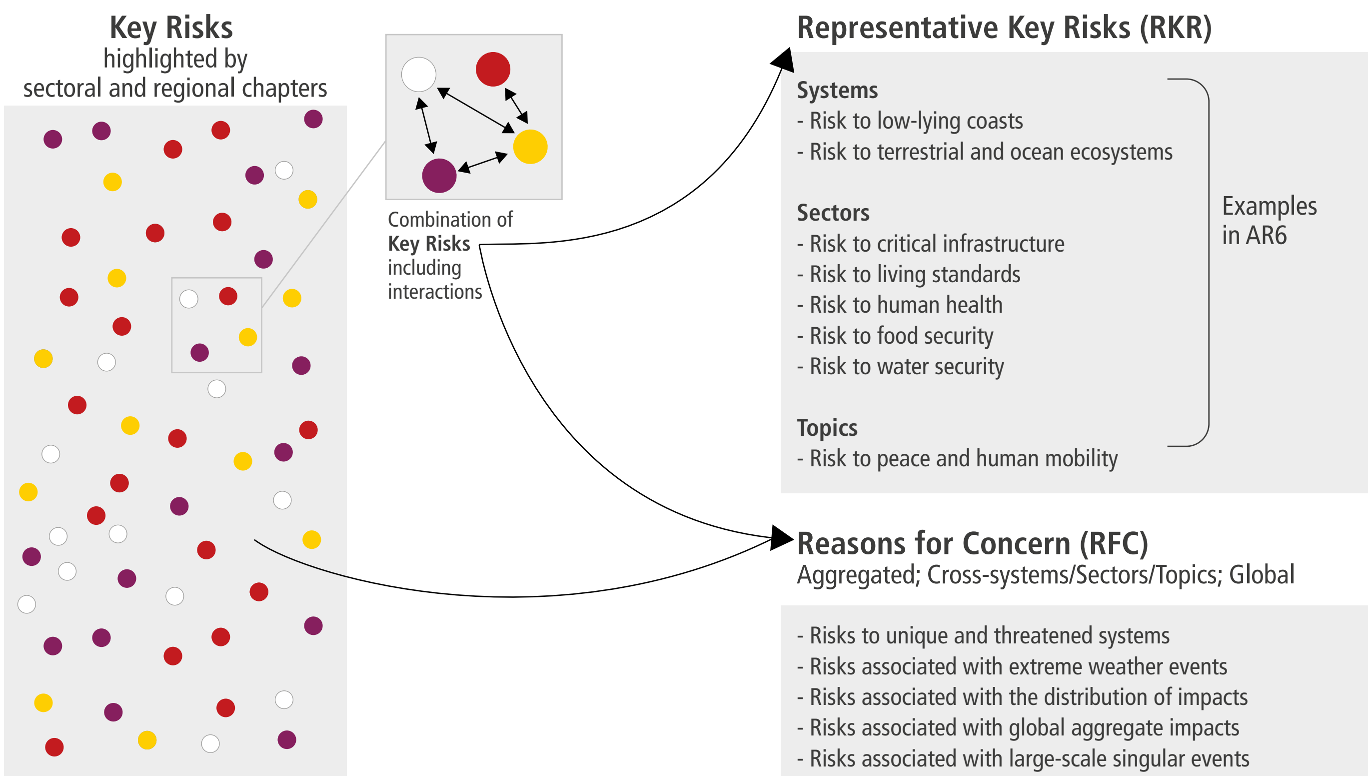


Figure TS.AII.4 | Interconnections among key risks, representative key risks and reasons for concern {Figure 16.13}

Working Group II
Frequently Asked Questions

FAQ

Frequently Asked Questions

These Frequently Asked Questions have been extracted from the chapters and papers of the underlying report and are compiled here. When referencing specific FAQs, please reference the corresponding chapter or paper in the report from where the FAQ originated (e.g., FAQ 3.1 is part of Chapter 3).

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FAQ

Frequently Asked Questions

FAQ 1.1 | What are the goals of climate change adaptation?

The goals of climate change adaptation, as a broad concept, are to reduce risk and vulnerability to climate change, strengthen resilience, enhance well-being and the capacity to anticipate, and respond successfully to change. Existing international frameworks provide a high-level direction for coordinating, financing and assessing progress toward these goals. However, specifying the goals for specific adaptation actions is not straightforward because the impacts of climate change affect people and nature in many different ways requiring different adaptation actions. Thereby, goals that accompany these actions are diverse. Goals can relate to health, water or food security, jobs and employment, poverty eradication and social equity, biodiversity and ecosystem services at international, national and local levels.

Climate change adaptation entails the process of adjustment to actual or expected climate change and its effects in order to moderate harm or exploit beneficial opportunities. At a high level, international frameworks, including the Paris Agreement and the SDGs, have come to provide a direction for coordinating, financing and assessing global progress in these terms. The Paris Agreement calls for climate change adaptation actions, referring to these actions as those that reduce risk and vulnerability, strengthen resilience, enhance the capacity to anticipate and respond successfully, and ensure the availability of necessary financial resources, as these processes and outcomes relate to climate change. In addition, the Sustainable Development Goals include 17 targets (with a specific goal SDG 13 on climate action) to fulfil its mission to end extreme poverty by 2030, protect the planet and build more peaceful, just and inclusive societies. These goals are difficult to reach without successful adaptation to climate change. Other notable frameworks that identify climate change adaptation as important global priorities include the SFDRR, the finance-oriented Addis Ababa Action Agenda and the New Urban Agenda.

While vital for international finance, coordination and assessment, the global goals set forth by these frameworks and conventions do not necessarily provide sufficient guidance to plan, implement or evaluate specific adaptation efforts at the community level. Specifying goals of adaptation is harder than setting goals for reducing emissions of climate-warming GHG emissions. For instance, emission reduction effort is ultimately measured by the total amount of GHGs in the Earth's atmosphere. Instead, adaptation aims to reduce risk and vulnerability from climate change and helps to enhance well-being in each individual community worldwide.

Because the impacts of climate change affect people and nature in so many different ways, the specific goals of adaptation depend on the impact being managed and the action being take. For human systems, adaptation includes actions aimed at reducing a specific risk, such as by fortifying a building against flooding, or actions aimed at multiple risks, such as requiring climate risk assessments in financial reporting in anticipation of different kinds of risk. At the local level, communities can take actions that include updating building codes and land use plans, improving soil management, enhancing water use efficiency, supporting migrants and taking measures to reduce poverty. For natural systems, adaptation includes organisms changing behaviours, migrating to new locations and genetic modifications in response to changing climate conditions. The goals for these adaptation actions can relate to health, water or food security, jobs and employment, poverty eradication and social equity, biodiversity and ecosystem services, among others. Articulating the goals of adaptation thus requires engaging with the concepts of equity, justice and effectiveness at the international, national and local levels.

Frequently Asked Questions

FAQ 1.2 | Is climate change adaptation urgent?

Climate impacts, such as stronger heat waves, longer droughts, more frequent floods, accelerating sea level rise and storm surges, are already being observed in some regions, and people around the world are increasingly perceiving changing climates, regarding these changes as significant and considering climate action as a matter of high urgency. Reducing climate risk to levels that avoid threatening private or social norms and ensuring sustainable development will require immediate and long-term adaptation efforts by governments, business, civil society and individuals at a scale and speed significantly faster than the current trends.

Current observed climate impacts and expected future risks include stronger and longer heat waves, unprecedented droughts and floods, accelerating sea level rise and storm surges affecting many geographies and communities. People around the world are increasingly perceiving changing climates, regarding these changes as significant and considering climate action as a matter of high urgency. In particular, marginalised and poor people, as well as island and coastal communities, experience relatively higher risks and vulnerability. The available evidence suggests that current adaptation efforts may be insufficient to help ensure sustainable development and other societal goals in many communities worldwide even under the most optimistic GHG emissions scenarios.

Climate change adaptation is, therefore, urgent to the extent that meeting important societal goals requires immediate and long-term action by governments, business, civil society and individuals at a scale and speed significantly faster than that represented by current trends.

Frequently Asked Questions

FAQ 1.3 | What constitutes successful adaptation to climate change?

The success of climate change adaptation is dependent on the extent to which relevant actions reduce risk and vulnerability, as well as achieve their respective goals. At a global scale, these goals are set and tracked according to international frameworks and conventions. At smaller scales, such as local and national, goals are dependent on the specific impacts being managed, the actions being taken and the relevant scale. While success can take shape as uniquely as goals can, the degree to which an adaptation is feasible, effective and conforms to principles of justice represents important attributes for measuring success across actions. Adaptation responses that lead to increased risk and impacts are considered maladaptation.

Altogether, adaptation success is dependent on the extent to which adaptation actions achieve their respective goals of reducing climate risk, increasing resilience and pursuing other climate-related societal goals. Viewed globally, successful adaptation consists of actions anticipated to make significant contributions to meeting SDGs, such as ending extreme poverty, hunger and discrimination, and reduce risks to ecosystems, water, food systems, human settlements, and health and well-being. Viewed locally, successful adaptation consists of actions that help communities meet their diverse goals, including reducing anticipated current and future risks, enhancing capacity to adapt and transform, avoiding maladaptation, yielding benefits greater than costs and serving vulnerable populations, and arising from an inclusive, evidence-based and equitable decision process.

While success can be unique to an adaptation action, there are important attributes that constitute it as a successful solution. These include the extent to which an action is considered feasible, effective and conforms to principles of justice.

The degree to which an action is *feasible* is the extent to which it is appraised as possible and desirable, taking into consideration barriers, enablers, synergies and trade-offs. These considerations are based on financial or economic, political, physical, historical and social factors, depending on what is required for an action to be implemented. The degree to which an action is *effective* depends on the extent it reduces climate risk, as well as the extent an action achieves its intended goals or outcomes. An adaptation action can sometimes—usually inadvertently—increase risk or vulnerability for some or all affected individuals or communities. In some cases, such risk increases will be sufficient to call the actions maladaptation. The degree to which an action is *just* is when its outcomes, the process of implementing the action and the process of choosing the action respects principles of distributive, procedural and recognitional justice. Distributive justice refers to the different distributions of benefits and burdens of an action across members of society; procedural justice refers to ensuring the opportunity for fairness, transparency, inclusion and impartiality in the decision making of an action; and recognitional justice insists on recognising and including those who are or may be most affected by an action.

These attributes of adaptation success can be assessed throughout the adaptation process of planning, implementation, Monitoring & Evaluation adjustment and learning. However, at the same time, the success of many adaptation actions depends strongly on context and time. For instance, the effectiveness of adaptation will depend on the success of GHG mitigation efforts, as adaptation has strong synergies and trade-offs with mitigation efforts

Frequently Asked Questions

FAQ 1.4 | What is transformational adaptation?

Continuing and expanding current adaptation efforts can reduce some climate risks. But even with emission reductions sufficient to meet the Paris Agreement goals, transformational adaptation will be necessary.

Over six assessment reports, the IPCC has documented transformative changes in the Earth's climate and ecosystems caused by human actions. These changes are now unequivocal and projected to become even more significant in the years and decades ahead. This AR6 report also highlights climate adaptation actions people are taking and can take in response to these significant changes in the climate system.

Some adaptation is incremental, which only modifies existing systems. Other actions are transformational, leading to changes in the fundamental characteristics of a system. For instance, building a seawall to protect a coastal community from flooding might exemplify incremental adaptation. Changing land use regulations in that community and establishing a programme of managed retreat might exemplify transformational adaptation. There is no definitive line between incremental and transformational adaptation. Some incremental actions stay incremental. Others may expand the future space of solutions. For instance, including climate risk in mortgages and insurance might at first seem incremental but might lead to more transformational change over time.

Transformation can be deliberate, envisioned and intended by at least some societal actors, or forced, arising without explicit intent.

Deliberate transformational adaptation is not without risks because change can disturb existing power relationships and can unfold in difficult to predict and unintended ways. But transformational adaptation is important to consider because it may be needed to avoid intolerable risks from climate change and to help meet development goals as articulated in the SDGs. In addition, some types of societal transformation may be inevitable and deliberate rather than forced transformation and may bring society closer to its goals.

Some types of transformation may be inevitable because the amount of transformational adaptation needed to avoid intolerable risks depends in part on the level of GHG mitigation. Low concentration pathways consistent with Paris Agreement goals require deliberate transformations that lead to significant and rapid change in energy, land, urban and infrastructure, and industrial systems. Even with low concentration pathways, some transformational adaptation will be necessary to limit intolerable risks. But with higher concentration pathways, more extensive transformational adaptation would be required to limit (though not entirely avoid) intolerable risks. In such circumstances, insufficient deliberate transformation could lead to undesirable forced transformations.

Frequently Asked Questions

FAQ 1.5 | What is new in this 6th IPCC report on impacts, adaptation and vulnerability?

Since IPCC Fifth Assessment Report, many new sources of knowledge have been employed to provide better understanding of climate change risks, impacts, vulnerability and also societal responses through adaptation, mitigation and sustainable development. This new, more integrative assessment focuses more on risk and solutions, social justice, different forms of knowledge including IK and LK, the role of transformation and the urgency of fast climate actions.

The IPCC Sixth Assessment Report (AR6) has played a prominent role in science–policy–society interactions on the climate issue since 1988 and has advanced in interdisciplinary climate change assessment since AR5. Many new sources of knowledge have been employed to provide better understanding of climate change risks, impacts, vulnerability and also societal responses through adaptation, mitigation and sustainable development.

This AR6 assessment focuses more on risk and solutions. The risk framing for the first time spans all three Working Groups. It 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 solutions framing 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.

The AR6 emphasises the emergent issue on social justice and different forms of knowledge. As climate change impacts and responses are implemented, there is heightened awareness of the ways that climate responses interact with issues of justice and social progress. In this report, there is expanded attention on 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 is also accompanied by increased consideration and incorporation of Indigenous knowledge and local knowledge and associated scholars.

The AR6 has a more extensive focus on the role of transformation and the urgency of fast climate actions in meeting societal goals. This report assesses extensive literatures with an increasing diversity of topics and geographical areas with more sectoral and regional details. The literature also increasingly evaluates the lived experiences of climate change—the physical changes underway, the impacts for people and ecosystems, the perceptions of the risks, and adaptation and mitigation responses planned and implemented.

The assessment in AR6 is more integrative across multiple disciplines and combines experts across Working Groups, chapters, papers and disciplines, such as natural and social sciences, medical and health sciences, engineering, humanities, law and business administration. The emphasis on knowledge for action has also included the role of public communication, stories and narratives within assessment and associated outreach.

Frequently Asked Questions

FAQ 2.1 | Will species become extinct with climate change and is there anything we can do to prevent this?

Climate change is already posing major threats to biodiversity, and the most vulnerable plants and animals will probably go extinct. If climate change continues to worsen, it is expected to cause many more species to become extinct unless we take actions to improve the resilience of natural areas, through protection, connection and restoration. We can also help individual species that we care most about by reducing the stress that they are under from human activities, and even helping them move to new places as their climate space shifts and they need to shift to keep up.

Climate change has already caused some species to become extinct and is expected to drive more species to extinction. Extinction of species has always occurred in the history of our planet, but human activities are accelerating this process, such that the estimated 10% of species that humans have driven to extinction in the past 10,000 years is roughly 1,000 times the natural background rate. Recent research predicts that climate change would add to that, with estimates that about one-third of all plant and animal species are at high risk of extinction by 2070 if climate change continues at its current rate. Species can adapt to some extent to these rapidly changing climate patterns. We are seeing changes in behaviour, dispersal to new areas as the climate becomes more suitable, and genetic evolution. However, these changes are small, and adaptations are limited. Species that cannot adapt beyond their basic climate tolerances (their ability to survive extremes of temperature or rainfall) or successfully reproduce in a different climate environment from that in which they have evolved, will simply disappear. In the Arctic, for example, the sea ice is melting and, unless there are deep cuts in greenhouse-gas emissions, will probably disappear in summer within the century. This means that the animals that have evolved to live on sea ice—polar bears and some seals—will become extinct soon after the ice disappears.

Fortunately, there are some things we can do to help. We can take action to assist, protect and conserve natural ecosystems and prevent the loss of our planet's endangered wildlife, such as:

'Assisting' the migration of species. This has many names, 'assisted colonisation', 'assisted translocation', 'assisted migration' and 'assisted movement'. In effect, it is about helping endangered species to move to a new area with a good habitat for them to survive. 'Passive' assisted colonisation focusses on helping species move themselves, while the most 'active' form implies picking up individuals and transporting them to a new location. This is different from reintroductions that are already a normal part of conservation programs. Climate-driven translocations constitute moving plants or animals to an area where they have never lived historically, a new location that is now suitable for them due to climate change.

This active form of 'assisted colonisation' has been controversial, because exotic species can become invasive when they are moved between continents or oceans. For example, no one would advocate moving polar bears to Antarctica, as they would likely feast on native penguins, thus causing another conservation problem. However, moving species only a few hundred kilometers avoids most adverse outcomes, and this is often all that is needed to help a wild plant or animal cope with lower levels of climate change. In extreme cases, another type of assisted adaptation is to preserve species until we can stabilize then reverse climate change, and then reintroduce them to the wild. This might include moving them into zoos or into seed or frozen embryo banks.

Extending protected zones and their connectivity. The ability of species to move to new locations and track climate change are very limited, particularly when a habitat has been turned into a crop field or a city. To help species move between their natural habitats, we can increase the connectedness of protected areas, or simply create small patches or corridors of semi-wild nature within a largely agricultural or inhabited region that encourages wildlife to move through an area, and in which they are protected from hunting and poisons. These semi-wild protected areas can be very small, like the hedgerows between fields in England that provide both a habitat for many flowers, birds and insects and corridors to move between larger protected areas. Alternatively, it can just be an abandoned field that is now growing 'weeds' and with a ban on use of pesticides or herbicides, hunting or farming. For instance, in the USA, private landowners get a tax break by making their land a 'wildlife conservation' area by using no pesticide, not cutting weeds too often, putting up brush piles and bird boxes for nesting by mammals and birds, and providing a stable water source.

Assisting, protecting and conserving natural ecosystems would help enhance biodiversity overall as well as aiding already endangered species. Diverse plant and animal communities are more resilient to disturbances, including climate change. A healthy ecosystem also recovers more quickly from increases in extreme events, such as floods, droughts and heat waves, that are a part of human-driven climate change. Healthy ecosystems are critical to prevent

Box FAQ 2.1 (continued)

species' extinctions from climate change, but are also important for human health and well-being, providing clean, plentiful water, cleaning the air, providing recreation and holiday adventures, and making people feel happier, calmer and more content.

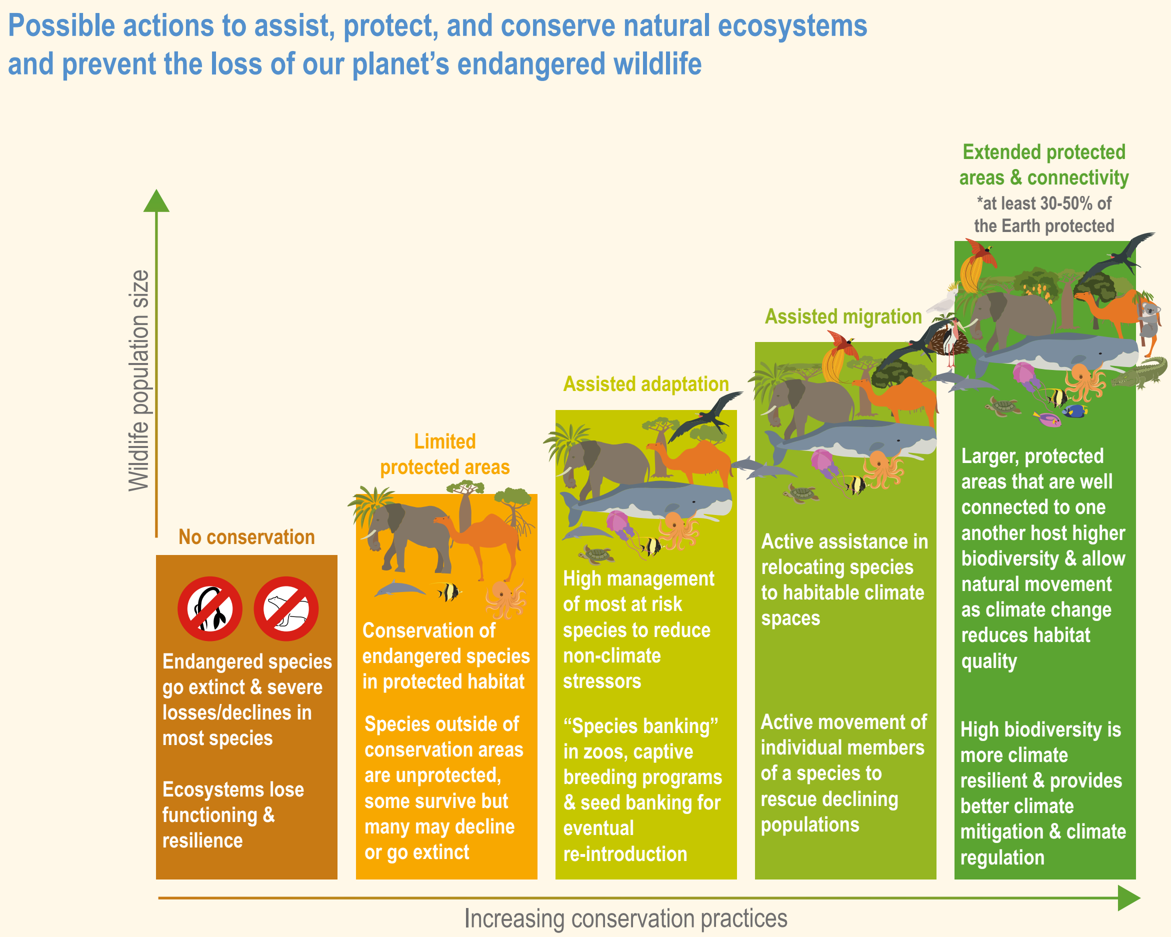

Figure FAQ2.1.1 | Possible actions to assist, protect and conserve natural ecosystems and prevent the loss of our planet's endangered wildlife in the face of continued climate change. (Inspired by the Natural Alliance website© Chris Heward/GWCT).

Frequently Asked Questions

FAQ 2.2 | How does climate change increase the risk of diseases?

Climate change is contributing to the spread of diseases in both wildlife and humans. Increased contact between wildlife and human populations increases disease risk, and climate change is altering where pathogens that cause diseases and the animals that carry them live. Disease risk can often be reduced by improving health care and sanitation systems, training the medical community to recognise and treat potential new diseases in their region, limiting human encroachment into natural areas, limiting wildlife trade and promoting sustainable and equitable socioeconomic development.

Diseases transmitted between humans and animals are called zoonoses. Zoonoses comprise nearly two-thirds of known human infectious diseases and the majority of newly emerging ones. COVID-19 is the most recent zoonosis and has killed millions of people globally while devastating economies. The risk posed by Emerging Infectious Diseases (EIDs) has increased because of: (1) the movement of wild animals and their parasites into new areas as a result of climate change, global trade and travel; (2) human intrusion in natural areas and the conversion of natural areas for agriculture, livestock, the extraction of industrial/raw materials and housing; (3) increased wildlife trade and consumption; (4) increased human mobility resulting from global trade, war/conflicts and migration, made faster and extending farther due to fossil fuel-powered travel; and (5) widespread antimicrobial use, which can promote antibiotic-resistant infections (Figure FAQ2.2.1).

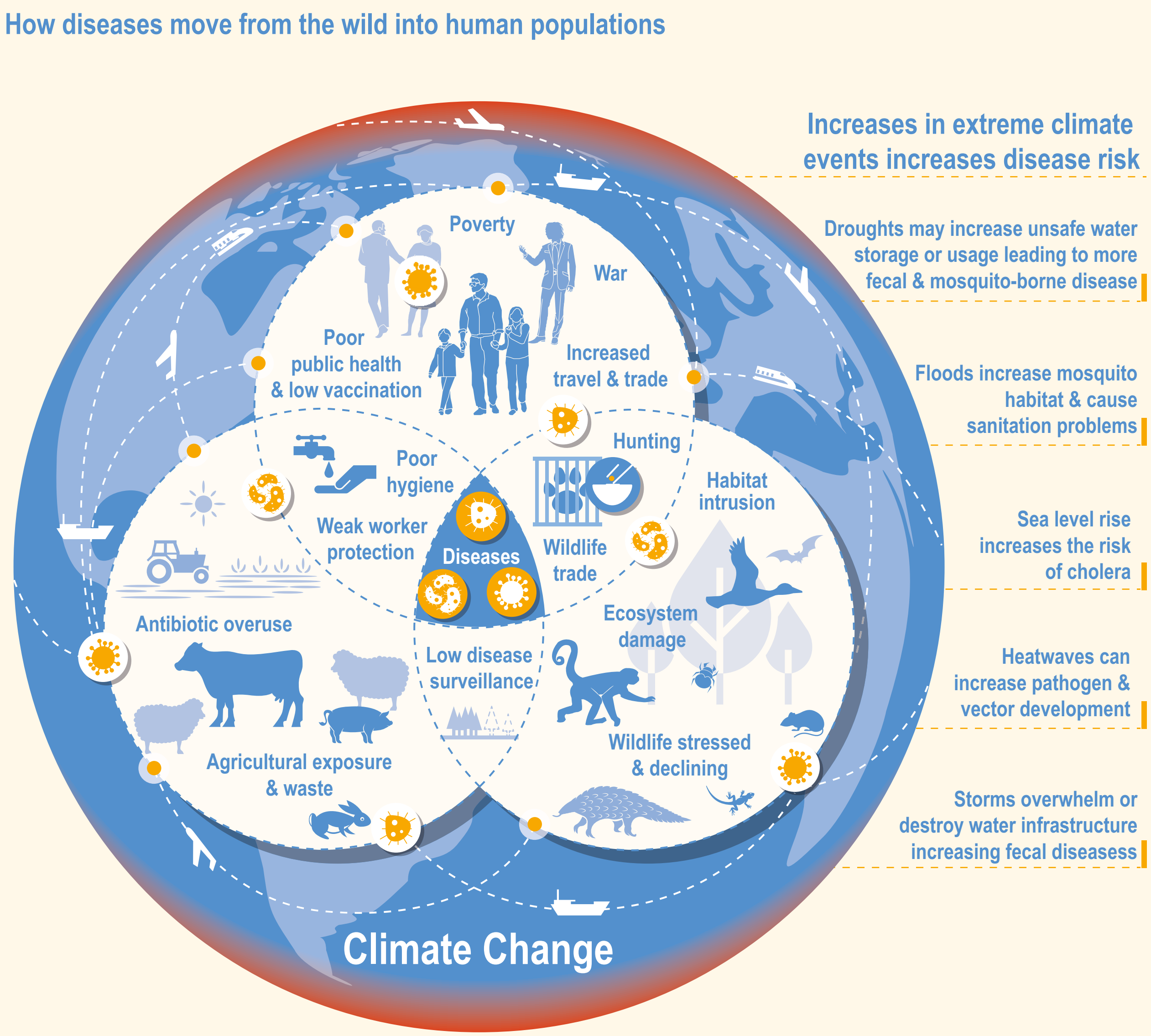

Figure FAQ2.2.1 | How diseases move from the wild into human populations. Climate change may increase diseases in nature, but whether or not this leads to an increase in the risk of disease in humans depends upon a range of societal, infrastructural and medical buffers that form a shield protecting humans.

FAQ

Box FAQ 2.2 (continued)

Climate change further increases risk by altering pathogen and host animal (1) geographic ranges and habitats; (2) survival, growth and development; (3) reproduction and replication; (4) transmission and exposure (5) behaviour; and (6) access to immunologically naïve animals and people who lack resistance to infection. This can lead to novel disease emergence in new places, more frequent and larger outbreaks, and longer or shifted seasons of transmission. Climate change is making it possible for many EIDs to colonise historically colder areas that are becoming warmer and wetter in temperate and polar regions and in the mountains. Vector-borne diseases (VBDs) are diseases spread by vectors such as mosquitoes, sand flies, kissing bugs and ticks. For example, ticks that carry the virus that causes tick-borne encephalitis have moved into the northern subarctic regions of Asia and Europe. Viruses like dengue, chikungunya and Japanese encephalitis are emerging in Nepal in hilly and mountainous areas. Novel outbreaks of *Vibrio* bacteria seafood poisoning are being traced to the the Baltic States and Alaska where they were never documented before. Many scientific studies show that the transmission of infectious disease and the number of individuals infected depends on rainfall and temperature; climate change often makes these conditions more favourable for disease transmission.

Climate change can also have complicated, compounding and contradictory effects on pathogens and vectors. Increased rainfall creates more habitat for mosquitoes that transmit diseases like malaria, but too much rain washes away the habitat. Decreased rainfall also increases disease risk when people without reliable access to water use containers to store water where mosquitoes, such as the vectors of dengue fever *Aedes aegypti* and *A. albopictus*, lay their eggs. Hotter temperatures also increase mosquito-bite rate, parasite development and viral replication! Certain species of snails are intermediate hosts for many helminth parasites that make humans, livestock and wild animals sick. When it gets hot, the snails can produce 2–3 times as many infective larvae; however, if it becomes too hot, many pathogens and their vectors cannot survive or reproduce.

Humans also contract zoonoses directly through their skin, mucus membranes and lungs, when eating or butchering animals or when they come into contact with pathogens that are shed into the air or passed in urine and faeces and contaminate water, food, clothing and other surfaces. Any activity that increases contact with wildlife, especially in high-biodiversity regions like the Tropics and subtropics, increases disease risk. Climate change-related disease emergence events are often rare but may become more frequent. Fortunately, there are ways to reduce risks and protect our health, as described below.

Habitat and biodiversity protection. Human encroachment into natural areas, due to expansion of agriculture and livestock, timber harvests, extraction of resources and urban development, has increased human contact with wild animals and creates more opportunities for disease spill-over (transmission from an animal to a new species, including humans). By conserving, protecting and restoring wild habitats, we can build healthier ecosystems that provide other services, such as clean air, clean and abundant water, recreation, spiritual value and well-being, as well as reduced disease spill-over. If humans must go into wild areas or hunt, they should take appropriate precautions such as wearing protective clothing, using insect repellant, performing body checks for vectors like ticks and washing their hands and clothing well.

Food resilience. Investing in sustainable agro-ecological farming will alleviate the pressure to hunt wild animals and reduce the conversion of more land to agriculture/livestock use. Stopping illegal animal trading and poaching and decreasing reliance on wild meats and products made from animal parts will reduce direct contact with potentially infected animals. This has the added benefit of increasing food security and nutrition, improving soil, reducing erosion, preserving biodiversity and mitigating climate change.

Disease prevention and response. The level of protection against infection is linked directly to the level of development and wealth of a country. Improved education, high-quality medical and veterinary systems, high food security, proper sanitation of water and waste, high-quality housing, disease surveillance and alarm systems dramatically reduce disease risk and improve health. Utilising a One Biosecurity or One Health framework further improves resilience. Sharing knowledge within communities, municipalities, regionally and between national health authorities globally is important to assessing, preventing and responding to outbreaks and pandemics more efficiently and economically.

Box FAQ 2.2 (continued)

Humans are facing many direct and indirect challenges because of climate change. The increase in EIDs is one of our greatest challenges, due to our ever-growing interactions with wildlife and climatic changes creating new disease transmission patterns. COVID-19 is a current crisis, and follows other recent EIDs: SARS, HIV/AIDS, H1N1 influenza, Ebola, Zika and West Nile fever. EIDs have accelerated in recent decades, making it clear that new societal and environmental approaches to wildlife interactions, climate change and health are urgently needed to protect our current and future well-being as a species.

Frequently Asked Questions

FAQ 2.3 | Is climate change increasing wildfire?

In the Amazon, Australia, North America, Siberia and other regions, wildfires are burning wider areas than in the past. Analyses show that human-caused climate change has driven the increases in burned area in the forests of western North America. Elsewhere, deforestation, fire suppression, agricultural burning and short-term cycles like El Niño can exert a stronger influence than climate change. Many forests and grasslands naturally require fire for ecosystem health but excessive wildfire can kill people, destroy homes and damage ecosystems.

Climate change and wildfires

(a)

(b)

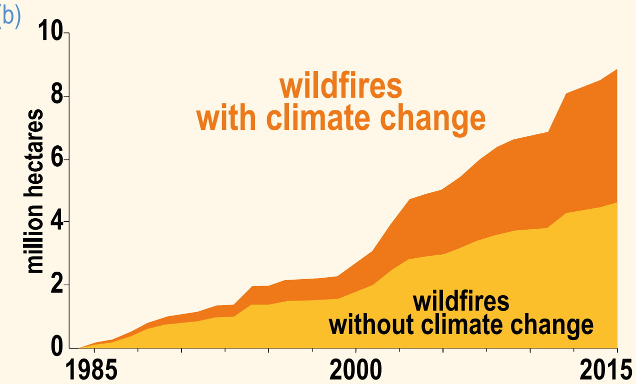

Figure FAQ2.3.1 | (a) Springs Fire, May 2, 2013, Thousand Oaks, California, USA (photo by Michael Robinson Chávez, Los Angeles Times). **(b)** Cumulative area burned by wildfire in the western USA, with (orange) and without (yellow) the increased heat and aridity of climate change.

Wildfire is a natural and essential part of many forest, woodland and grassland ecosystems, killing pests, releasing plant seeds to sprout, thinning out small trees and serving other functions essential for ecosystem health. Excessive wildfire, however, can kill people with the smoke causing breathing illnesses, destroy homes (Figure FAQ2.3.1a) and damage ecosystems.

Human-caused climate change increases wildfire by intensifying its principal driving factor, heat. The heat of climate change dries out vegetation and accelerates burning. Non-climate factors also cause wildfires. Agricultural companies, small-scale farmers and livestock herders in many tropical areas cut down forests and intentionally set fires to clear fields and pastures. Cities, towns and roads increase the number of fires that people ignite. Governments in many countries suppress fires, even natural ones, producing unnatural accumulations of fuel in the form of coarse woody debris and dense stands of small trees. The fuel accumulations cause particularly severe fires that burn upwards into tree crowns.

Evidence shows that human-caused climate change has driven increases in the area burned by wildfire in the forests of western North America. Across this region, the higher temperatures of human-caused climate change doubled burned area from 1984 to 2015, compared with what would have burned without climate change (Figure FAQ2.3.1b). The additional area burned, 4.9 million hectares, is greater than the land area of Switzerland. Human-caused climate change drove a drought from 2000 to 2020 that has been the most severe since the 1500s, severely increasing the aridity of vegetation. In British Columbia, Canada, the higher maximum temperatures of human-caused climate change increased burned area in 2017 to its widest extent in the 1950–2017 record, seven to eleven times the area that would have burned without climate change. Moreover, in national parks and other protected areas of Canada and the USA, most of the area burned from 1984 to 2014 can be attributed to climate factors (temperature, rainfall and aridity) and these outweigh local human factors (population density, roads and urban area).

In other regions, wildfires are also burning wider areas and occurring more often. This is consistent with climate change, but analyses have not yet shown if climate change is more important than other factors. In the Amazon, deforestation by companies, farmers and herders who cut down and intentionally burn rainforests to expand agricultural fields and pastures causes wildfires even in relatively moister years. Drought exacerbates these fires. In Australia, much of the southeastern part of the continent has experienced extreme wildfire years, but analyses

Box FAQ 2.3 (continued)

suggest that El Niño, a heat phenomenon that cycles up and down periodically, is more important than long-term climate change. In Indonesia, intentional burning of rainforests for oil palm plantations and El Niño seem to be more important than long-term climate change. In Mediterranean Europe, fire suppression seems to have prevented any increasing trend in burned area but the suppression and abandonment of agricultural lands have allowed fuel to build up in some areas and contribute to major fires in years of extreme heat. In Canada and Siberia, wildfires are now burning more often in permafrost areas where fire was rare, but analyses are lacking regarding the relative influence of climate change. For the world as a whole, satellite data indicate that the vast amount of land converted from forest to farmland in the period 1998–2015 actually decreased the total burned area. Nevertheless, the evidence from the forests of western North America shows that human-caused climate change has, at least on one continent, clearly driven increases in wildfire.

Frequently Asked Questions

FAQ 2.4 | How does nature benefit human health and well-being and how does climate change affect this?

Human health and well-being are highly dependent on the 'health' of nature. Nature provides material and economic services that are essential for human health and productive livelihoods. Studies also show that being in 'direct contact with natural environments' has direct positive effects on well-being, health and socio-cognitive abilities. Therefore, the loss of species and biodiversity due to climate change will reduce natural spaces and, in turn, decrease human well-being and health worldwide.

Human health and well-being are highly dependent on the 'health' of nature. Biodiversity—the variety of genes, species, communities and ecosystems—provides services that are essential for human health and productive livelihoods, such as breathable air, drinkable water, productive oceans and fertile soils for growing food and fuels. Natural ecosystems also help store carbon and regulate climate, floods, disease, pollution and water quality. The loss of species, leading to reduced biodiversity, has direct and measurable negative effects on all of these essential services, and therefore on humankind. A recent demonstration of this is the decline of pollinator species, with potential negative effects on crop pollination, a fundamental ecosystem function crucial for agriculture. The loss of wild relatives of the domesticated varieties that humans rely on for agriculture reduces the genetic variability that may be needed to support the adaptation of crops to future environmental and social challenges.

Positive relationship between human health and well-being and nature conservation

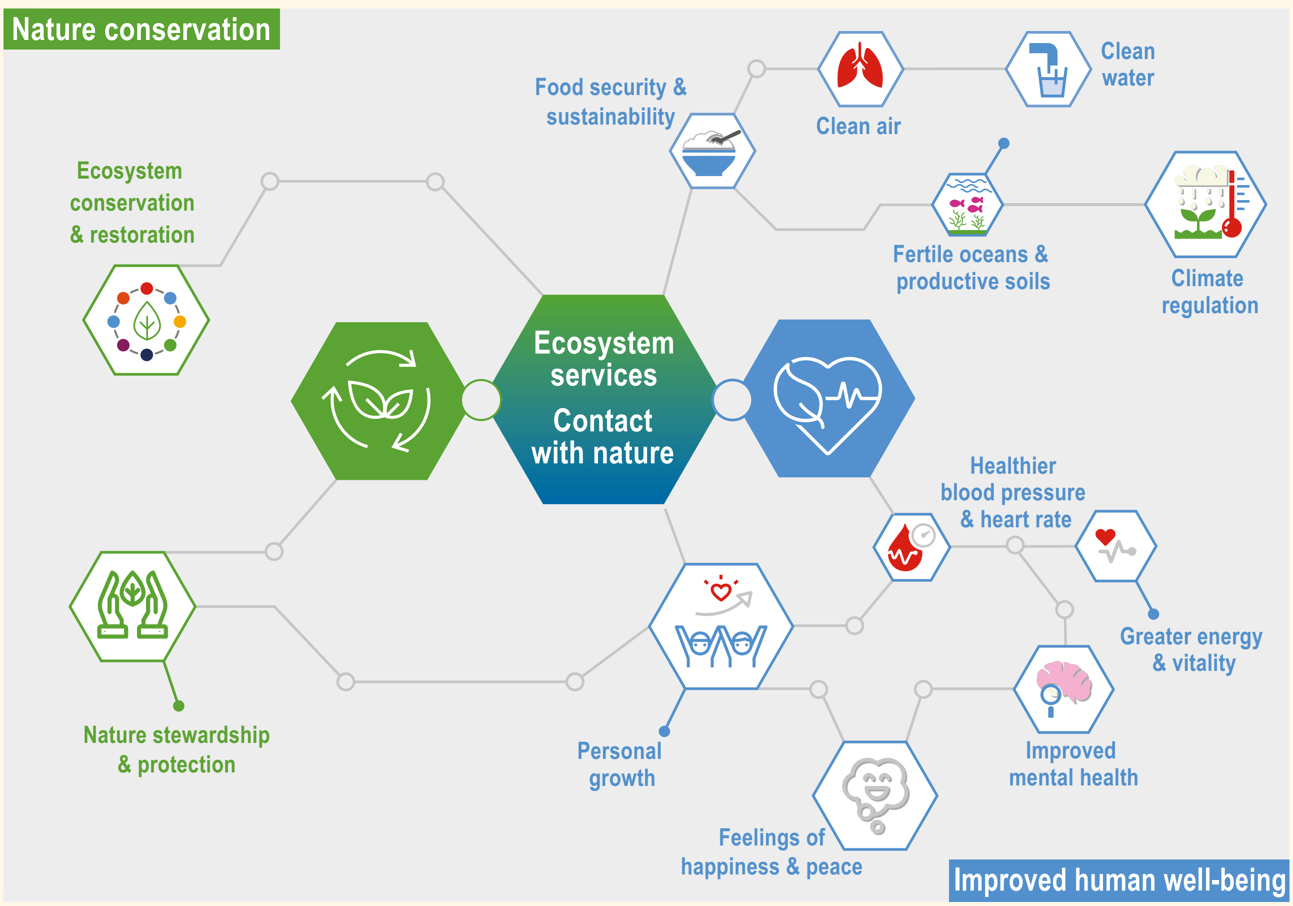

Figure FAQ2.4.1 | The positive relationship between human health and well-being and nature conservation. Nature provides essential services to humans including material and economic services (i.e., ecosystem services) as well as cultural, experiential and recreational services, which, in turn, enhance human psychological and physical health and well-being. People who are more connected to nature are not only happier and healthier but are also more likely to engage in pro-nature behaviours, making the enhancement of human–nature connectedness worldwide a valuable win–win solution for humans and nature to face environmental challenges.

Box FAQ 2.4 (continued)

The number of species that can be lost before negative impacts occur is not known and is likely to differ in different systems. However, in general, more diverse systems are more resilient to disturbances and able to recover from extreme events more quickly. Biodiversity loss means there are fewer connections within an ecosystem. A simpler food web with fewer interactions means less redundancy in the system, reducing the stability and ability of plants and animal communities to recover from disturbances and extreme weather events such as floods and drought.

In addition to 'material' and economic services such as eco-tourism, nature also provides cultural services such as recreation, spirituality and well-being. Specifically, being in 'direct contact with natural environments' (vs. an urban environment) has a high positive impact on human well-being (e.g., mood, happiness), psychological and physical health (energy, vitality, heart rate, depression) and socio-cognitive abilities (attention, memory, hyperactivity, altruism, cooperation). Therefore, the loss of species from climate change and urbanisation will reduce natural spaces, decrease biodiversity, and, in turn, decrease human well-being and health worldwide.

Finally, the extent to which humans consider themselves part of the natural world—known as human-nature connectedness—has been demonstrated to be closely associated with human health and well-being. Individuals who are more connected to nature are not only happier and healthier but also tend to engage more in pro-nature behaviours, making the enhancement of human–nature connectedness worldwide a valuable win–win solution for humans and nature to face environmental challenges.

Frequently Asked Questions

FAQ 2.5 | How can we reduce the risks of climate change to people by protecting and managing nature better?

Damage to our natural environment can increase the risks that climate change poses to people. Protecting and restoring nature can be a way to adapt to climate change, with benefits for both humans and biodiversity. Examples include reducing flood risk by restoring catchments and coastal habitats, the cooling effects of natural vegetation and shade from trees and reducing the risk of extreme wildfires by better management of natural fires.

Protecting and restoring natural environments, such as forests and wetlands, can reduce the risks that climate change poses to people as well as supporting biodiversity, storing carbon and providing many other benefits for human health and well-being. Climate change is bringing an increasing number of threats to people, including flooding, droughts, wildfire, heat waves and rising sea levels. These threats can, however, be reduced or aggravated, depending on how land, sea and freshwater are managed or protected. There is now clear evidence that 'Nature-based Solutions' (NbS) can reduce the risks that climate change presents to people. 'Ecosystem-based Adaptation' (EbA) is a part of NbS and includes:

- *Natural flood management:* As warm air holds more water and, in some places, because of changing seasonal rainfall patterns, we are seeing more heavy downpours in many parts of the world. This can create serious flooding problems, with loss of life, homes and livelihoods. The risk of flooding is higher where natural vegetation has been removed, wetlands drained or channels straightened. In these circumstances, water flows quicker and the risk of flood defences being breached is increased. Restoring the natural hydrology of upstream catchments by restoring vegetation, creating wetlands and re-naturalising watercourse channels and reinstating connections with the floodplain can reduce this risk. In a natural catchment with trees or other vegetation, water flows slowly overland and much of it soaks into the soil. When the water reaches a watercourse, it moves slowly down the channel, both because of the longer distance it travels when the channel bends and because vegetation and fallen trees slow the flow. Wetlands, ponds and lakes can also hold water back and slowly release it into river systems.
- *Restoring natural coastal defences:* Rising sea levels as a result of climate change mean that coasts are eroding at a fast rate and storm surges are more likely to cause damaging coastal flooding. Natural coastal vegetation, such as saltmarshes and mangrove swamps can, in the right places, stabilise the shoreline and act as a buffer, absorbing the force of waves. On a natural coast, the shoreline will move inland and as the sea level rises, the coastal vegetation will gradually move inland with it. This contrasts with hard coastal defences such as sea walls and banks, which can be overwhelmed and fail. In many places, however, coastal habitats have been cleared and where there are hard sea defences behind the coastal zone, the vegetation disappears as the coast erodes rather than moving inland. This is often referred to as 'coastal squeeze' as the vegetation is squeezed between the sea and the sea wall. Restoring coastal habitats and removing hard sea defences, can help reduce the risks of catastrophic flooding.
- *Providing local cooling:* Climate change is bringing higher temperatures globally, which can result in heat waves that affect people's health, comfort and agriculture. In cities, this can be a particular problem for health as temperatures are typically higher than in the countryside. Trees give shade, which people, in both rural and urban areas, have long used to provide cool places for themselves, for growing crops such as coffee and for livestock. Planting trees in the right place can be a valuable, low-cost natural-based solution to reduce the effects of increasing heat, including reducing water temperatures in streams and rivers which can help to maintain fisheries. Trees and other vegetation also have a cooling effect as a result of water being lost from their leaves through evaporation and transpiration (i.e., the loss of water through pores in the leaves, known as stomata). Natural areas, parks, gardens in urban areas can help reduce air temperatures by up to a few degrees.
- *Restoring natural fire regimes:* Some natural ecosystems are adapted to burning, such as savannas and some temperate and boreal forests. Where fire has been suppressed or non-native species of trees are planted in more open habitats, there is a risk that potential fuel accumulates, which can result in larger and hotter fires. Solutions can include restoring natural fire regimes and removing non-native species to decrease the vulnerability of people and ecosystems to the exacerbated fire risk that climate change is bringing due to higher temperatures and, in some places, changing rainfall patterns.

NbS, including protecting and restoring mangroves, forests and peatlands, also play an important part in reducing greenhouse gas emissions and taking carbon dioxide out of the atmosphere. They can also help people in a wide range of other ways, including through providing food, materials and opportunities for recreation. There is increasing evidence that spending time in natural surroundings is good for physical and mental health.

Box FAQ 2.5 (continued)

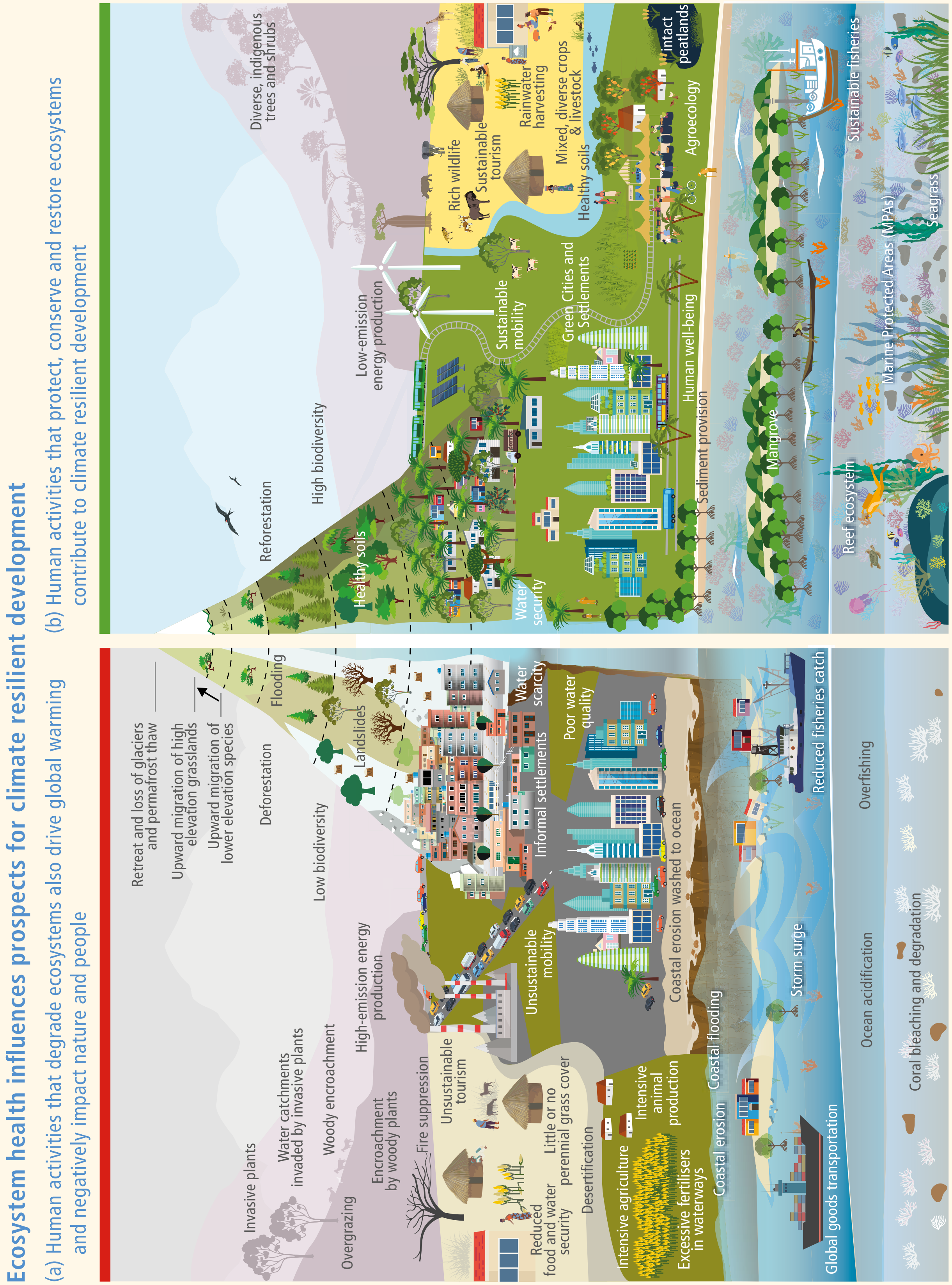

Figure FAQ2.5.1 | Different NbS strategies that contribute to climate resilient development

Box FAQ 2.5 (continued)

If NbS are to be effective, it is important that the right adaptation actions are carried out in the right place and that local communities play an active part in making decisions about their local environment. When they are not part of the process, conflicts can emerge and benefits can be lost.

While NbS help us to adapt to climate change and reduce the amount of greenhouse gases in the atmosphere, it is important to note that there are limits to what they can do. To provide a safe environment for both people and nature, it will be essential to radically reduce greenhouse gas emissions, especially those from fossil-fuel burning in the near future.

Frequently Asked Questions

FAQ 2.6 | Can tree planting tackle climate change?

Restoring and preventing further loss of native forests is essential for combatting climate change. Planting trees in historically unforested areas (grasslands, shrublands, savannas and some peatlands) can reduce biodiversity and increase the risks of damage from climate change. It is therefore essential to target tree planting to the appropriate locations and use appropriate species. Restoring and protecting forests reduces human vulnerability to climate change, reduces air pollution, stores carbon and builds the resilience of natural systems.

Like all living plants, trees remove carbon dioxide from the atmosphere through the process of photosynthesis. In trees, this carbon uptake is relatively long-term, since much of it is stored in the trees' woody stems and roots. Therefore, tree planting can be a valuable contribution to reducing climate change. Besides capturing carbon, planting trees can reduce some negative impacts of climate change by providing shade and cooling. It can also help prevent erosion and reduce flood risk by slowing water flow and improving ground water storage. Restoring forest in degraded areas supports biodiversity and can provide benefits to people, ranging from timber to food and recreation.

There are some areas where replacing lost trees is useful. These include forest that has been recently cut down and where reforestation is usually practical. However, it is very important to correctly identify areas of forest that are degraded or have definitely been deforested. Reforesting places, especially where existing native forest patches occur, brings benefits both in sucking up carbon from the atmosphere and helping us to adapt to climate change. Plantations of a non-native species, although offering some economic benefits, do not usually provide the same range of positive impacts, generally have lower biodiversity, reduced carbon uptake and storage, and are less resilient to climate change.

Reforestation options include the natural regeneration of the forest, assisted restoration, enrichment planting, native-tree plantations, commercial plantations and directed tree planting in agro-forestry systems and urban areas. Reforestation with native species usually contributes to a wide range of sustainability goals, including biodiversity recovery, improved water filtration and groundwater recharge. It can reduce the risks of soil erosion and floods. In cities, planting trees can support climate change adaptation by reducing the heat of the area, and promote a wide range of social benefits such as providing shade and benefitting outdoor recreation. Urban trees can also lower energy costs by reducing the demand for conventional sources of cooling like air-conditioning, especially during peak-demand periods. It is therefore important to recognise that there are a wide range of different planting and forest management strategies. The choice will depend on the objectives and the location.

Not everywhere is suitable for tree planting. It is particularly problematic in native non-forested ecosystems. These natural ecosystems are not deforested and degraded but are instead naturally occurring non-forested ecosystems. These areas vary from open grasslands to densely wooded savannas and shrublands. Here, restoring the natural ecosystems instead of afforesting them will better contribute to increasing carbon storage and increasing the area's resilience to climate change and other environmental changes. It is important to remember that, just because a tree can grow somewhere, it does not mean that it should. These systems are very important in their own right, storing carbon in soils, supporting rich biodiversity and providing people with important ecosystem services such as grasslands for animal grazing. Planting trees in these areas destroys the ecosystem and threatens the biodiversity which is adapted to these environments. They can also impact on ecosystem services such as forage for livestock, on which many people rely.

Many of these open areas also occur in low-rainfall areas. Planting trees there uses a lot of water and can cause reductions in stream flow and groundwater. Many of these locations also burn regularly, and planting trees threatens the establishing trees but can also increase the intensity of the fires from that of a grass-fuelled fire to that of a wood-fuelled fire. Swapping grassy ecosystems for forests may contribute to warming, as forests absorb more incoming radiation (warmth) than grasslands. Aside from the negative impacts to adaptation, it is also questionable just how much carbon can be sequestered in these landscapes as planting trees in grassy ecosystems can reduce carbon gains. Furthermore, a high below-ground carbon store prevents carbon loss to fire in these fire-prone environments.

Another example is peatlands. Peat stores an incredible amount of carbon; maintaining and restoring peatlands is therefore important to reduce atmospheric carbon. However, the restoration actions depend on what type of peatland it is and where it is located. Many temperate and boreal peatlands are naturally treeless. Here, planting trees is often only possible following drainage, but draining and planting (especially of non-native species) destroys native biodiversity and releases GHGs. Many peatlands, especially in the Tropics, are naturally forested, and restoring them requires re-wetting and restoring the natural tree cover (see Figure FAQ2.2.1) which will increase carbon storage.

Box FAQ 2.6 (continued)

There are actions we can perform instead of planting trees in non-forested ecosystems, and these include:

- Address the causes of deforestation, forest degradation and widespread ecosystem loss
- Reduce carbon emissions from fossil fuels
- Focus on ecosystem restoration over tree planting. For example, in restoring tropical grassy ecosystems, we can look at actions that cut down trees, enhance grass regrowth and restore natural fire regimes. We then have a much better chance of both enhancing carbon capture and reducing some of the harmful effects of climate change.

In between the two extremes of where planting trees is highly suitable and areas where it is not, it is important to remember that the context matters and that decisions to (re)forest should look beyond simply the act of planting trees. We can consider **what the ecological, social and economic goals are of tree planting**. It is then important to verify the local context and decide **what restoration action will be most effective**. It is also more efficient and effective to conserve existing forests before worrying about reforesting.

Basic biome specific guidelines when planting in natural and semi-natural vegetation

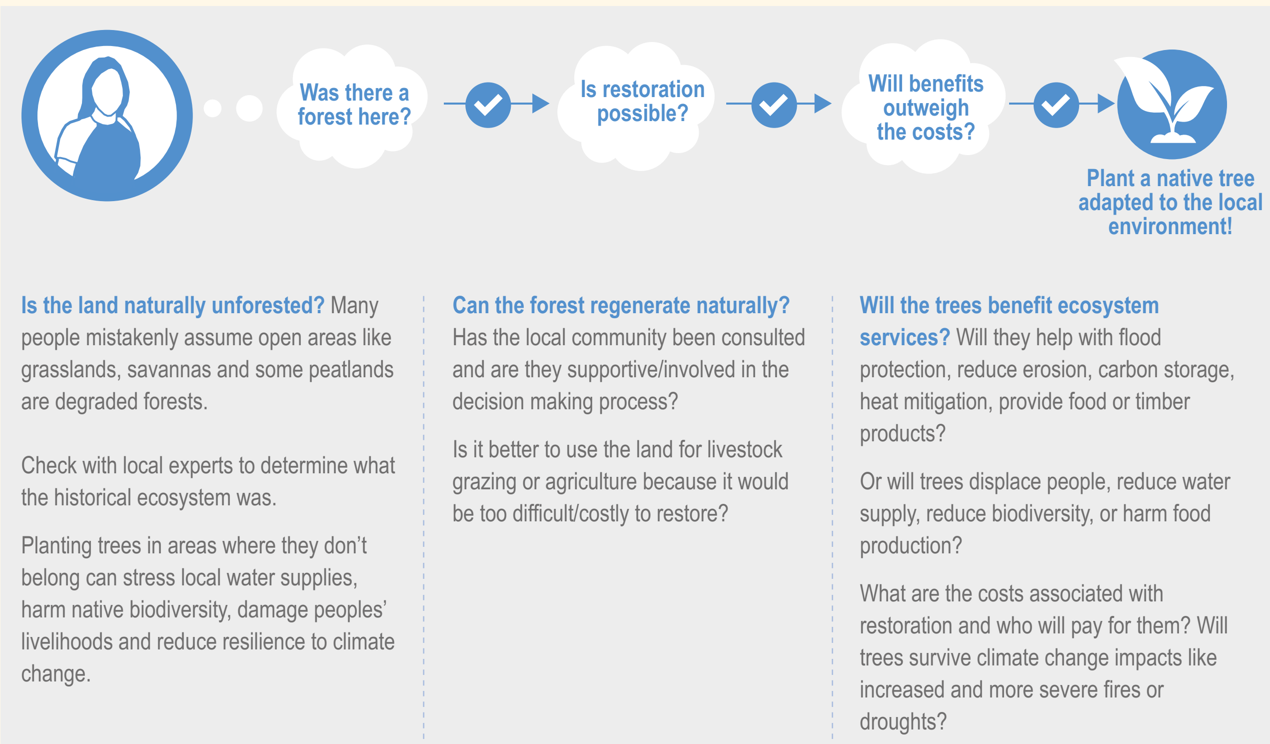

Figure FAQ2.6.1 | Some places are more appropriate for tree planting than others and caution needs to be applied when planting in different biomes, with some biomes being more suitable than others. This figure highlights some basic biome-specific guidelines when planting in natural and semi-natural vegetation.

Frequently Asked Questions

FAQ 3.1 | How do we know which changes to marine ecosystems are specifically caused by climate change?

To attribute changes in marine ecosystems to human-induced climate change, scientists use paleorecords (reconstructing the links between climate, evolutionary and ecological changes in the geological past), contemporary observations (assessing current climate and ecological responses in the field and through experiments) and models. We refer to these as multiple lines of evidence, meaning that the evidence comes from diverse approaches, as described below.

Emissions of greenhouse gases like carbon dioxide from human activity cause ocean warming, acidification, oxygen loss, and other physical and chemical changes that are affecting marine ecosystems around the world. At the same time, natural climate variability and direct human impacts, such as overfishing and pollution, also affect marine ecosystems locally, regionally and globally. These climate and non-climate impact drivers counteract each other, add up or multiply to produce smaller or larger changes than expected from individual drivers. Attribution of changes in marine ecosystems requires evaluating the often-interacting roles of natural climate variability, non-climate drivers, and human-induced climate change. To do this work, scientists use

- paleorecords: reconstructing the links between climate and evolutionary and ecological changes of the past;
- contemporary observations: assessing current climate and ecological responses;
- manipulation experiments: measuring responses of organisms and ecosystems to different climate conditions; and
- models: testing whether we understand how organisms and ecosystems are impacted by different stressors, and quantifying the relative importance of different stressors.

Paleorecords can be used to trace the correlation between past changes in climate and marine life. Paleoclimate is reconstructed from the chemical composition of shells and teeth or from sediments and ice cores. Changes to sea life signalled by changing biodiversity, extinction or distributional shifts are reconstructed from fossils. Using large datasets, we can infer the effects of climate change on sea life over relatively long time scales–usually hundreds to millions of years. The advantage of paleorecords is that they provide insights into how climate change affects life from organisms to ecosystems, without the complicating influence of direct human impacts. A key drawback is that the paleo and modern worlds do not have fully comparable paleoclimate regimes, dominant marine species and rates of climate change. Nevertheless, the paleorecord can be used to derive fundamental rules by which organisms, ecosystems, environments and regions are typically most affected by climate change. For example, the paleorecord shows that coral reefs repeatedly underwent declines during past warming events, supporting the inference that corals may not be able to adapt to current climate warming.

Contemporary observations over recent decades allow scientists to relate the status of marine species and ecosystems to changes in climate or other factors. For example, scientists compile large datasets to determine whether species usually associated with warm water are appearing in traditionally cool-water areas that are rapidly warming. A similar pattern observed in multiple regions and over several decades (i.e., longer than time scales of natural variability) provides confidence that climate change is altering community structure. This evidence is weighed against findings from other approaches, such as manipulation experiments, to provide a robust picture of climate-change impacts in the modern ocean.

In manipulation experiments, scientists expose organisms or communities of organisms to multiple stressors, for example, elevated CO_2, high temperature, or both, based on values drawn from future climate projections. Such experiments will involve multiple treatments (i.e., different aquarium tanks) in which organisms are exposed to different combinations of the stressors. This approach enables scientists to understand the effects of individual stressors as well as their interactions to explore physiological thresholds of marine organisms and communities. The scale of manipulation experiments can range from small tabletop tanks to large installations or natural ocean experiments involving tens of thousands of litres of water.

Ecological effects of climate change are also explored within models developed from fundamental scientific principles and observations. Using these numerical representations of marine ecosystems, scientists can explore how different levels of climate change and non-climate stressors influence species and ecosystems at scales not possible with experiments. Models are commonly used to simulate the ecological response to climate change over recent decades and centuries. Convergence between the model results and the observations suggests that our understanding of the key processes is sufficient to attribute the observed ecological changes to climate change, and to use the models to project future ecological changes. Differences between model results and observations indicate gaps in knowledge to be filled in order to better detect and attribute the impacts of climate change on marine life.

Box FAQ3.1 (continued)

Using peer-reviewed research spanning the full range of scientific approaches (paleorecords, observations, experiments and models), we can assess the level of confidence in the impact of climate change on observed modifications in marine ecosystems. We refer to this as multiple lines of evidence, meaning that the evidence comes from the diverse approaches described above. This allows policymakers and managers to address the specific actions needed to reduce climate change and other impacts.

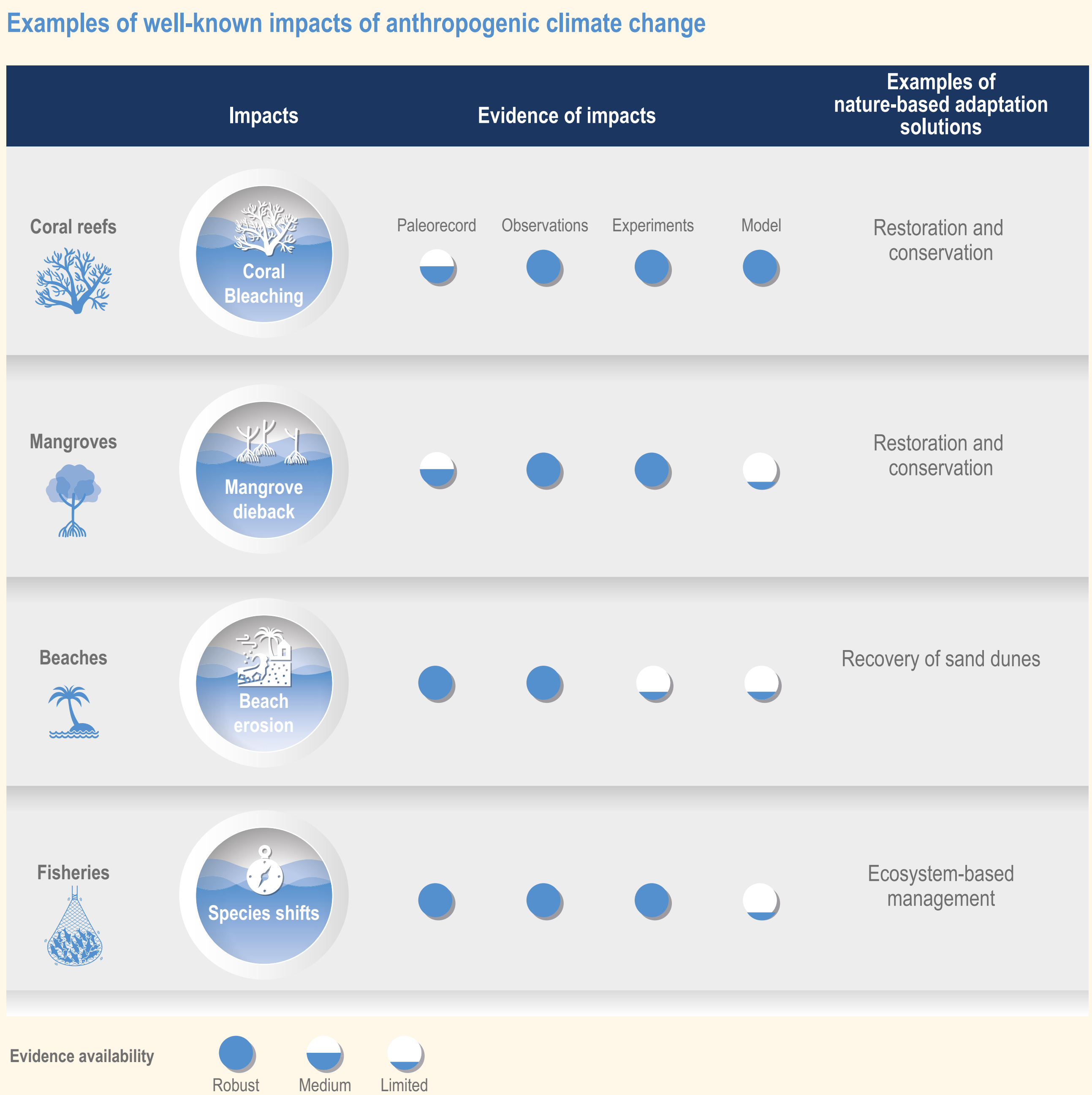

Figure FAQ3.1.1 | Examples of well-known impacts of anthropogenic climate change and associated nature-based adaptation. To attribute changes in marine ecosystems to anthropogenic climate change, scientists use multiple lines of evidence including paleorecords, contemporary observations, manipulation experiments and models.

Frequently Asked Questions

FAQ 3.2 | How are marine heatwaves affecting marine life and human communities?

Heatwaves happen in the ocean as well as in the atmosphere. Marine heatwaves (MHWs) are extended periods of unusually warm ocean temperatures relative to the typical temperatures for that location and time of year. Due to climate change, the number of days with MHWs have increased by 54% over the past century. These MHWs cause mortalities in a wide variety of marine species, from corals to kelp to seagrasses to fish to seabirds, and have consequent effects on ecosystems and industries like aquaculture and fisheries.

Extreme events in the ocean can have damaging effects on marine ecosystems and the human communities that depend on them. The most common form of ocean extremes are MHWs, which are becoming more frequent and intense due to global warming. Because seawater absorbs and releases heat more slowly than air, temperature extremes in the ocean are not as pronounced as over land, but they can persist for much longer, often for weeks to months over areas covering hundreds of thousands of square kilometres. These MHWs can be more detrimental for marine species, in comparison with land species, because marine species are usually adapted to relatively stable temperatures.

A commonly used definition of MHWs is a period of at least 5 days whose temperatures are warmer than 90% of the historical records for that location and time of year. Marine heatwaves are described by their abruptness, magnitude, duration, intensity and other metrics. In addition, targeted methods are used to characterize MHWs that threaten particular ecosystems; for example, the accumulated heat stress above typical summer temperatures, described by 'degree heating weeks', is used to estimate the likelihood of coral bleaching.

Over the past century, MHWs have doubled in frequency, become more intense, lasted for longer and extended over larger areas. Marine heatwaves have occurred in every ocean region over the past few decades, most markedly in association with regional climate phenomena such as the El Niño/Southern Oscillation. During the 2015–2016 El Niño event, 70% of the world's ocean surface encountered MHWs.

Such MHWs cause mortality of a wide variety of marine species, from corals to kelp to seagrasses to fish to seabirds, and they have consequent effects on ecosystems and industries such as mariculture and fisheries. Warm-water coral reefs, estuarine seagrass meadows and cold-temperate kelp forests are among the ecosystems most threatened by MHWs since they are attached to the seafloor (see FAQ 3.2). Unusually warm temperatures cause bleaching and associated death of warm-water corals, which can lead to shifts to low-diversity or algae-dominated reefs, changes in fish communities and deterioration of the physical reef structure, which causes habitat loss and increases the vulnerability of nearby shorelines to large-wave events and SLR. Since the early 1980s, the frequency and severity of mass coral bleaching events have increased sharply worldwide. For example, from 2016 through 2020, the Great Barrier Reef experienced mass coral bleaching three times in 5 years.

Mass loss of kelp from MHWs effects on the canopy-forming species has occurred across ocean basins, including the coasts of Japan, Canada, Mexico, Australia and New Zealand. In southern Norway and the northeast USA, mortality from MHWs contributed to the decline of sugar kelp over the past two decades and the spread of turf algal ecosystems that prevent recolonisation by the original canopy-forming species.

One of the largest and longest-duration MHWs, nicknamed the 'Blob', occurred in the Northeast Pacific Ocean, extending from California north towards the Bering Sea, from 2013 through 2015. Warming from the MHW persisted into 2016 off the West Coast of the USA and into 2018 in the deeper waters of a Canadian fjord. The consequent effects of this expansive MHW included widespread shifts in abundance, distribution and nutritional value of invertebrates and fish, a bloom of toxic algae off the West Coast of the USA that impacted fisheries, the decline of California kelp forests that contributed to the collapse of the abalone fishery, and mass mortality of seabirds.

The projected increase in the frequency, severity, duration and areal extent of MHWs threaten many marine species and ecosystems. These MHWs may exceed the thermal limits of species, and they may occur too frequently for the species to acclimate or for populations to recover. The majority of the world's coral reefs are projected to decline and begin eroding due to more frequent bleaching-level MHWs if the world warms by more than 1.5°C. Recent research suggests possible shifts to more heat-tolerant coral communities but at the expense of species and habitat diversity. Other systems, including kelp forests, are most threatened near the edges of their ranges, although more research is needed into the effect of re-occurring MHWs on kelp forests and other vulnerable systems.

Box FAQ3.2 (continued)

The projected ecological impacts of MHWs threaten local communities and Indigenous Peoples, incomes, fisheries, tourism and, in the case of coral reefs, shoreline protection from waves. High-resolution forecasts and early-warning systems, currently most advanced for coral reefs, can help people and industries prepare for MHWs and also collect data on their effects. Identifying and protecting locations and habitats with reduced exposure to MHWs is a key scientific endeavour. For example, corals may be protected from MHWs in tidally stirred waters or in reefs where cooler water upwells from subsurface. Marine protected areas and no-take zones, in addition to terrestrial protection surrounding vulnerable coastal ecosystems, cannot prevent MHWs from occurring. But, depending on the location and adherence by people to restrictions on certain activities, the cumulative effect of other stressors on vulnerable ecosystems can be reduced, potentially helping to enhance the rate of recovery of marine life.

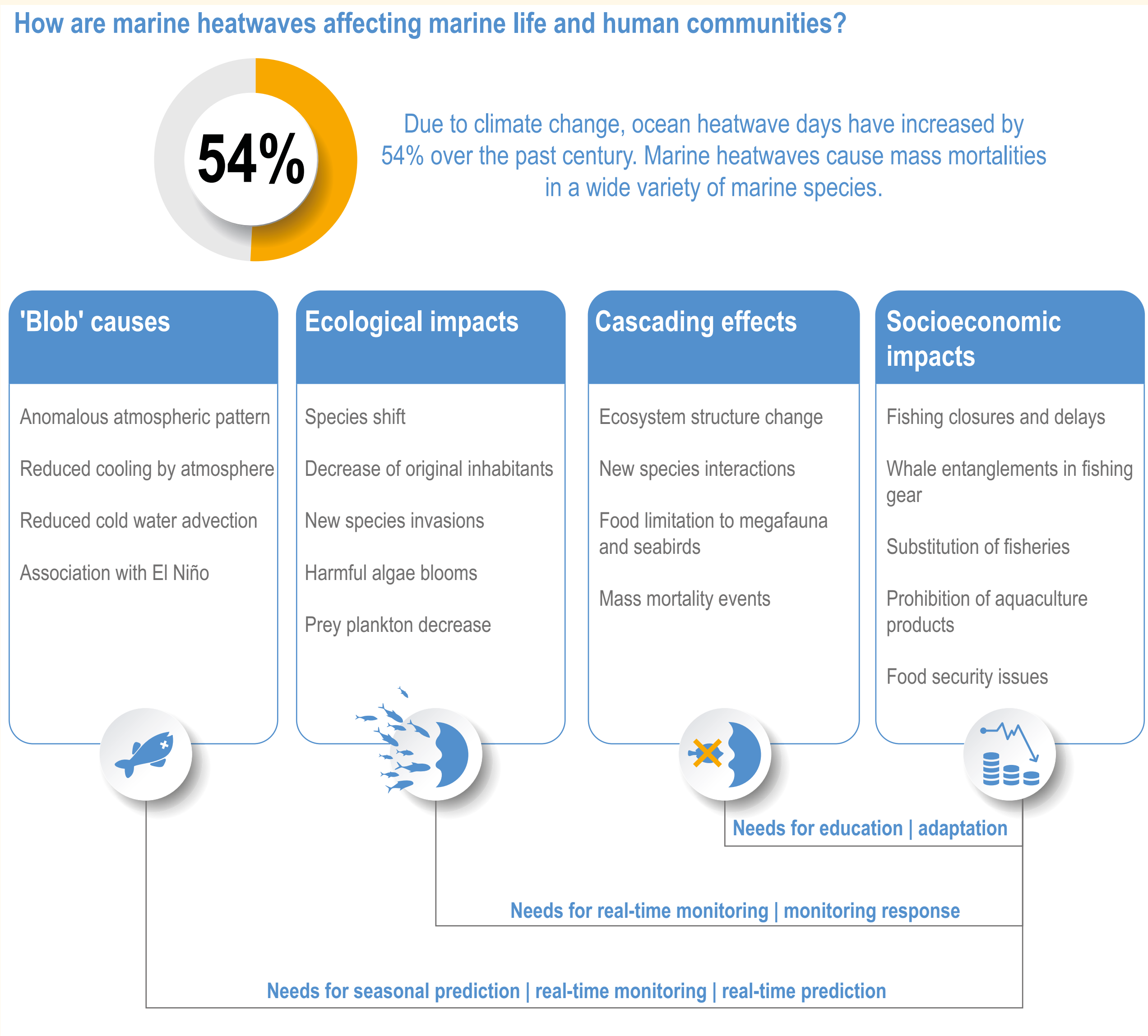

Figure FAQ3.2.1 | Impact pathway of a massive extreme marine heatwave, the northwest Pacific 'Blob', from causal mechanisms to initial effects, resulting nonlinear effects and the consequent impacts for humans. Lessons learnt from the Blob include the need to advance seasonal forecasts, real-time predictions, monitoring responses, education, possible fisheries impacts and adaptation.

Frequently Asked Questions

FAQ 3.3 | Are we approaching so-called tipping points in the ocean and what can we do about it?

A tipping point is a threshold beyond which an abrupt or rapid change in a system occurs. Tipping points that have already been reached in ocean systems include the melting of sea ice in the Arctic, thermal bleaching of tropical coral reefs and the loss of kelp forests. Human-induced climate change will continue to force ecosystems into abrupt and often irreversible change, without strong mitigation and adaptation action.

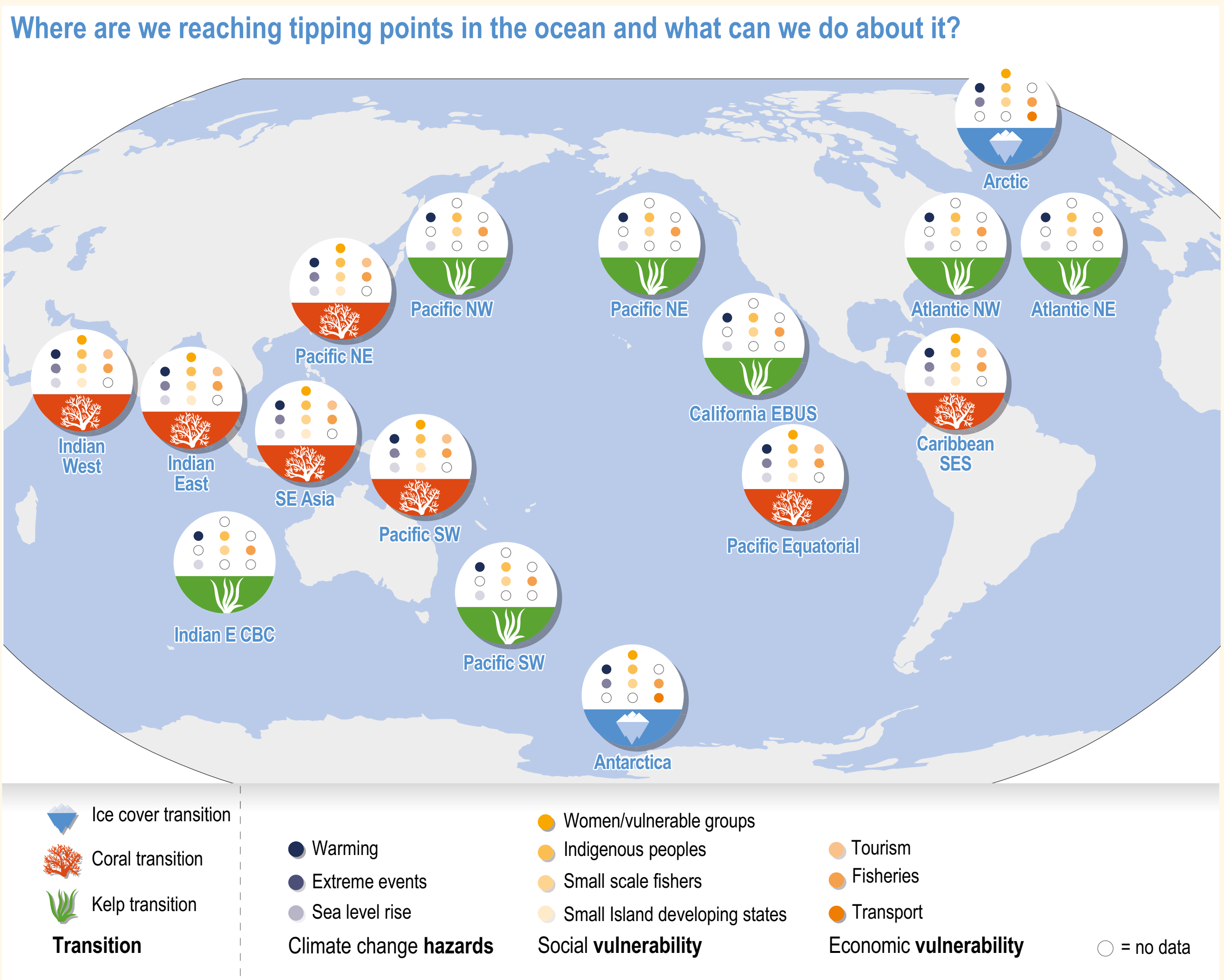

Figure FAQ3.3.1 | Global map with examples of tipping points that have been passed in ocean systems around the world. Tipping points in ecological systems are linked to increasing impacts and vulnerability of dependent human communities. SES: semi-enclosed sea; EBUS: eastern boundary upwelling system; CBC; coastal boundary current.

A gradual change in water temperature or oxygen concentration can lead to a fundamental shift in the structure and/or composition of an ecosystem when a tipping point is exceeded. For example, all species have upper temperature limits below which they can thrive. In the tropics, prolonged warm temperatures can cause fatal 'bleaching' of tropical corals, leading reef ecosystems to degrade and become dominated by algae. In temperate regions, MHWs can kill or reduce the growth of kelp, threatening the other species that depend on the tall canopy-forming marine plants for habitat. In the Arctic, rising temperatures are melting sea ice and reducing the available habitat for communities of ice-dependent species.

Box FAQ3.3 (continued)

Once a tipping point is passed, the effects can be long-lasting and/or irreversible over time scales of decades or longer. An ecosystem or a population can remain in the new state, even if the driver of the change returns to previous levels. For example, once a coral reef has been affected by bleaching, it can take decades for corals to grow back, even if temperatures remain below the bleaching threshold. Crossing a tipping point can cause entire populations to collapse, causing local extinctions.

Tipping points are widespread across oceanic provinces and their ecosystems for climate variables like water temperature, oxygen concentration and acidification. Evidence suggests that ocean tipping points are being surpassed more frequently as the climate changes; scientists have estimated that abrupt shifts in communities of marine species occurred over 14% of the ocean in 2015, up from 0.25% of the ocean in the 1980s. Other human stressors to the ocean, including habitat destruction, overfishing, pollution and the spread of diseases, combine with climate change to push marine systems beyond tipping points. As an example, nutrient pollution from land together with climate change can lead to low-oxygen coastal areas referred to as 'dead zones'.

Human communities can also experience tipping points that alter people's relationships with marine ecosystem services. Indigenous Peoples and local communities may be forced to move from a particular location due to SLR, erosion or loss of marine resources. Current activities that help sustain Indigenous Peoples and their cultures may no longer be possible in the coming decades, and traditional diets or territories may have to be abandoned. These tipping points have implications for physical and mental health of marine-dependent human communities.

Adaptation solutions to the effects of ecological tipping points are rarely able to reverse their environmental impacts, and instead often require human communities to transform their livelihoods in different ways. Examples include diversifying income by shifting from fishing to tourism and relocating communities threatened by flooding to other areas to continue their livelihoods. Tipping points are being passed already in coral reefs and polar systems, and more will probably be reached in the near future given climate-change projections. Nevertheless, the chances of moving beyond additional tipping points in the future will be minimised if we reduce greenhouse gas emissions and we also act to limit other human impacts on the ocean, such as overfishing and nutrient pollution.

Frequently Asked Questions

FAQ 3.4 | Which industries and jobs are most vulnerable to the impacts of climate change in the oceans?

The global ocean underpins human well-being through the provision of resources that directly and indirectly feed and employ many millions of people. In many regions, climate change is degrading ocean health and altering stocks of marine resources. Together with over-harvesting, climate change is threatening the future of the sustenance provided to Indigenous Peoples, the livelihoods of artisanal fisheries, and marine-based industries including tourism, shipping and transportation.

The ocean is the lifeblood of the planet. In addition to regulating planetary cycles of carbon, water and heat, the ocean and its vast resources support human livelihoods, cultural practices, jobs and industries. The impacts of climate change on the ocean can influence human activities and employment by altering resource availability, spreading pathogens, flooding shorelines and degrading ocean ecosystems. Fishing and mariculture are highly exposed to change. The global ocean and inland waters together provide more than 3.3 billion people at least 20% of the protein they eat and provide livelihoods for 60 million people. Changes in the nutritional quality or abundance of food from the oceans could influence billions of people.

Substantial economic losses for fisheries resulting from recent climate-driven harmful algal blooms and marine pathogen outbreaks have been recorded in Asia, North America and South America. A 2016 event in Chile caused an estimated loss of 800 million USD in the farmed-salmon industry and led to regional government protests. The recent closure of the Dungeness crab and razor clam fishery in the USA, due to a climate-driven algal bloom, harmed 84% of surveyed residents from 16 California coastal communities. Fishers and service industries that support commercial and recreational fishing experienced the most substantial economic losses, and fishers were the least able to recover their losses. This same event also disrupted subsistence and recreational fishing for razor clams, important activities for Indigenous Peoples and local communities in the Pacific Northwest of the USA.

Other goods from the ocean, including non-food products like dietary supplements, food preservatives, pharmaceuticals, biofuels, sponges and cosmetic products, as well as luxury products like jewellery coral, cultured pearls and aquarium species, will change in abundance or quality due to climate change. For instance, ocean warming is endangering the 'candlefish' ooligan (*Thaleichthys pacificus*), whose oil is a traditional food source and medicine of Indigenous Peoples of the Pacific Northwest of North America. Declines in tourism and real estate values, associated with climate-driven harmful algal blooms, have also been recorded in the USA, France and England.

Small-scale fisheries livelihoods and jobs are the most vulnerable to climate-driven changes in marine resources and ecosystem services. The abundance and composition of their harvest depend on suitable environmental conditions and on IKLK developed over generations. Large-scale fisheries, though still vulnerable, are more able to adapt to climate change due to greater mobility and greater resources for changing technologies. These fisheries are already adapting by broadening catch diversity, increasing their mobility to follow shifting species, and changing gear, technology and strategies. Adaptation in large-scale fisheries, however, is at times constrained by regulations and governance challenges.

Jobs, industries and livelihoods which depend on particular species or are tied to the coast can also be at risk to climate change. Species-dependent livelihoods (e.g., a lobster fishery or oyster farm) are vulnerable due to a lack of substitutes if the fished species are declining, biodiversity is reduced, or mariculture is threatened by climate change or ocean acidification. Coastal activities and industries ranging from fishing (e.g., gleaning on a tidal flat) to tourism to shipping and transportation are also vulnerable to sea level rise and other climate-change impacts on the coastal environment. The ability of coastal systems to protect the shoreline will decline due to sea level rise and simultaneous degradation of nearshore systems including coral reefs, kelp forests and coastal wetlands.

The vulnerability of communities to losses in marine ecosystem services varies within and among communities. Tourists seeking to replace lost cultural services can adapt by engaging in the activity elsewhere. But communities who depend on tourism for income or who have strong cultural identity linked to the ocean have a more difficult time. Furthermore, climate-change impacts exacerbate existing inequalities already experienced by some communities, including Indigenous Peoples, Pacific Island countries and territories and marginalised peoples, such as migrants and women in fisheries and mariculture. These inequities increase the risk to their fundamental human rights by disrupting livelihoods and food security, while leading to loss of social, economic and cultural rights. These maladaptive outcomes can be avoided by securing tenure and access rights to resources and territories for all people depending on the ocean, and by supporting decision-making processes that are just, participatory and equitable.

Box FAQ3.4 (continued)

A key adaptation solution is improving access to credit and insurance in order to buffer against variability in resource access and abundance. Further actions that decrease social and institutional vulnerability are also important, such as inclusive decision-making processes, access to resources and land for Indigenous Peoples, and participatory approaches in management. For the fishing industry, international fisheries agreements and investing in sustainable mariculture and fisheries reforms is often recommended. Immediate adaptations to other challenges, such as harmful algal blooms, frequently include fishing-area closures; these can be informed by early-warning forecasts, public communications; and education. These types of adaptations are more effective when built on trusted relationships and effective coordination among involved parties, and are inclusive of the diversity of actors in a coastal community.

Box FAQ3.4 (continued)

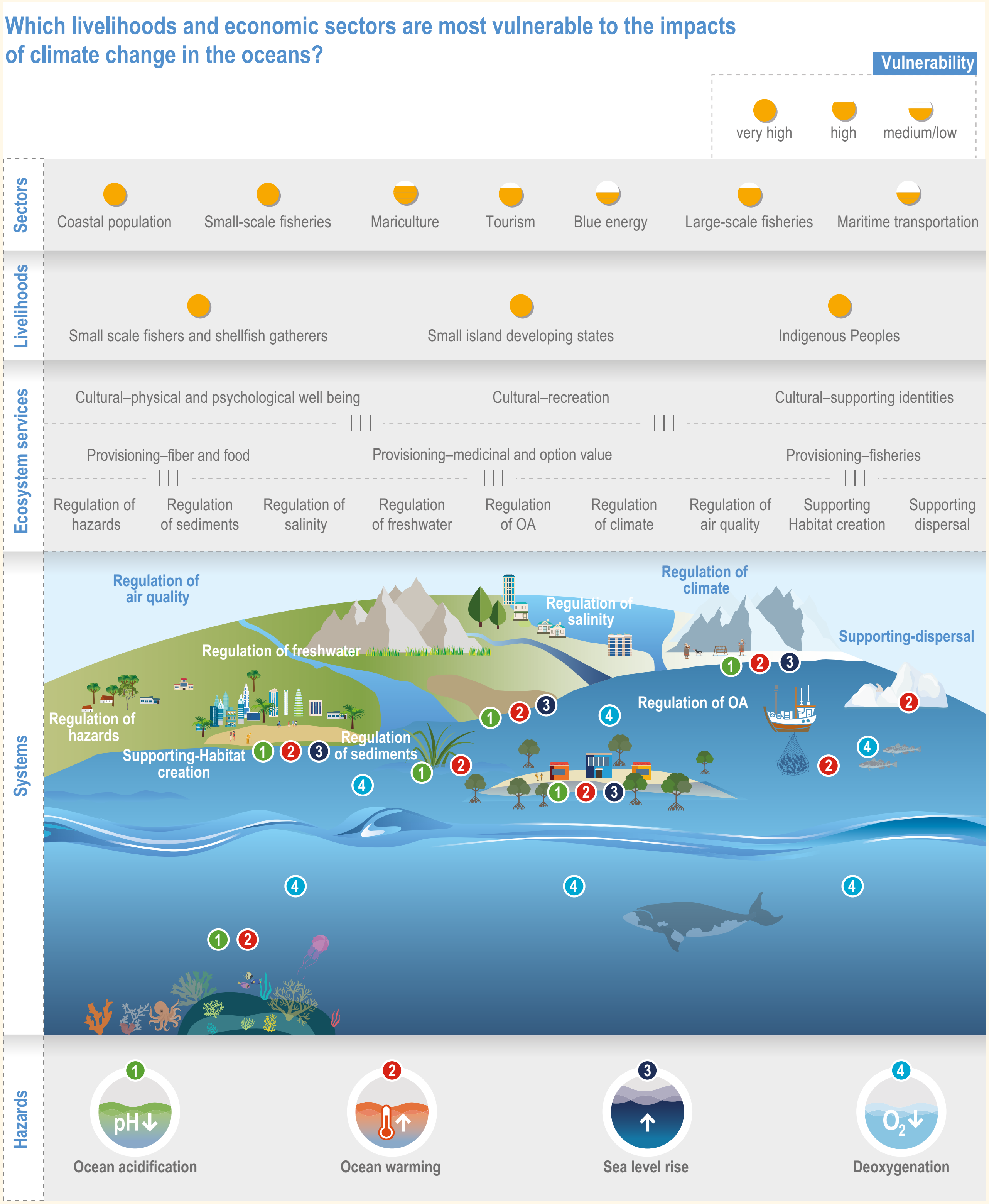

Figure FAQ3.4.1 | Illustration of vulnerable ocean and coastal groups, the climate-induced hazards they experience, and anticipated outcomes for human systems.

Frequently Asked Questions

FAQ 3.5 | How can nature-based solutions, including Marine protected areas, help us to adapt to climate-driven changes in the oceans?

Coastal habitats, such as mangroves or vegetated dunes, protect coastal communities from sea level rise and storm surges while supporting fisheries, sequestering carbon and providing other ecosystem services as well. Efforts to restore, conserve and/or recover these natural habitats help people confront the impacts of climate change. These marine nature-based solutions (NbS), such as Marine protected areas (MPAs), habitat restoration and sustainable fisheries, are cost-effective and provide myriad benefits to society.

In the oceans, NbS comprise attempts to recover, restore or conserve coastal and marine habitats to reduce the impacts of climate change on nature and society. Marine habitats, such as seagrasses and coral reefs, provide services like food and flood regulation in the same way as forests do so on land. Coastal habitats, such as mangroves or vegetated dunes, protect coastal communities from sea level rise and storm surges while supporting fisheries as well as recreational and aesthetic services. Seagrasses, coral reefs and kelp forests also provide important benefits that help humans adapt to climate change, including sustainable fishing, recreation and shoreline protection services. By recognising these services and benefits of the ocean, NbS can improve the quality and integrity of the marine ecosystems.

Nature-based solutions offer a wide range of potential benefits, including protecting ecosystem services, supporting biodiversity and mitigating climate change. Coastal and marine examples include MPA, habitat restoration, habitat development and maintaining sustainable fisheries. While local communities with limited resources might find NbS challenging to implement, they are generally 'no-regret' options, which bring societal and ecological benefits regardless of the level of climate change.

Carefully designed and placed MPAs, especially when they exclude fishing, can increase resilience to climate change by removing additional stressors on ecosystems. While MPAs do not prevent extreme events, such as marine heatwaves (FAQ3.2), they can provide marine plants and animals with a better chance to adapt to a changing climate. Current MPAs, however, are often too small, too poorly connected and too static to account for climate-induced shifts in the range of marine species. Marine protected area networks that are large, connected, have adaptable boundaries and are designed following systematic analysis of future climate projections can better support climate resilience.

Habitat restoration and development in coastal systems can support biodiversity, protect communities from flooding and erosion, support the local economy and enhance the livelihoods and well-being of coastal peoples. Restorations of mangroves, salt marshes and seagrass meadows provide effective ways to remove carbon dioxide from the atmosphere and at the same time protect coasts from the impacts of storms and SLR. Active restoration techniques that target heat-resistant individuals or species are increasingly recommended for coral reefs and kelp forests, which are highly vulnerable to marine heatwaves and climate change.

Sustainable fishing is also seen as an NbS because managing marine commercial species within sustainable limits maximises the catch and food production, thus contributing to the UN's Sustainable Development Goal 2 (Zero Hunger). Currently, the oceans provide 17% of the animal protein eaten by the global population, but the contribution could be larger if fisheries were managed sustainably. Aquaculture, such as oyster farming, can be an efficient and sustainable means of food production and also provide additional benefits like shoreline protection. Through NbS that conserve and restore marine habitats and species, we can sustain marine biodiversity, respond to climate change and provide benefits to society.

Box FAQ3.5 (continued)

Contributions of nature-based solutions in the oceans to the Sustainable Development Goals

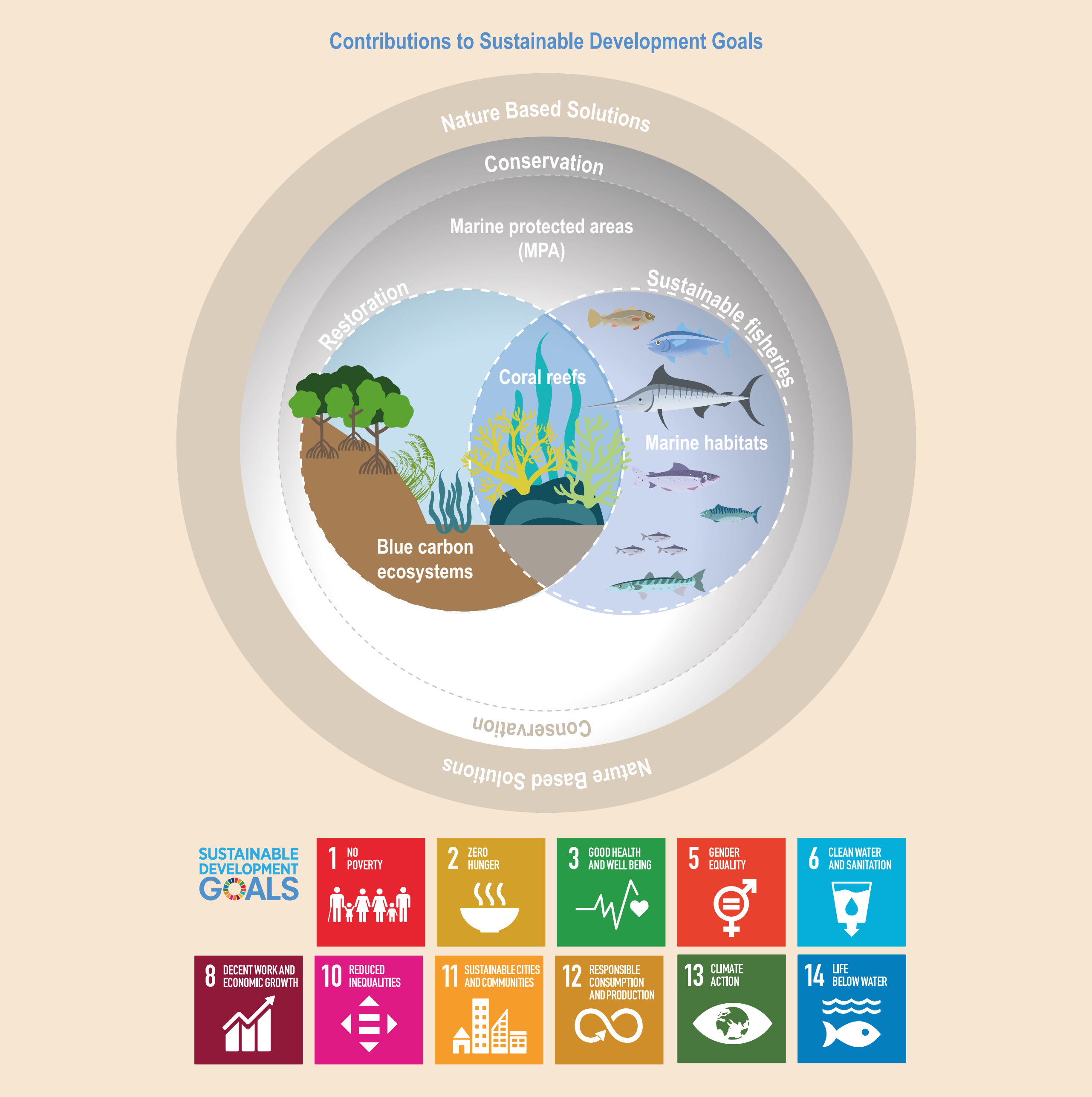

Figure FAQ3.5.1 | Contributions of nature-based solutions (NbS) in the oceans to the Sustainable Development Goals. The icons at the bottom show the Sustainable Development Goals to which NbS in the ocean possibly contribute.

FAQ

Frequently Asked Questions

FAQ 4.1 | What is water security, and how will climate change affect it?

Water is essential for all societal and ecosystems needs. Water security is multi-dimensional and not just about water availability. Water needs to be available in sufficient quantity and quality and needs to be accessible in an acceptable form. Accordingly, a situation of water security indicates the availability and accessibility of sufficient clean water to allow a population to sustainably ensure its livelihoods, health, socioeconomic development and political stability. Many socioeconomic factors, such as population growth and food consumption patterns, play an important role in determining water security. Still, climate change is increasingly shown to be an important contributor to water insecurity worldwide, with some regions more at risk than others.

Climate change can affect these different dimensions of water security in different ways. Most directly, climate change is affecting the overall availability of water across regions and during important seasons. More extended periods of dry spells and droughts are already affecting water availability, especially in the arid areas of India, China, the USA and Africa. Other extremes, such as heavy precipitation and flooding, can affect water quality, making water unsafe for drinking, for example. In coastal regions and small islands, the combined effects of higher sea levels and more intense storms affect water security by increasing the salinisation of groundwater resources. Indirect effects of climate change on water security include impacts on infrastructure for the provision and recovery of water resources, which can affect the safe access to adequate water resources, both in terms of quality and quantity.

In terms of assessing the extent of water scarcity, studies estimate that currently, between 1.5 and 2.5 billion people live within areas exposed to water scarcity globally. These numbers are projected to increase continuously, with estimates of up to 3 billion at 2°C and up to 4 billion at 4°C by 2050. Many socioeconomic factors, such as population growth and food consumption patterns, determine water scarcity. Still, climate is increasingly shown to be an important component that drives scarcity across the world. Water scarcity is often a seasonal occurrence, and climate change is projected to increase seasonal extremes. Often, consecutive years with drier conditions lead to a long-term decrease in groundwater tables, affecting water availability directly and soil moisture in the longer term.

As an essential component of water security, climate change will affect water quality in different ways. Drier conditions lead to a reduction in water availability, causing a potential increase in the concentration of contaminants. Increasing runoff and floods can wash pollutants into water bodies. With climate change projected to increase the variability of rain over space and time, such impacts on water quality are becoming increasingly likely. Higher temperatures add to deteriorating water quality by reducing oxygen levels.

Another critical component to ensure secure access to water resources is adequate water infrastructure for access, disposal and sanitation. Unfortunately, increasing extremes due to climate change, especially floods and increasing storm activity, have great potential to damage such infrastructure, especially in developing world regions, where infrastructure is much more susceptible to damage and pollution.

There are substantial differences in the distribution of risks across regions, with some areas facing a much higher risk burden than others. Also, projections of the potential impacts of climate change on water security vary across regions. However, patterns of projected water-related extremes are emerging more clearly globally with increasing confidence.

FAQ 4.2 | Which places are becoming wetter and which are becoming drier, and what risks do these bring to people?

Due to climate change, substantial numbers of people are now living in climates with average precipitation levels significantly different to the average over the 20th century. Nearly half a billion people are living in unfamiliar wet conditions, mostly in mid- and high latitudes, and over 160 million people are living in unfamiliar dry conditions, mostly in the tropics and subtropics. In addition to changes in average precipitation, precipitation patterns over time are also changing, as well as river flows. Societal impacts and increased risks from both wetter and drier conditions are starting to emerge.

Some parts of the world are becoming wetter, and some are becoming drier, in terms of either changes in precipitation and/or the water available in the soil, in rivers or underground. Soil moisture, river water and groundwater are affected by changes in precipitation and also by changes in evaporation, which is affected by temperature and by uptake by vegetation.

All these factors are affected by climate change. Rising temperatures drive higher evaporation, which dries the landscape, although this can be offset in some areas by reduced uptake of water from the soil by plants in response to rising CO_2 concentrations. A warming climate brings more precipitation overall, although changes in global wind patterns mean that some areas are seeing less precipitation.

As a result, substantial numbers of people are now living in climates with average precipitation levels significantly different to the average over the 20th century. Nearly half a billion people are living in unfamiliar wet conditions, mostly in mid- and high latitudes, and over 160 million in unfamiliar dry conditions, mostly in the tropics and subtropics (Figure FAQ4.2.1).

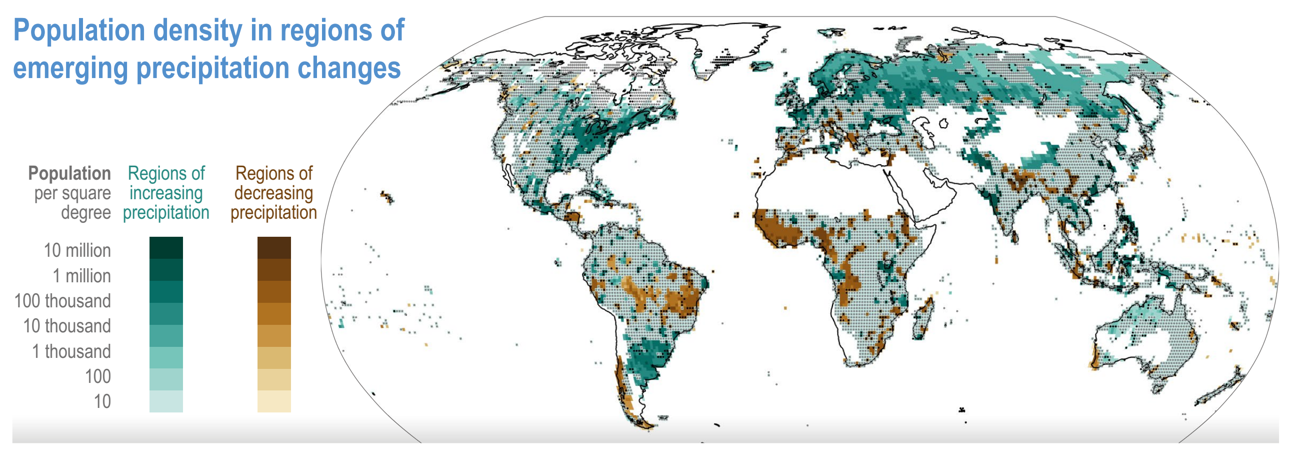

Figure FAQ4.2.1 | Numbers of people seeing increases and decreases in precipitation.

In addition to changes in average precipitation, the patterns over time are also changing, such as the length of dry spells and the amount of precipitation falling in heavy events. Again, these changes vary across the world due to shifting wind patterns. Approximately 600 million people live in places with longer dry spells than in the 1950s, mostly in West Africa, south Asia and parts of South America. Approximately 360 million people experience shorter dry spells, in North America, northern Asia and other parts of South America.

In contrast, far more people (about 600 million people) are seeing heavier precipitation than less heavy precipitation (80 million). A more widespread increase in heavy precipitation is expected in a warming world, where the warmer atmosphere takes up more moisture and hotter ground drives more intense storms.

River flows are also changing in many parts of the world, often due to changes in precipitation, although direct human impacts are also important. Generally, the most widespread increased river flows are seen in high latitudes, while decreasing flows are seen in mid- and low latitudes, although there are major exceptions to these trends and data is sparse in many regions (Figure FAQ4.2.2).

FAQ 4.2 (continued)

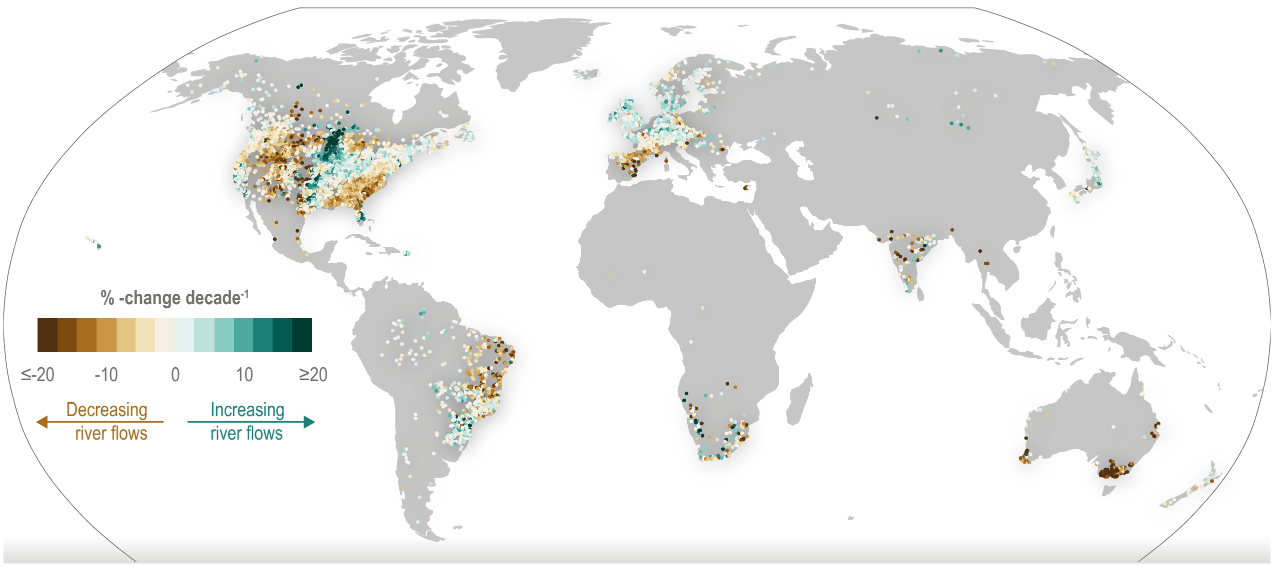

Figure FAQ4.2.2 | Observed changes in mean river flows from 1971 to 2010

Some of these changes are starting to have impacts on society. For example, increasing rainfall in the USA has led to increased crop yields. Heavy rainfall and long periods of rainfall lead to flooding, causing deaths, injuries, infrastructural damage, spread of disease, disruptions to employment and education, psychological trauma and territorial displacement. The weather conditions associated with many recent major flooding events were made *more likely* by climate change, although non-climatic factors remain the dominant driver of increased flooding.

Drier soils have made heatwaves more severe. A drying of the landscape has increased the length of the fire season across much of the world, contributing to unprecedented severity of wildfires in recent years. In recent years, several major drought events with impacts on agriculture were made *more likely* by climate change.

Overall, the general picture is of increased average precipitation and/or longer periods of precipitation in the mid and high latitudes, but decreased precipitation and/or longer times between precipitation across much of the tropics and subtropics. Where heavy precipitation is changing, this is mostly towards increasing intensity. Societal impacts and increased risks from both wetter and drier conditions are starting to emerge.

Frequently Asked Questions

FAQ 4.3 | How will climate change impact the severity of water-related disasters, such as droughts and floods?

Climate change will lead to populations becoming more vulnerable to floods and droughts due to an increase in the frequency, magnitude and total area affected by water-related disasters. Floods and droughts will also affect more people in the course of this century as a result of population growth and increased urbanisation, especially if warming cannot be limited to 1.5°C. The impact of floods and droughts are expected to increase across all economic sectors, resulting in negative outcomes for the global production of goods and services, industry output, employment, trade and household consumption. Floods will pose additional risks to people's lives and health through inundation, facilitating the further spread of waterborne diseases. At the same time, droughts can have adverse health impacts due to the limited availability of food and water for drinking and hygienic purposes. All losses, both in terms of lives and in economic terms, will be more limited in a 1.5°C than in a 3°C warmer world.

Anthropogenic land use changes and climate change will exacerbate the intensity, frequency and spatial extent of floods and droughts, leading to populations becoming more vulnerable. According to projections, these increases in extreme events will be more significant with higher levels of global warming. However, the location and severity of floods and droughts are context-dependent and complex phenomena.

The processes that lead to droughts include lack of or less frequent precipitation, increased evapotranspiration and decreased soil moisture, snow cover, runoff and streamflow. For example, warming temperatures may result in higher evapotranspiration, in turn leading to drier soils. In addition, reduced soil moisture diminishes the amount of water filtering into rivers in both the short and long term while also increasing the aridity that can foster the conditions for fire. Moreover, decreased snow cover represents less runoff supply to downstream areas during warmer seasons. Depending on this process and the propagation of a meteorological drought onto further systems, a drought can be defined as hydrological, agricultural or ecological. Agricultural drought threatens food production through crop damage and yield decreases, and consequent economic impacts, and therefore, can be the most impactful to humans. Geographically, the likelihood of agricultural drought is projected to increase across most of southern Africa, Australia, the majority of Europe, the southern and western USA, Central America and the Caribbean, northwest China, parts of South America, and the Russian Federation; but due to increased precipitation, it is projected to decline in southeastern South America, central Africa, central Canada, western India and the south of the Arabian Peninsula.

Flood hazard natural processes usually result from increases in heavy precipitation events, but they can also be caused by saturated soils, increased runoff and land use changes. A warming climate usually causes greater energy for the intense upward motion for storm formation and increases evapotranspiration, which leads to heavier precipitation. Many places around the world will experience more-than-average rainfall, which may increase soil moisture. Wetter soils saturate faster during precipitation events, resulting in increased runoff that can muddy the waters and lead to floods. Anthropogenic land use changes, such as urbanisation, deforestation, grasslands and agricultural extension, can also reduce the amount of water infiltrating the soil and leading to frequent flooding. Floods are expected to increase in Asia, the USA and Europe, particularly in areas dependent on glacier water where melting will lead to earlier spring floods. Additionally, fluvial floods are projected to be more frequent in some regions in central Africa and northern high latitudes and less frequent in the southern areas of North America, southern South America, the Mediterranean, parts of Australia and southern parts of Europe.

Globally, socioeconomic development will lead to heightened societal hazards. Due to population growth and increased urbanisation, floods and droughts will affect more people in the course of this century, especially if warming cannot be limited to 1.5°C. All losses, both in lives and in economic terms, will be more limited in a 1.5°C than in a 3°C warmer world. The impacts of floods and droughts are expected to increase across all economic sectors, from agriculture to energy production, resulting in negative outcomes for our global production of goods and services, industry output, employment, trade and household consumption. Landslides, sinkholes and avalanches arising from heavy rainfall events will increasingly threaten infrastructure and agricultural production. In cities, increased flood frequency could disrupt waste management systems, resulting in the clogging of waterways. In addition, unprecedented flood magnitudes could overwhelm hydraulic infrastructure, affecting the energy, industry and transportation sectors. An expansion in inundation area, coupled with urban sprawl, would increase flood damage. Floods will pose additional risks to people's lives and health through inundation, thus facilitating the spread of waterborne diseases. At the same time, drought can have adverse health impacts due to the limited availability of

FAQ 4.3 (continued)

food and water for drinking and hygienic purposes. Although there are no agreed-upon projections for migration and displacement due to water-related disasters, it is known that drought and desertification cause harvest failures, which may lead subsistence farmers to relocate to urban areas. Whether temporary or permanent, displacement is often mired with diminished safety, loss of social ties, and a weakened sense of place and cultural identity.

Finally, vulnerable groups such as people living in poverty, women, children, Indigenous Peoples, uninsured workers and the elderly will be the most affected by water-related disasters.

Frequently Asked Questions

FAQ 4.4 | Globally, agriculture is the largest user of water. How will climate change impact this sector, and how can farmers adapt to these changes?

Climate-induced changes in the global hydrological cycle are already impacting agriculture through floods, droughts and increased rainfall variability, which have affected yields of major crops such as maize, soybeans, rice and wheat. These changes are projected to continue in a warmer world, which will cause yields of rain-fed crops to decline and reduce the amount of water available for irrigation in water-stressed regions. Farmers already use adaptation and coping strategies to manage agricultural water use. Some of the most important adaptation responses are the application of irrigation, on-farm water and soil conservation; changing cropping patterns; adopting improved cultivars; and improved agronomic practices. In many parts of the world, farmers increasingly use Indigenous knowledge and local knowledge to inform their decisions of what to grow, when to grow and how much to irrigate. To offset the risks of market-related volatility coupled with climate change, farmers also adopt economic and financial instruments such as index-based crop insurance. Training and capacity-building programmes and social safety nets are other forms of adaptation that farmers are using to respond to these changes.

Worldwide, and especially in developing countries, agriculture (including crop cultivation and livestock and fisheries) is the largest water user, accounting for 50–90% of all water use. Moreover, a substantial part of the water used in agriculture is 'consumptive' use, which means that the water is 'consumed' for crop growth and is not immediately available for other uses. This is different from other sectors, such as energy production, where only a fraction of the water is consumed, and other downstream users can reuse the rest. Agriculture also accounts for a large share of employment in developing countries, with 60–80% of the rural population dependent on agriculture for their livelihoods. Agriculture provides food security for all. This makes farmers and agriculture particularly vulnerable to climate change.

Climate-induced changes in the global hydrological cycle are already impacting agriculture through floods, droughts and increased rainfall variability. For example, loss in yields has been reported for major crops such as maize (by 4.1%), soybeans (by 4.5%), rice (by 1.8%) and wheat (by 1.8%) due to changes in precipitation between 1981 and 2010. In addition, drought has affected both the area under cultivation and the yields of major crops. According to one estimate, globally, there has been a loss of 9–10% of total cereal production due to droughts and other weather extremes. Similarly, floods are one of the significant reasons for crop losses worldwide. Climate change-induced losses in livestock and fisheries have also been documented. In some parts of the world, especially in cold temperate zones, agro-climatic zones have become more conducive to yield growth in crops like maize and soybean due to increases in summer precipitation. Yet, negative impacts far outweigh positive impacts.

Projected impacts on agriculture due to changes in water availability are also severe. For example, yields of rain-fed crops such as maize are projected to decline by one fifth to one third by the end of the century. In contrast, many areas which currently support multiple crops may become unsuitable for rain-fed farming or support only one crop in a year. Irrigation, which is often one of the most effective adaptive strategies against water-induced stress, is also projected to be affected by a reduction of the amount of water available for irrigation in some parts of the world that are already water-stressed or as a result of groundwater depletion in places such as India, North China and the northwestern USA. Overall, future droughts and floods will pose a major risk to food security, and agriculture and impacts will be more severe on countries and communities that are already food insecure.

Given that farmers are already dealing with variability in the amount and timing of rainfall. In many places, demand for agricultural water is greater than supply, and farmers are using many adaptations and coping strategies to meet water demands for their crops, fish and livestock. Some of the most popular adaptation responses around crops and water include:

- changing cropping patterns to less water-intensive crops, and changes in the timing of sowing and harvesting to respond to unfamiliar trends in the onset of rains
- adoption of improved cultivars, such as drought and flood-resistant seed varieties
- improved agronomic practices, including conservation agriculture that helps reduce water application rates
- irrigation and water-saving technologies such as efficient irrigation and on-farm water management techniques
- on-farm water and soil moisture conservation

Most of these measures are beneficial across multiple indicators (water saving, increased incomes, etc.); however, whether they also reduce climate-related risks is not well understood and remains a knowledge gap. Irrigation and changes in crop choices and cultivars are also shown to be effective for future adaptation, especially at 1.5°C global warming, but much less effective at 2°C and 3°C when these responses will not mitigate a large part of the climate risk. Most of these adaptation measures mentioned above are autonomous. However, some, such as improved seeds

FAQ 4.4 (continued)

and cultivars, are supported by national agricultural research agencies, international research coalitions such as the CGIAR [Consultative Group on International Agricultural Research], and private seed companies. In many parts of the world, farmers are also increasingly using Indigenous knowledge and local knowledge to inform these decisions of what to grow, when to grow and how much to irrigate.

Figure FAQ4.4.1 | Water-related adaptation responses in agriculture sector: benefits, co-benefits with mitigation, and possible maladaptation

FAQ 4.4 (continued)

Given the predominance of market economies worldwide, most farmers also depend on the market to sell their produce, and market fluctuations affect their incomes. In addition, market-related volatility coupled with climate change is a source of increased risk for farmers. Several economic and financial instruments are being used with varying levels of success to offset some of these interlinked impacts. Index-based crop insurance is one such instrument that compensates farmers for losing crops due to hazards such as floods and droughts. However, several limitations in their implementation remain.

In cases of severe droughts and floods, which have debilitating impacts on already poor and vulnerable populations, national governments provide social safety programmes, such as food or cash-for-work programmes, which are shown to be successful in reducing risks for the most vulnerable people, even though there are often concerns with targeting efficiency. Providing training and capacity building of farmers to adopt new farming practices and technologies to manage risk better are also known to be effective when the training is conceptualised, targeted and implemented in consultation with farmers. Planned adaptation practices include managing weather and market risks through insurance products, social safety nets for vulnerable populations, and providing the right mix of training and capacity building. These adaptation practices are generally implemented by civil society, governments and the private sector.

Frequently Asked Questions

FAQ 4.5 | Which principles can communities implement to sustainably adapt to the ways that climate change is impacting their water security?

For communities to sustainably adapt to climate impacts on water security, their participation, cooperation and bottom-up engagement are critical in all stages of decision-making processes. In addition to enhancing the legitimacy of the decision-making process, the community's involvement can increase the equitability and effectiveness of the adaptation approach. As water insecurity disproportionately affects marginalised social groups, their participation in water governance and implementation can help improve their water security. Combining and integrating local, indigenous and traditional ecological knowledge with Western understandings of climate change can enhance the effectiveness of adaptation measures and strategies while ensuring that the adaptation is equitable and just. Improving water security is fundamental to achieving many of the 17 Sustainable Development Goals (SDGs).

For decades, communities worldwide have already been adapting to climate change-induced hydrological changes to maintain their livelihood and safety. Adaptation is a multi-faceted process that is implemented differently depending on the sector affected by changes in the hydrological cycle and the region where these changes happen. For instance, farmers in the semiarid areas might adapt to changing rain patterns through irrigation (see also FAQ4.4). At the same time, urban dwellers can adopt measures such as rainwater harvesting and other nature-based solutions. Several principles have been documented as crucial for achieving sustainable adaptation as they support communities in becoming more resilient to climate change. However, these principles can be implemented singularly or in tandem, and it is essential to acknowledge that long-term adaptation success is context-specific. Therefore, it is critical to involve local communities in co-designing effective adaptation responses.

For communities to sustainably adapt to climate impacts on water security, participation, cooperation and bottom-up engagement are critical in all stages of the decision-making processes, from planning to full implementation. Many of the countries and social groups most threatened by climate change have contributed least to global warming and do not have access to adequate resources to adapt. Effective participation of these actors in water-related climate change adaptation planning can contribute to more equitable adaptation actions. The involvement of the most vulnerable in the design of adaptation responses makes it more probable that these solutions will suit their needs and have therefore a higher chance of being effective. Accessible, inclusive and well-coordinated efforts to enhance water security will improve the legitimacy of water governance and work synergistically with reducing inequalities (UN SDG, SDG 10) and encouraging more sustainable communities (SDG 11). Communities can also be involved in sector-specific adaptation responses. These are often water-related and help ensure that climate action (SDG 13) is well aligned with clean water and sanitation (SGD 6).

The participation of traditionally excluded groups such as women and marginalised communities and Indigenous Peoples and ethnic minorities contributes to more equitable and socially just adaptation actions. Water insecurity disproportionately affects these marginalised groups, and their participation in water governance and implementation can help alleviate this burden.

Recognising the importance of Indigenous knowledge and local knowledge in improving water security is vital to ensuring that decisions and solutions align with the interests of Indigenous Peoples and local peoples and benefit their communities culturally and economically. Furthermore, the effectiveness of adaptation measures and strategies improves when Indigenous knowledge and local knowledge and traditional ecological knowledge are combined and integrated with technical understandings of climate change.

The climate adaptation plans led by national governments and local authorities will only be accepted and adequately implemented when supported by the community. Therefore, strong political and societal support is necessary to ensure effective policy changes, whether local or national. Significantly, access to financial assistance from private and public sources expands the range of strategies that communities can consider for enhancing their water security.

These principles are also conducive to the achievement of the United Nations SDGs. Actions that reduce climate risk and enhance water security can positively interact with sustainable development objectives (synergies). Therefore, improving water security is fundamental to achieving many of the 17 SDGs.

Frequently Asked Questions

FAQ 5.1 | How is climate change (already) affecting people's ability to have enough nutritious food?

Climate change has already made feeding the world's people more difficult. Climate-related hazards have become more common, disrupting the supply of crops, meat and fish. Rapid changes in weather patterns have put financial strain on producers, while also raising prices and limiting the choices and quality of produce available to consumers.

Most of our food comes from crops, livestock, aquaculture and fisheries. Global food supply increased dramatically in the last century, but ongoing climate change has begun to slow that growth, reducing the gains that would have been expected without climate change. Regionally, negative effects are apparent in regions closer to the equator, with some positive effects further north and south.

Climate impacts are also negatively affecting the quality of produce, from changes in micronutrient content to texture, colour and taste changes that reduce marketability. With warmer and more humid condition, many food pests thrive, food decays more quickly, and food contains more toxic compounds produced by fungi and bacteria.

Warming of the oceans has reduced potential fish catch. The increased carbon dioxide in the atmosphere has led to ocean acidification, which is already impacting the production of farmed fish and shellfish. Changes in local climate have forced producers to shift to new locations, changing what they grow or where they work (e.g., pole-ward shifting fishing grounds).

Climate hazards have increased over the past 50 years and are the major cause of sudden losses of production (food production shocks). Food shocks occur following droughts, heatwaves, floods, storms and outbreaks of climate-related pests and combine to cause multiplying impacts. Climate hazards sometimes disrupt food storage and transport, which impairs the food supply.

All of these negative impacts can lead to increased food prices, and reduced income for producers and retailers as there are fewer products to sell. Together, these impacts threaten to reduce the supply of varied, nutrient-rich foods to poor populations that already suffer ill health.

Box FAQ5.1 (continued)

Trends in food production shocks in different food supply sectors from 1961-2013

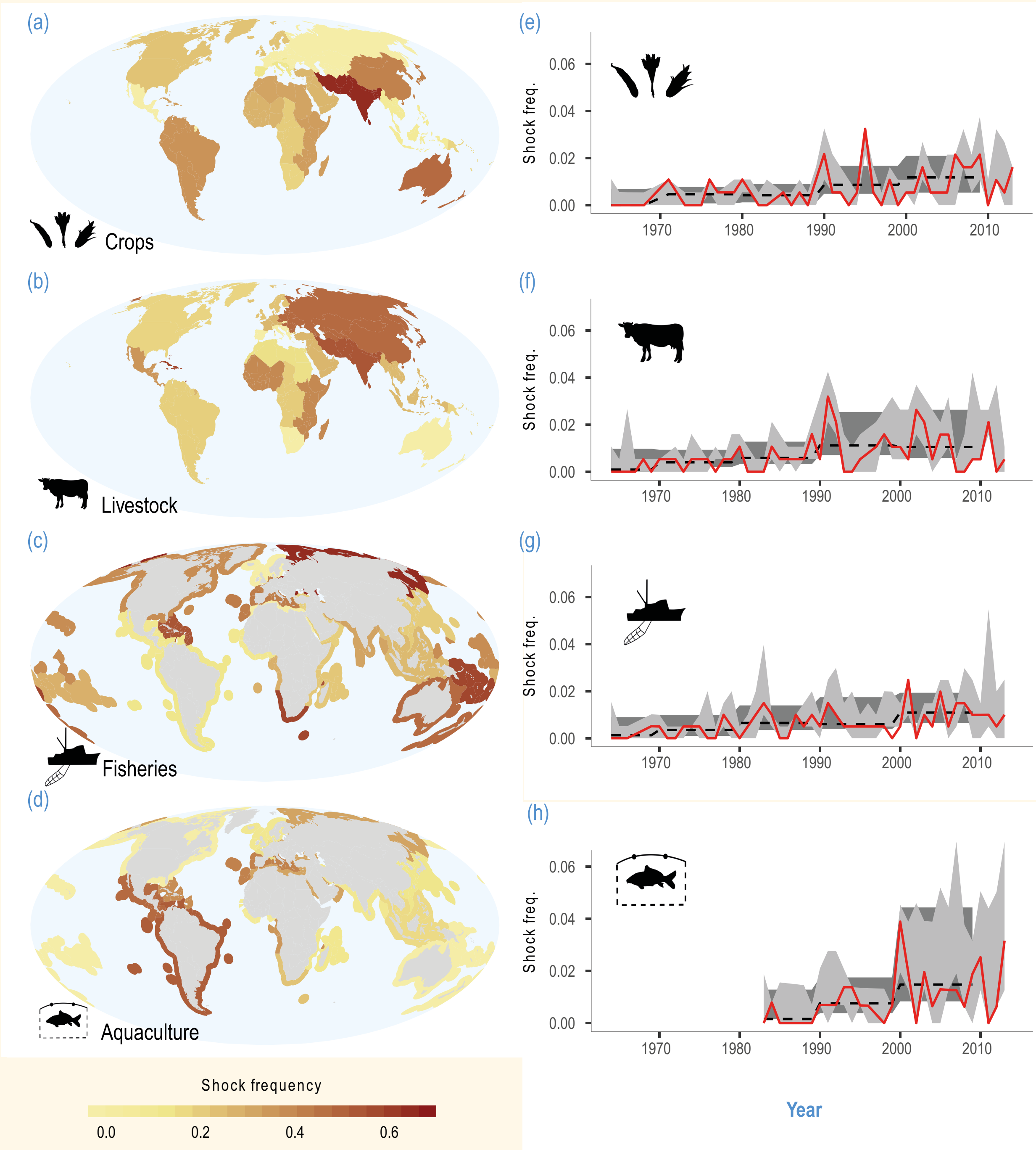

Figure FAQ5.1.1 | Trends in food production shocks in different food supply sectors from 1961 to 2013 (Cottrell et al., 2019). The red lines in the time series are the annual shock frequency, and the dashed line is the decadal mean.

Frequently Asked Questions

FAQ 5.2 | How will climate change impact food availability by mid and late century and who will suffer most?

Climate change impacts will worsen over time, with the period after mid-century seeing more rapid growth in negative impact than in the early part of this century. The impacts will be global, but people with fewer resources, and those who live in regions where impacts will worsen more rapidly, will be hurt the most.

Climate change impacts will worsen over time, but the extent depends on how rapidly greenhouse-gas emissions grow. If the current rate of emissions continues, the impacts will worsen, especially after mid-century, with rapid growth in the number and severity of extreme weather events. Yields of plants, animals and aquaculture will decline in most places, and marine and inland fisheries will suffer. Food production in some regions will become impossible, either because the crops or livestock there cannot survive in the new climatic conditions, or it is too hot and humid for farm workers to be in the fields.

After harvest, agricultural production passes through the agricultural value chain, supplying animal feeds, industrial uses and international markets, with some stored for use in the future. Each of these transitions will be affected by climate change. Food storage facilities will face more challenges in dealing with spoilage. Transportation of perishable fruits, vegetables and meats will become costlier to maintain quality. Households and food services will need to spend more on food preservation.

Low-income countries and poor people are at higher risk, as they have limited social safety nets and suffer more from rising food prices and an unstable food supply. But large famers will also be hurt. Rural communities, especially smallholder farmers, pastoralists and fishers, are extremely vulnerable because their livelihoods mainly depend on their production. The urban poor will have to spend more on food.

A flood, for example, may force low-income families out of their homes, affect their employment and reduce their access to food supplies, with prices often rising after natural disasters. Families will have less access to safe water supplies, and this combination of lower food supplies, uncertain employment, displacement from home and rising food costs will increase the number of children who are undernourished.

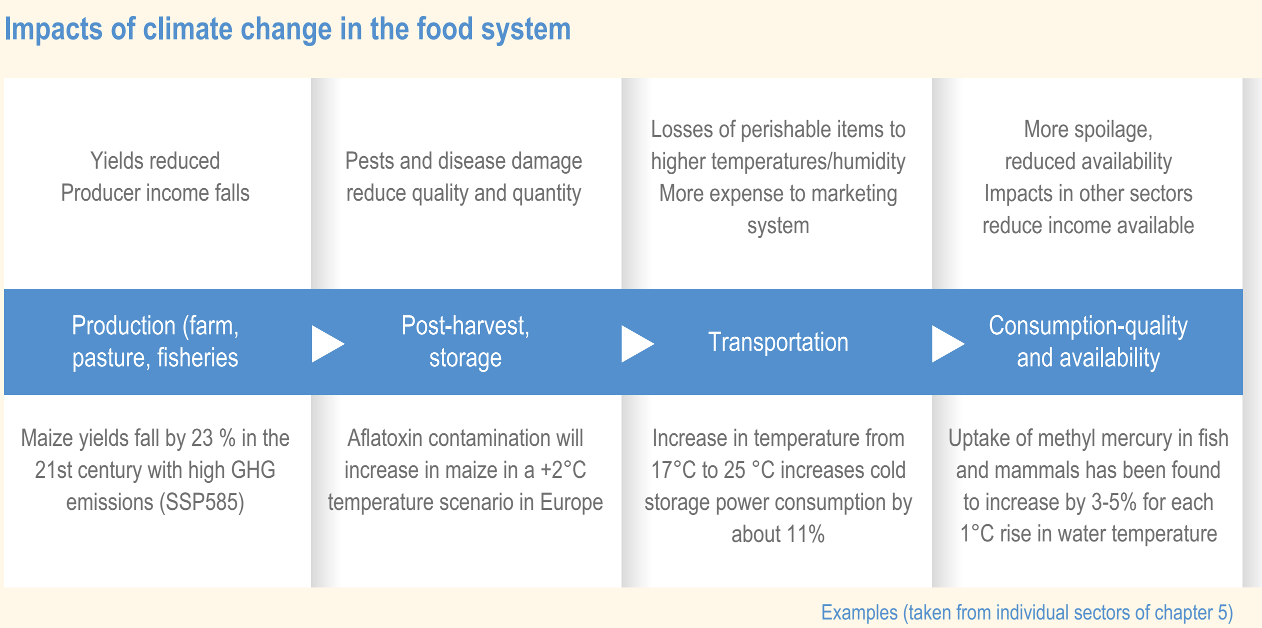

Figure FAQ5.2.1 | Impacts of climate change on the food system.

Frequently Asked Questions

FAQ 5.3 | Land is going to be an important resource for mitigating climate change: how is the increasing competition for land threatening global food security and who will be affected the most?

Climate change will affect food production. Meeting future food needs requires greater land shares unless we change what we eat and how we grow food. Additionally, large-scale land projects that aim to mitigate climate change will increase land competition. Less land will then be available for food production, increasing food insecurity. People at greater risk from land competition are smallholder farmers, Indigenous Peoples and low-income groups.

Why is land important?

Land is a limited resource on which humans and ecosystems depend on to grow plants, which capture carbon dioxide and release oxygen, and provide food, timber and other products. We also have cultural, recreational and spiritual connections to land.

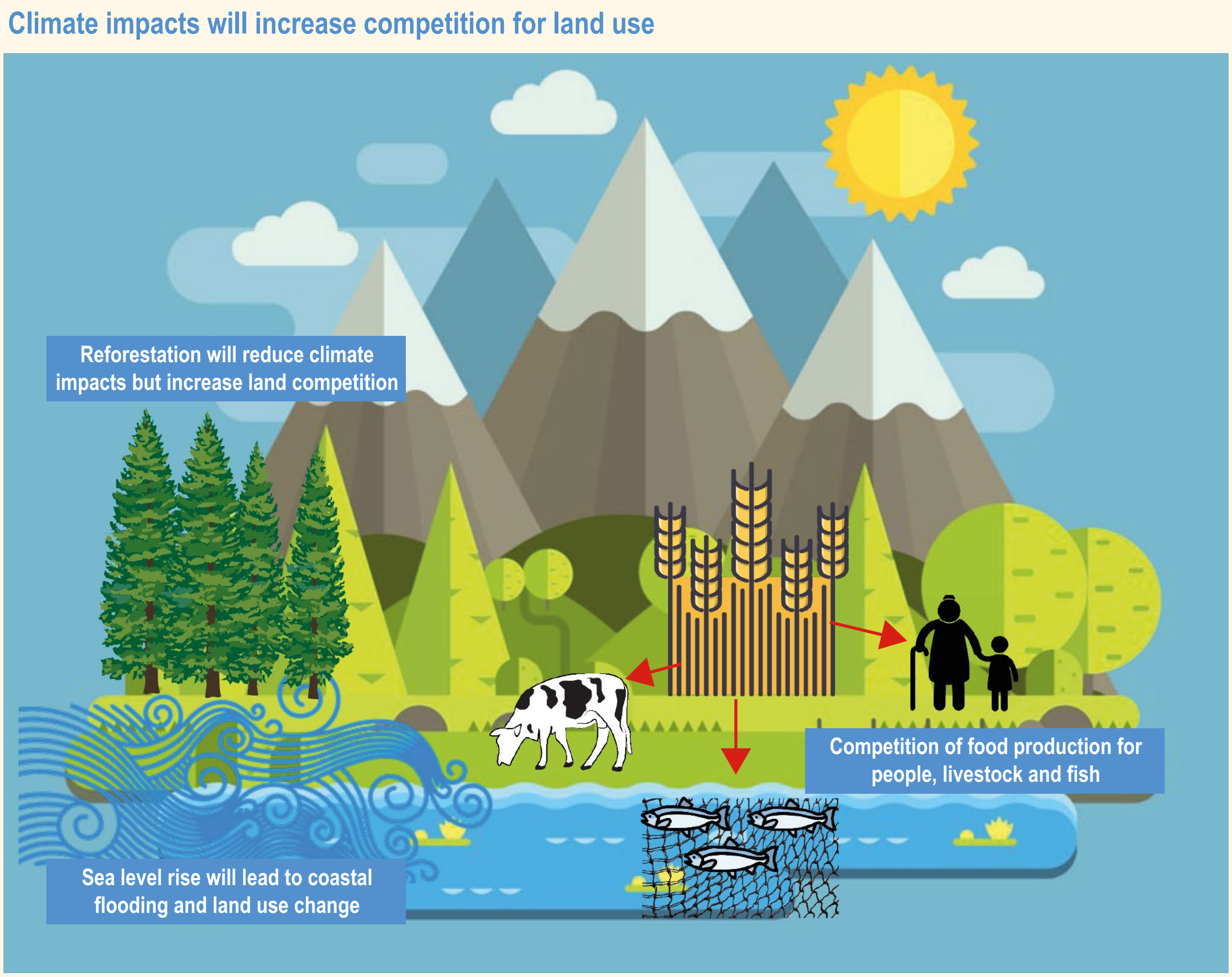

Figure FAQ5.3.1 | Climate impacts will increase competition for land use, reducing coastal land for crops and affecting food security for vulnerable groups. Adaptation methods like coastal aquaculture and mangrove reforestation reduce climate effects but may increase land competition.

Box FAQ5.3 (continued)

Why will climate change affect land use?

Climate change results in more frequent heatwaves, extreme rainfall, drought and rising sea levels, which negatively affect crop yields. More land is thus needed to grow crops, increasing land competition with other food systems that use crops to feed their animals (e.g., livestock, fish). Where land will be flooded, humans cannot grow crops, but food production could be adapted to grow seafood instead. Extensive land allocations aiming at reducing carbon emissions, such as afforestation, reduce land availability for food. Unless carefully managed, competition for land will increase food prices and food security.

Solutions to reduce land competition and protect food security

Sustainable land management allows land to remain productive and support key functions. Other land practices include growing cover crops to improve soil quality. Governments can provide incentives to producers to grow alternative foods and use sustainable practices. Making sure that vulnerable groups (e.g., low-income communities, Indigenous people and small-scale producers) strengthen land tenure rights will help protect food security.

Food by-products used as alternative food sources and other products reduce waste and increase sustainability. Dietary changes are another important solution. People that eat high amounts of meat or unhealthy foods could reduce consumption of these foods and have more diverse diets. These dietary changes will benefit their health and reduce pressure on land. Regulated labelling, education and other policies which encourage healthy diets can support these shifts.

Frequently Asked Questions

FAQ 5.4 | What are effective adaptation strategies for improving food security in a warming world?

A variety of adaptation options exist to improve food security in a warming world. Examples of adaptation for crop production include crop management and livelihood diversification. For livestock-based systems, an example is matching number of animals with the production capacity of pastures. For fisheries, eliminating overfishing is an effective adaptation practice. For mixed cropping and nature-based systems, an appropriate adaptation is agroforestry.

Adaptation strategies to enhance food security vary from farm-level interventions to national policies and international agreements. They cover the following dimensions of food security: availability, access, utilisation (food quality and safety) and stability.

For the production of crops, adaptation strategies include field and farm-level options such as crop management, livelihood diversification and social protection such as crop insurance. The most common field management options are changes in planting schedules, crop varieties, fertilizers and irrigation. For example, farmers can shift their planting schedules in response to the early or late onset of the rainy season. Moreover, there are new crop insurance schemes that are based on changes in weather patterns.

For livestock-based systems, adaptation options include matching the number of animals with the production capacity of pastures; adjusting water management based on seasonal and spatial patterns of forage production; managing animal diet; more effective use of fodder, rotational grazing; fire management to control woody thickening of grass; using more suitable livestock breeds or species; migratory pastoralist activities; and activities to monitor and manage the spread of pests, weeds and diseases.

For ocean and inland fisheries, adaptation options are primarily concentrated in the socioeconomic dimension and governance and management. In general, eliminating overfishing could help rebuild fish stocks, reduce ecosystem impacts, and increase fishing's adaptive capacity. Aquaculture is often viewed as an adaptation option for fisheries declines. However, there are adaptation strategies specific to aquaculture, including proper species selections at the operational level, such as the cultivation of brackish species (shrimp, crabs) in inland ponds during dry seasons and rice–freshwater finfish in wetter seasons.

For so-called mixed farming systems that produce a combination of crops, livestock, fish and trees, these systems' inherent diversity provides a solid platform for adaptation. A good example is agroforestry, the purposeful integration of trees or shrubs with crop or livestock systems, which increases resilience against climate risks.

Overall, nature-based systems or ecosystem-based strategies in food systems, such as agroecology, can be a useful adaptation method to increase wild and cultivated food sources. Agroecological practices include agroforestry, intercropping, increasing biodiversity, crop and pasture rotation, adding organic amendments, integration of livestock into mixed systems, cover crops and minimising toxic and synthetic inputs with adverse health and environmental impacts.

Frequently Asked Questions

FAQ 5.5 | Climate change is not the only factor threatening global food security: other than climate action, what other actions are needed to end hunger and ensure access by all people to nutritious and sufficient food all year round?

Our food systems depend on many factors other than climate change, such as food production, water, land, energy and biodiversity. People's access to healthy food can be also be affected by factors such as poverty and physical insecurity. We are all stakeholders in food systems, whether as producers or consumers, and we can all contribute to the goal of a food-secure world by the choices we make in our everyday lives.

Today more than 820 million people are hungry, and hunger is on the rise in Africa. Two billion people experience moderate or severe food shortages, and another 2 billion suffer from overnutrition, a state of obesity or being overweight from unbalanced diets, with related health impacts such as diabetes and heart disease. The changing climate is already affecting food production. These effects are worsening, affecting food production from crops, livestock, fish and forests in many places where people already do not have enough to eat. Food prices will be affected as a result, with increasing risk that poorer people will not be able to buy enough for their families. Food quality will increasingly be affected too.

Our ability to grow and consume food depends on many factors other than climate change. There are tight connections between food production, water, land, energy and biodiversity, for example. Other factors like gender inequity, poverty, political exclusion, remoteness from urban centres and physical insecurity can all affect people's access to healthy food.

Food systems are complicated (Figure FAQ5.5.1). To improve food production, supply and distribution, we need to make changes throughout the food supply chain. For instance: improving the way farmers access the inputs needed to grow food; improving the ways in which food is grown, with climate and market information, training and technical know-how, water-saving and water-harvesting technologies; adopting new low-cost and less carbon-intensive storage and processing methods; and creating local networks of producers and processors For food consumers, we could consider shifts to different diets that are healthier and make more efficient use of natural resources; depending on context, these could involve rebalancing consumption of meat and highly processed foods, reducing food loss and waste, and preparing food in more energy-efficient ways. Policymakers can enable such actions through appropriate price and trade policies, implementing policies for sustainable and low-emission agriculture, providing safety nets where needed, and empowering women, youth and other socially disadvantaged groups.

Our food systems need to be robust and sustainable; otherwise we will not be able to manage the additional pressures imposed on them by climate change. We can all contribute to this goal.

Box FAQ5.5 (continued)

Conceptual framework of food systems for diets and nutrition

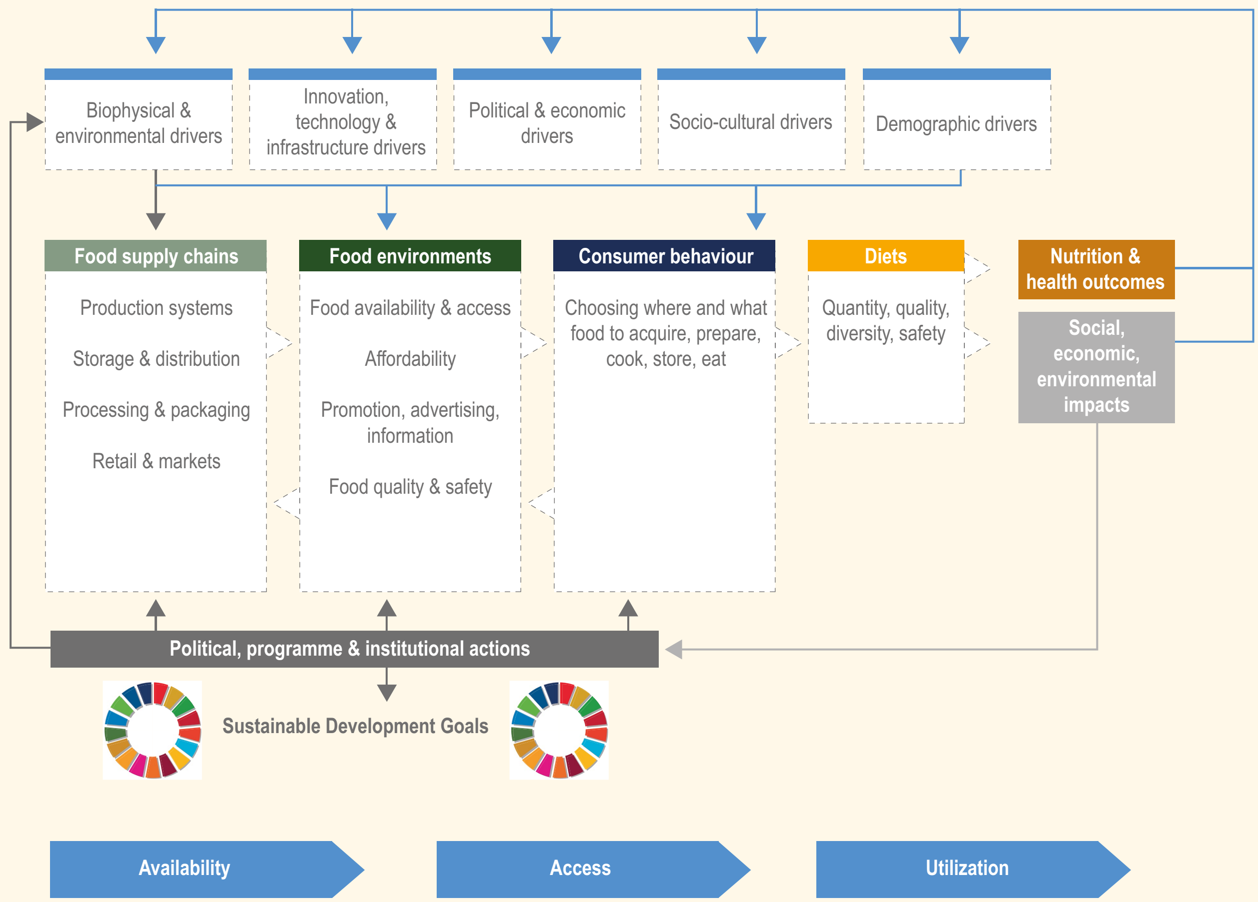

Figure FAQ5.5.1 | Conceptual framework of food systems for diets and nutrition (modified from HLPE, 2017a).

Frequently Asked Questions

FAQ 6.1 | Why and how are cities, settlements and different types of infrastructure especially vulnerable to the impacts of climate change?

Cities, settlements and infrastructure become vulnerable when investment decisions fail to take the risks of climate change fully into account. Such failures can result from a lack of understanding, competing priorities, a lack of finance or access to appropriate technology. Around the world, smaller cities and poorer populations are often most vulnerable and suffer the most over time, while large cities can register the greatest losses to individual events.

The world is urban. Billions of people live in towns and cities. Hardly anyone, even in remote rural locations, is separated from the flows of trade that connect the world and are held together by networks of transport and communication infrastructure systems. Connected networks once broken can cascade out, multiplying impacts across urban and rural areas. When major manufacturing centres or regionally important ports are impacted, global trade suffers. For example, flooding in Bangkok in 2011 led to a global shortage in semiconductors and a slowdown in global computer manufacturing.

Despite cities generating wealth, additional vulnerability to climate change is being created in urban areas every day. Demographic change, social and economic pressures, and governance failures that drive inequality and marginality mean that increasing numbers of people who live in towns and cities are exposed to flooding, temperature extremes and water or food insecurity. This leads to an adaptation gap, where rich neighbourhoods can afford strategies to reduce vulnerability while poorer communities are unable to do the same. Although this would be so even without a changing climate, climate change increases the variability and extremes of weather, exposing more people, businesses and buildings to floods and other events. The combination of rising vulnerability and increasing exposure translates to a growth in the number of people and properties at risk from climate change in cities worldwide.

Around the world, vulnerability is rising but differs considerably between and within urban areas. Settlements of up to 1 million people are the most rapidly expanding and also among the most vulnerable. These settlements often have limited community level organisation and might not have a dedicated local government. Coping with rapid population growth under conditions of climate change and constrained capacity is a major challenge. For large cities, multiple local governments and well-organised community-based organisations interact with large businesses and national political parties in a complicated cocktail of interests that can interfere with planning and action to reduce vulnerability.

For the poorest living in urban slums, informal settlements or renting across the city, lack of secure tenure and inadequate access to basic services compound vulnerability. But even the wealthy in large cities are not fully protected from climate change-related shocks. Just like breaks in infrastructure between towns and rural settlements, big city infrastructure can be broken by even local landslides, floods or temperature events, with consequences cascading across the city. Electricity blackouts are the most common and can affect water pumping, traffic regulation and streetlights, as well as hospitals, schools and homes. Still, it is the urban poor and marginalised who experience the greatest exposure, most vulnerability and least capacity to cope.

Rounds of exposure and impact can reduce the capacity of survivors to cope with future events. As a result, the already vulnerable and exposed become more vulnerable over time, increasing urban inequalities. But this need not be the case. Focussing on vulnerability reduction is not easy, it requires joined-up action across social and economic development sectors, together with critical infrastructure planning. It often also means partnering local government with informal and community-based actors. But there is considerable experience globally on what works and how to deliver reduced vulnerability for the urban poor and for cities as a whole. The challenge is to scale up this experience and accelerate its application to keep pace with climate change and address the adaptation gap.

Frequently Asked Questions

FAQ 6.2 | What are the key climate risks faced by cities, settlements and vulnerable populations today, and how will these risks change in a mid-century (2050) 2°C warmer world?

Climate change will interact with the changing physical environment in cities and settlements to create or exacerbate a range of risks. Rising temperatures and heatwaves will cause human illness and morbidity, as well as infrastructure degradation and failures, while heavy rainfall and sea level rise will worsen flooding. Low-income groups and other vulnerable populations will be affected most severely because of where they live and their limited ability to cope with these stresses.

Cities and settlements are constantly changing. Their populations grow and shrink, economic activities expand or decline, and political priorities shift. The risks that cities and their residents face are influenced by both urban change and climate change. The seriousness of these risks into the 21st Century will be shaped by the interactions between drivers of change including population growth, economic development and land use change.

In a warming world, increasing air temperature makes the urban heat island effect in cities worse. One key risk is heatwaves in cities that are *likely* to affect half of the future global urban population, with negative impacts on human health and economic productivity. Heat and built infrastructure such as streets and houses interact with each other and magnify risks in cities. For instance, higher urban temperatures can cause infrastructure to overheat and fail, as well as increase the concentration of harmful air pollutants such as ozone.

The density of roads and buildings in urban areas increases the area of impermeable surfaces, which interact with more frequent heavy precipitation events to increase the risk of urban flooding. This risk of flooding is greater for coastal settlements due to sea level rise and storm surges from tropical cyclones. Coastal inundation in the Miami-Dade region in Florida, USA, is estimated to have caused over USD 465 million in lost real estate value between 2005 and 2016, and it is *likely* that coastal flood risks in the region beyond 2050 will increase without adaptation to climate change.

Within cities, different groups of people can face different risks. Many low-income residents live in informal settlements alongside coasts or rivers, which greatly heightens exposure and vulnerability to climate-driven hazards. In urban areas in Ghana, for example, risks from urban flooding can compound health risks, and have resulted in outbreaks of malaria, typhoid and cholera. Those outbreaks have been shown to disproportionately affect poorer communities.

Severe risks in cities and settlements also arise from reduced water availability. As urban areas grow, the amount of water required to meet basic needs of people and industries increases. When increased demand is combined with water scarcity from lower rainfall due to climate change, water resource management becomes a critical issue. Low-income groups already face major challenges in accessing water, and the situation is *likely* to worsen due to growing conflicts over scarce resources, increasing water prices and diminishing infrastructure provisions in ever-expanding informal settlements.

These key risks already differ greatly between cities, and between different groups of people in the same city. By 2050, these discrepancies are likely to be even more apparent. Cities with limited financial resources, regulatory authority and technical capacities are less equipped to respond to climate change. People who already have fewer resources and constrained opportunities face higher levels of risk because of their vulnerability. As a result of this, key risks vary not only over time as climate change is felt more strongly, but also over space, between cities exposed to different hazards and with different abilities to adapt, and between social groups, meaning between people who are more or less affected and able to cope.

Frequently Asked Questions

FAQ 6.3 | What adaptation actions in human settlements can contribute to reducing climate risks and building resilience across building, neighbourhood, city and global scales?

Settlements bring together many activities, so climate action will be most effective if it is integrated and collaborative. This requires (i) embedding information on climate change risks into decisions; (ii) building capacity of communities and institutions; (iii) using both nature-based and traditional engineering approaches; (iv) working in partnership with diverse local planning and community organisations; and (v) sharing best practice with other settlements.

Settlements bring together people, buildings, economic activities and infrastructure services, and thus integrated, cross-sector, adaptation actions offer the best way to build resilience to climate change impacts. For example, actions to manage flood risk include installing flood proofing measures within and outside properties, improving capacity of urban drainage along roads, incorporating nature-based solutions (NbS) within the urban areas, constructing flood defences and managing land upstream of settlements to reduce runoff.

Adaptation actions will be more effective if they are implemented in partnership with local communities, national governments, research institutions, and the private and third sector. Climate action should not be considered as an additional or side action to other activities. Rather, climate action should be mainstreamed into existing processes, including those that contribute to the UN Sustainable Development Goals (2015) and New Urban Agenda adopted at the UN Conference on Housing and Sustainable Urban Development (Habitat III) in 2016. Cities are already coming together through international networks to share good practice about adaptation actions, speeding up the dissemination of knowledge.

This integrated approach to adaptation in human settlements needs to be supported by various other actions, including potential co-benefits with carbon emissions reductions, public health and ecosystem conservation goals. First, information on climate risks needs to be embedded into the architectural design, delivery and retrofitting of housing, transportation, spatial planning and infrastructure across neighbourhood and city scales. This includes making information on climate impacts widely available, updating design standards and strengthening regulation to avoid development in high-risk locations. Second, the capacity of communities needs to be strengthened, especially among those in informal settlements, the poorest and other vulnerable groups including minorities, migrants, women, children, elderly, disabled and people with serious health conditions such as obesity. This involves raising awareness, incorporating communities into adaptation processes, and strengthening regulation, policies and provision of infrastructure services. Third, nature-based solutions should be integrated to work alongside traditional 'grey' or engineered infrastructure. Vegetation corridors, greenspace, wetlands and other green infrastructure can be woven into the built environment to reduce heat and flood risks, whilst providing other benefits such as health and biodiversity.

Although even the largest city covers only a small area of the planet, all settlements are part of larger catchments from which people, water, food, energy, materials and other resources support them. Actions within cities should be mindful of wider impacts and avoid displacing issues elsewhere.

Frequently Asked Questions

FAQ 6.4 | How can actions that reduce climate risks in cities and settlements also help to reduce urban poverty, enhance economic performance and contribute to climate mitigation?

If carefully planned, adaptation actions can reduce exposure to climate risk and reduce urban poverty, advance sustainable development and mitigate greenhouse gas emissions. When adaptation responses are equitable, and if a range of voices are heard in the planning process, the needs of the disadvantaged are more likely to be addressed and wider societal benefits can be maximised.

Urbanisation is a global trend which is interacting with climate change to create complex risks in cities and settlements, especially for those that already have high levels of poverty, unemployment, housing informality and backlogs of services. Many cities and settlements are seeing increasing action to manage climate risks. On top of reducing communities' exposure to climate risk, adaptation actions can have benefits for reducing urban poverty and enhancing economic performance in ways that reduce inequality and advance sustainability goals. Adaptation actions, however, can also have unintended consequences. That is why care needs to be taken to ensure climate adaptation planning and development of new infrastructure does not exacerbate inequality or negatively impact other sustainable development priorities. Climate adaptation planning is most effective when it is sensitive to the diverse ways that low-income and minority communities are more *likely* to experience climate risk, including women, children, migrants, refugees, internally displaced peoples and racial/ethnic minority groups, among others.

Adapting to climate change can have benefits for reducing greenhouse gas (GHG) emissions and urban inequalities. In cities where growing numbers of people live in informal settlements, introducing risk-reducing physical infrastructure such as piped water, sanitation and drainage systems can enhance the quality of life of the community. At the same time, those measures can increase health outcomes and reduce urban inequalities by reducing exposure to flooding or heat impacts. In less developed countries, less than 60% of the urban population have access to piped water which, in turn, impacts their health and well-being. Increasingly, housing is being built better to manage heat risk through insulation or changing building orientation, or to flood risk by raising structures, which then contributes to well-being and ability to work. Improvements to early warning systems can help people evacuate rapidly in case of storm surges or flooding. Although the most vulnerable often do not get these warnings in time.

Carefully planned nature-based solutions (NbS), such as public green space, improved urban drainage systems and storm water management, can deliver both health and development benefits. When these adaptation actions succeed, water, waste and sanitation can be improved to better manage climate risk and provide households and cities with better services. Many nature-based solutions entail bringing back plants and trees into cities, which also helps to reduce the concentration of heat-trapping GHGs in the atmosphere.

When care is taken to ensure that adaptation responses are equitable, and that a range of voices are heard in planning, the needs of the disadvantaged are more likely to be addressed. For example, a study that looked at transport plans across 40 cities in Portugal saw that some urban communities have prioritised the needs of disadvantaged users such as the elderly and disabled, while at the same time reducing urban transport emissions and enhancing public well-being and equity of transport. On the other hand, in some cities, there is evidence of emerging trade-offs associated with climate adaptation actions where sea walls and temporary flood barriers were erected in economically valuable areas and not is less well-off areas. Going forward, it is important to ensure that vulnerable groups' needs are carefully considered, both in terms of climate and other risks, as this has not been sufficiently done in the past.

Frequently Asked Questions

FAQ 6.5 | What policy tools, governance strategies and financing arrangements can enable more inclusive and effective climate adaptation in cities and settlements?

Inclusive and effective climate adaptation requires efforts at all levels of governance, including the public sector, the private sector, the third sector, communities and intermediaries such as universities or think tanks. Inclusive and effective adaptation requires action fit for the diverse conditions in which it is needed. Collaborative dialogues can help to map both adaptation opportunities and potential negative impacts.

There is no one-size-fits-all approach to ensure that climate adaptation efforts have positive results and include the concerns of everyone affected. Cities and local communities are diverse, and thus they have diverse perspectives on what responses to prioritise. Moreover, adaptation efforts may impact people's lives in very different ways. Policy tools, strategies and financial arrangements for adaptation can include all society sectors and address socioeconomic inequalities. Planning and decision making must respond to marginalised voices and future generations (including children and youth).

Efforts to adapt to climate change can be incremental, reformist or transformational, depending on the scale of the change required. Incremental action may address specific climate impacts in a given place, but do not challenge the social and political institutions that prevent people from bouncing back better. Reformist action may address some of the social and institutional drivers of exposure and vulnerability, but without addressing the underlying socioeconomic structures that drive differential forms of exposure. For example, social protection measures may improve people's capacity to cope with climate impacts, but that improved capacity will depend on maintaining such protection measures. Transformative action involves fundamental changes in political and socioeconomic systems, oriented toward addressing vulnerability drivers (e.g., socioeconomic inequalities, consumption cultures). All forms of adaptation are relevant to deliver resilient futures because of the variability of conditions in which adaptation action is needed.

Local and regional governments play an essential role in delivering planning and institutional action suited to local conditions in cities and settlements. Potential strategies can span multiple sectors and scales, ranging from land use management, building codes, critical infrastructure designs and community development actions, to different legal, financial, participatory decision making and robust monitoring and evaluation arrangements. NGOs or third sector organisations can also play a coordinating role by building dialogues across governments, the private sectors and communities through effective communication and social learning. Local action tends to falter without the support of national governments as they are often facilitators of resources and finance. They can create institutional frameworks that facilitate (rather than impede) local action. National governments also play a crucial role in the development of large-scale infrastructures.

Private actors can also drive adaptation action. The evaluation of private-led infrastructure and housing projects suggests that the prioritisation of profit, however, may have a detrimental impact on the overall resilience of a place. New institutional models such as public–private partnerships respond to the shortcomings of both the public and private sectors. Still, the evidence of them facilitating the inclusion of multiple actors is mixed.

The private sector can mobilise finance. However, the forms of finance available for adaptation are limited and directed to huge projects that do not always address local adaptation needs. Private actors tend to join adaptation projects when there is an expectation of large profits, such as in interventions that increase real estate value. Private-led adaptation can lead to 'gentrification' whereby low-income populations are relocated from urban centres and safer settlements. Models that enable the collaboration between public, private and civil society sectors have greater potential to mobilise adaptation finance in inclusive ways.

Forms of collaborative planning and decision making can create dialogues for a sustainable future in cities, settlements and infrastructure systems. Adaptation action needs multiple approaches. For example, adaptation needs both actions that depend on dialogues between multiple actors (e.g., urban planning and zoning) and action that follows strong determination and leadership (e.g., declarations of emergency and target commitments). There are adaptation actions that depend on place-based conditions (e.g., flood defences) and those that require considering interactions across scales (e.g., regulatory frameworks). The growth of adaptation capacities, fostering dialogues, empowered communities, multi-scalar assessments and foresight within current institutions can support effective and inclusive adaptation action that is also sustained in the long term.

Frequently Asked Questions

FAQ 7.1 | How will climate change affect physical and mental health and well-being?

Climate change will affect human health and well-being in a variety of direct and indirect ways that depend on exposure to hazards and vulnerabilities that are heterogeneous and vary within societies, and that are influenced by social, economic and geographical factors and individual differences (see Figure FAQ7.1.1). Changes in the magnitude, frequency and intensity of extreme climate events (e.g., storms, floods, wildfires, heatwaves and dust storms) will expose people to increased risks of climate-sensitive illnesses and injuries and, in the worst cases, higher mortality rates. Increased risks for mental health and well-being are associated with changes caused by the impacts of climate change on climate-sensitive health outcomes and systems (see Figure FAQ7.1.2). Higher temperatures and changing geographical and seasonal precipitation patterns will facilitate the spread of mosquito- and tick-borne diseases, such as Lyme disease and dengue fever, and water- and food-borne diseases. An increase in the frequency of extreme heat events will exacerbate health risks associated with cardiovascular disease and affect access to freshwater in multiple regions, impairing agricultural productivity and increasing food insecurity, undernutrition and poverty in low-income areas.

Pathways from hazards, exposure and vulnerabilities to climate change impacts on health outcomes and health Systems

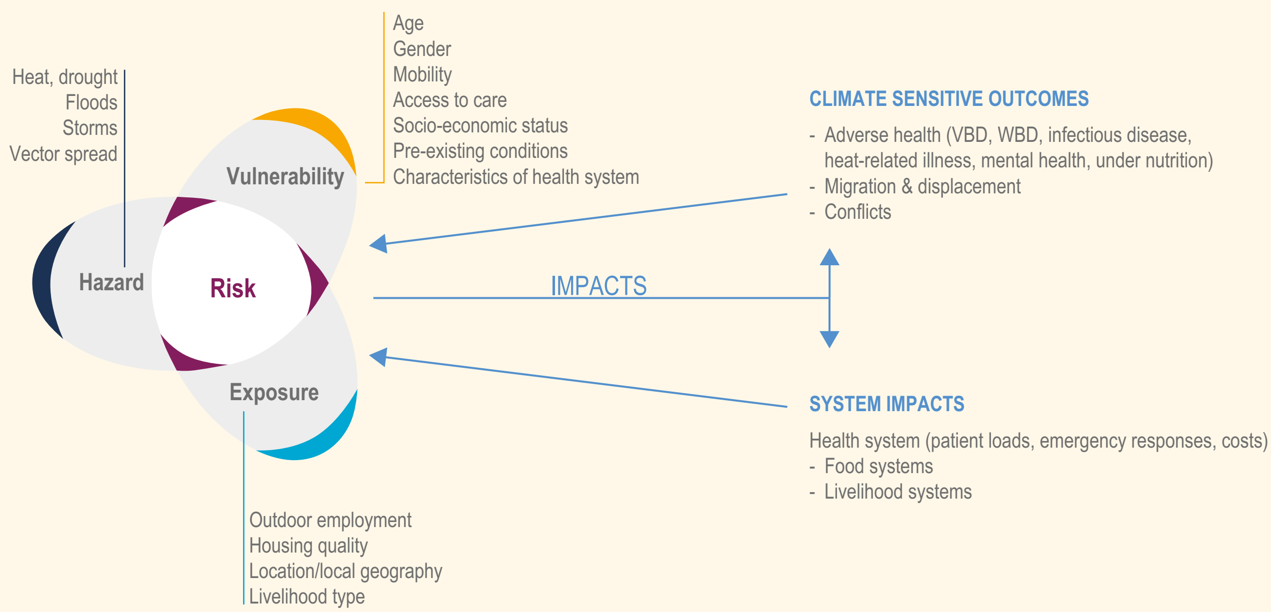

Figure FAQ7.1.1 | Pathways from hazards, exposure and vulnerabilities to climate change impacts on health outcomes and health systems. WBD: waterborne disease, VBD: Vector-borne disease, and FBD: Food-borne disease.

Box FAQ 7.1 (continued)

Climate change impacts on mental health and adaptation responses

1 Hazard

Acute events
(e.g. storms, floods, wildfires, extreme heat)

Chronic changes
(e.g. drought, sea level rise, sea ice loss, changing climate normals)

2 Vulnerability

Pre-existing health conditions
Socio-economic inequities
Gender
Age
Occupation

3 Exposure

Direct exposure(s)

Indirect exposure(s)
(e.g. displacement, food systems disruption, occupational loss)

Vicarious exposure(s)
(e.g. observed experiences of others, media depictions of climate change)

4 Key adaptation responses

Scale of adaptation

Institutional
State and non-state actors: effective mental health systems, planning and preparedness, informed policies, early intervention
Local governments: planning, design, green infrastructure

Community
- Supportive social networks, effective information channels

Individuals
- awareness, preparedness, mental health support, nature-based therapy

5 Risks to mental health and wellbeing

Mental illness
[e.g., PTSD, depression, suicide]

Diminished wellbeing
[e.g., stress, climate anxiety, cognitive impairment)

Diminished social relations
[e.g., loss of culture, interpersonal violence)

Figure FAQ7.1.2 | Climate change impacts on mental health and key adaptation responses.
PTSD: Post traumatic stress disorder.

Frequently Asked Questions

FAQ 7.2 | Will climate change lead to wide-scale forced migration and involuntary displacement?

Climate change will have impacts on future migration patterns that will vary by region and over time, depending on the types of climate risks people are exposed to, their vulnerability to those risks and their capacity—and the capacity of their governments—to adapt and respond. Depending on the range of adaptation options available, households may use migration as a strategy to adapt to climate risks, often through labour migration. The most common drivers of climate-related displacement are extreme weather events, floods and droughts, especially when these events cause severe damage to homes, livelihoods and food systems. Rising sea levels will present a new risk for communities situated in low-lying coastal areas and small island states. The greater the scale of future warming and extreme events, the greater the potential scale of future, involuntary climate-related migration and displacement.Progress towards achieving the Sustainable Development Goals (SDGs) has strong potential to reduce future involuntary climate-related migration and displacement.

Frequently Asked Questions

FAQ 7.3 | Will climate change increase the potential for violent conflict?

Climate hazards have affected armed conflict within countries but the observed influence of climate is small relative to socioeconomic, political and cultural factors. Adverse impacts of climate change threaten to increase poverty and inequality, undermine progress in meetings Sustainable Development Goals (SDGs) and place strain on civil institutions—all of which are factors that contribute to the emergence or worsening of civil unrest and conflict. Climate change impacts on crop productivity and water availability can function as a 'risk multiplier' for conflict in areas that are already politically and/or socially fragile and, depending on circumstances, could increase the length or the nature of an existing conflict. Institutional initiatives within or between states to protect the environment and manage natural resources can serve simultaneously as mechanisms for engaging rival groups and adversaries to cooperate in policymaking and peacebuilding.

Frequently Asked Questions

FAQ 7.4 | What solutions can effectively reduce climate change risks to health, well-being, forced migration and conflict?

The solution space includes policies, strategies and programmes that consider why, how, when and who should be involved to sustainably adapt to climate change. Effectively preparing for and managing the health risks of climate change requires considering the multiple interacting sectors that affect population health and effective functioning of health systems. Considering the close inter-connections between health, migration and conflict, interventions that address climate risks in one area often have synergistic benefits in others. For example, conflicts often result in large numbers of people being involuntarily displaced and facilitate the spread of climate-sensitive diseases; tackling the underlying causes of vulnerability and exposure that generate conflict reduces risks across all areas. A key starting point for health and well-being is strengthening public health systems so that they become more climate resilient, which also requires cooperation with other sectors (water, food, sanitation, transportation, etc.) to ensure appropriate funding and progress on sustainable development goals. Interventions to enhance protection against specific climate-sensitive health risks could reduce morbidity and mortality and prevent many losses and damages (Figure FAQ7.4.1). These range from malaria net initiatives, vector control programmes, health hazard (syndromic) surveillance and early warning systems, improving access to water, sanitation and hygiene (WASH), heat action plans (HAPs), behavioural changes and integration with disaster risk reduction (DRR) and response strategies. More importantly, climate resilient development pathways (CRDPs) are essential to improve overall health and well-being, reduce underlying causes of vulnerability and provide a framework for prioritising mitigation and adaptation options that support sustainable development. Transformative changes in key sectors including water, food, energy, transportation and built environments offer significant co-benefits for health.

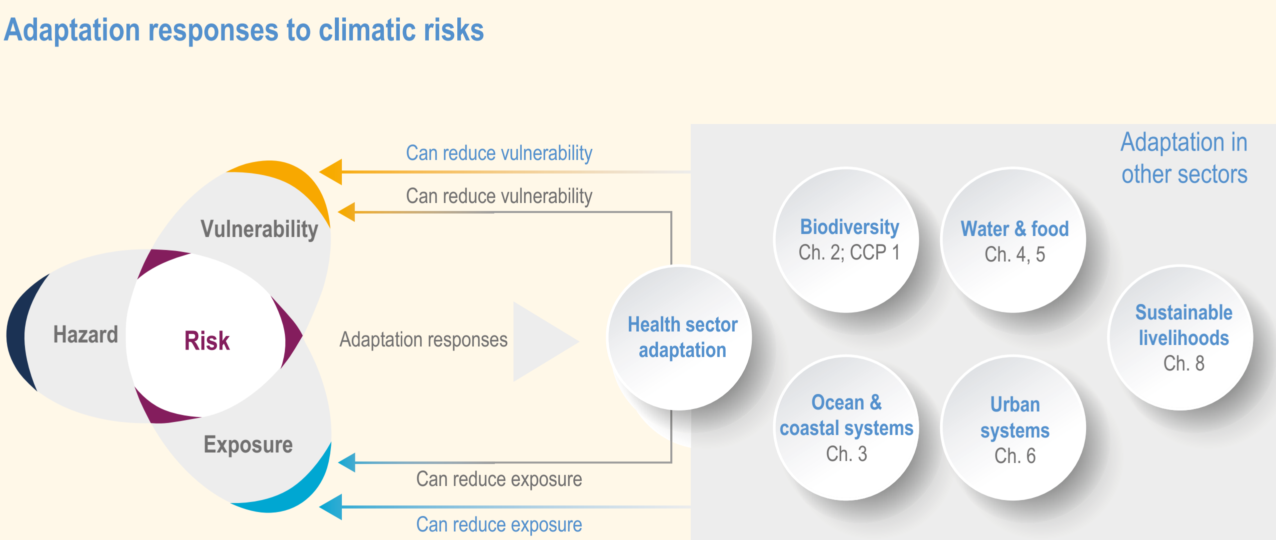

Figure FAQ7.4.1 | Solution space for adaptation to climate change in health and other sectors.

Frequently Asked Questions

FAQ 7.5 | What are some specific examples of actions taken in other sectors that reduce climate change risks in the health sector?

Many actions taken in other sectors to address the risks of climate change can lead to benefits for health and well-being. Adaptive urban design that provides greater access to green and natural spaces simultaneously enhances biodiversity, improves air quality and moderates the hydrological cycle; it also helps reduce health risks associated with heat stress and respiratory illnesses, and mitigates mental health challenges associated with congested urban living. Transitioning away from internal-combustion vehicles and fossil fuel-powered generating stations to renewable energy mitigates greenhouse gas emissions, improves air quality and lowers the risks of respiratory illnesses. Policies and designs that facilitate active urban transport (walking and bicycling) increase efficiency in that sector, reduce emissions, improve air quality and generate physical and mental health benefits for residents. Improved building and urban design that foster energy efficiency improve indoor air quality and reduce risks of heat stress and respiratory illness. Food systems that emphasise healthy, plant-centred diets reduce emissions in the agricultural sector while helping in the fight against malnutrition.

Frequently Asked Questions

FAQ 8.1 | Why are people who are poor and disadvantaged especially vulnerable to climate change and why do climate change impacts worsen inequality?

Poor people and their livelihoods are especially vulnerable to climate change because they usually have fewer assets and less access to funding, technologies and political influence. Combined, these constraints mean they have fewer resources to adapt to climate change impacts. Climate change impacts tend to worsen inequalities because they disproportionately affect disadvantaged groups. This in turn further increases their vulnerability to climate change impacts and reduces their ability to cope and recover.

Climate change and related hazards (e.g., droughts, floods, heat stress, etc.) affect many aspects of people's lives—such as their health, access to food and housing, or their source of income such as crops or fish stocks—and many will have to adapt their way of life in order to deal with these impacts. People who are poor and have few resources with which to adapt are thus much more seriously negatively affected by climate-related hazards. 'Vulnerability' is when a person or community is not able to cope and adapt to climate-related hazards. For example, if someone who is very rich has their house washed away in a flood, this is terrible, but they often have more resources to rebuild, have insurances that support recovery and maybe even build a house that is not in a flood-prone area. Whereas for someone who is very poor and who does not live in a state that provides support, the loss of their house in a flood could mean homelessness. This example shows that the same climate hazard (flood) can have a very different impact on people depending on their vulnerability (their capacity to cope and adapt to hazards).

It is not just poverty that can make people more vulnerable to climate change and climate-related hazards. Disadvantage due to discrimination, gender and income inequalities and lack of access to resources (e.g., those with disabilities or of minority groups) can mean these groups have fewer resources with which to prepare and react to climate change and to cope with and recover from its adverse effects. They are therefore more vulnerable. This vulnerability can then increase due to climate change impacts in a vicious cycle unless adaptation measures are supported and made possible.

Frequently Asked Questions

FAQ 8.2 | Which world regions are highly vulnerable and how many people live there?

A mix of multiple development challenges, such as poverty, hunger, conflict and environmental degradation, make countries and whole regions vulnerable to climate change. Many of the people in the most vulnerable situations and in the most vulnerable regions are also highly exposed to climate hazards, such as droughts, floods or sea level rise at present and will become increasingly so in the future. Studies estimate that around 3.3 to 3.6 billion people are living in regions classified as highly vulnerable to climate change impacts, which is significantly higher than the number of people who reside in regions classified as least vulnerable. The most vulnerable regions include East, Central and West Africa, South Asia, Micronesia and Melanesia, and Central America.

When a country or region is considered 'vulnerable' to climate change this means that climate hazards (e.g., drought, flood, heatwaves) have a very negative impact because there is a high number of people in these areas that lack the ability or opportunity to cope and adapt to such events, due to, for example, high average poverty, inequality and lack of institutional support. This vulnerability could be due to many different development challenges that all come together and influence each other, such as poverty, lack of access to basic infrastructure services, high numbers of uprooted people, state fragility, low or below average life expectancy and biodiversity degradation. These structural social issues often affect regions for many decades and make it difficult for the state and for individuals to respond to climate change and climate-related hazards.

For example, if a region is already characterised by poverty and struggling to feed its population and provide adequate access to basic infrastructure services, such as water and sanitation, this makes them vulnerable. If this region is then faced with an increased number of extremely dry years, this exposes them to drought and will make things even harder causing more hunger, poverty and worsened health—these are climate impacts.

Most vulnerable regions are in Africa, as well as in South Asia, the Pacific and the Caribbean. In these regions, there are often multiple neighbouring countries that all are highly vulnerable, for example in Central and West Africa. These regional clusters require special attention.

There are also highly vulnerable groups and individuals within less vulnerable regions. For example, marginalised, disadvantaged and poor minorities within highly affluent cities. Programmes that aim to support adaptation to climate change need to focus on reducing the vulnerability of individuals, groups, countries and regions.

Frequently Asked Questions

FAQ 8.3 | How does and will climate change interact with other global trends (e.g., urbanisation, economic globalisation) and shocks (e.g., COVID-19) to influence livelihoods of the poor?

A range of local, regional and global economic and political processes already underway have put the livelihoods of the poor at risk. These processes include urbanisation, industrialisation, technological transformation, monetisation of rural economies, increasing reliance on wages, and inequality at national and international levels. Climate change intersects with these processes.

The world's poorest already struggle to provide for themselves and their families in their pursuit of livelihoods. Despite hard work there are many factors beyond an individual's control that can make earning a living very difficult. Climate change is one problem among many that puts stress on livelihoods. Poor and marginal groups disproportionately bear impacts of climate change, in ways that accelerate transitions from traditional livelihoods, such as rural farming, to wage jobs in urban areas. Where adaptation measures are insufficient and where the poor are excluded from decision making, these livelihood transitions can be severely destabilising.

For example, climate change may alter the frequency or intensity of hazards that threaten the viability of a community's traditional farming or fishing livelihoods. Local farmers or fishers are then forced to adapt how they farm or fish or abandon livelihood practices entirely. The latter may mean migrating to a city to find work. As many communities face the same challenge, this intersects with a global trend that is affecting billions of lives and livelihoods—urbanisation—as seen in the rapid growth of informal settlements at the peripheries of cities around the world, particularly rapidly growing mega-cities in Africa, Asia and Latin America. These developments will be accelerated by negative impacts of climate change and increase risks that larger segments of the population enter conditions of persistent poverty.

At the same time, people whose livelihoods have been upended by climate change are subject to new threats, such as the global COVID-19 pandemic, which has shone a light on the plight of the most vulnerable people. For example, the elderly, Indigenous Peoples and Communities of Colour were disproportionately severely impacted by COVID-19; also the indirect economic consequences particularly hit the poor. Hence, COVID-19 demonstrates that the livelihoods of the poorest and most marginalised are vulnerable to other global trends beyond climate change. Also, most severe impacts are expected in regions that are already characterised by high levels of systemic human vulnerability.

Frequently Asked Questions

FAQ 8.4 | What can be done to help reduce the risks from climate change, especially for the poor?

Public and private investment in different types of assets can help reduce risks from climate change. Exactly which assets require investment depends on the specific situation. However, the provision of access to basic services, such as water and sanitation, education and health care as well as the importance of reducing inequity is shown within the assessment for many regions. The poor have fewer resources to invest, so in poorer countries greater public investment is needed. Legal, social, political, institution and economic interventions can alter human behaviour, though care must be taken that these do not amplify existing inequalities, create new inequalities or reduce future adaptation options.

Adaptation can help to reduce risks for the poor and requires both public and private investment in various natural assets (e.g., mangroves, farmland, wetlands), human assets (e.g., health, skills, Indigenous knowledge), physical assets (e.g., mobile phone connectivity, housing, electricity, technology), financial assets (e.g., savings, credit) and social assets (e.g., social networks, membership of organisations such as farmer cooperatives). Often, the poor have the least to invest, so poverty can reduce adaptation options. Sometimes people migrate as a reaction to floods or droughts, though the poorest groups often lack the resources to move. Exactly what needs investing in to reduce risks varies according to the scale and livelihood system in need of adaptation. In general, risks can be reduced through a range of different technological and engineering approaches (for example, building sea defences to reduce storm surge impacts), as well as ecosystem-based approaches (such as replanting mangroves, altering the types of crops grown, changing the timing of farming activities, or using climate-smart agriculture or agroforestry approaches).

At the same time, legal, social, political, institutional and economic solutions can alter human behaviour (e.g., through enforcement of building codes to prevent construction on low-lying land prone to flooding, timely provision of weather information and early warning systems, knowledge-sharing activities, including adaptation strategies grounded in Indigenous knowledge, crop insurance schemes, incentives such as payments to stop people cutting down trees or to enable them to plant them and social protection to provide a safety net in times of crisis).

The poorest groups often require greater public adaptation investments. Efforts to support adaptation need to be mindful of reinforcing existing inequalities and introducing new ones, making sure they are inclusive, culturally sensitive and that the voices of all groups of people are heard. It is also important that adaptations which reduce immediate risks for the poor do not rule out adaptation options that could help them later on or which could cause them to increase their emissions. Political will is needed to put people at the centre of climate change risk reduction efforts, including support for their livelihoods.

Frequently Asked Questions

FAQ 8.5 | How do present adaptation and future responses to climate change affect poverty and inequality?

Present adaptation can help to reduce the current and possibly future impacts of climate change. Future responses to climate change can reduce poverty and inequality, and even help transition toward climate-resilient livelihoods and climate resilient development. Pro-poor adaptation planning is necessary to ensure future risks for the poor are being accounted for and the inequality underlying the poverty is being addressed.

There are many ways in which poverty and inequality are influenced by climate change. The livelihood sources of the poor are likely to be affected and cumulative effects of losses and damages, and may influence future poverty. There are cases when present adaptation worsens future poverty and exacerbates inequality—this is called maladaptation. The risks of maladaptation are greater in societies characterised by high inequality, and in many cases the poor and most vulnerable groups are the ones most adversely affected.

Effective decision making in adaptation should be informed by past, present and future climate data, information and scenarios to cater for reliable plans and actions for climate-resilient livelihoods. Adaptation lessons from the past play an important role in decision making regarding responses to climate change. There is an emerging debate on the role of learning, particularly forward-looking (anticipatory) learning, as a key element or important aspect for adaptation and resilience in the context of climate change. Memory, monitoring of key drivers of change, scenario planning and measuring anticipatory capacity are seen as crucial ingredients for future adaptation and resilience pathways, and, hence overcoming maladaptation. Moreover, climate resilient development calls for ensuring synergies between adaptation, mitigation and development are maximised, while trade-offs, especially those affecting the poor, are minimised.

Frequently Asked Questions

FAQ 9.1 | Which climate hazards impact African livelihoods, economies, health and well-being the most?

Climate extremes, particularly extreme heat, drought and heavy rainfall events, impact the livelihoods, health, and well-being of millions of Africans. They will also continue to impact African economies, limiting adaptation capacity. Interventions based on resilient infrastructure and technologies can achieve numerous developmental and adaptation co-benefits.

Multi-year droughts have become more frequent in west Africa, and the 2015–2017 Cape Town drought was three times more likely due to human-caused climate change. Above 2°C global warming, drought frequency is projected to increase, and duration will double from approximately 2 to 4 months over north Africa, the western Sahel and southern Africa. Estimates of increased exposure to water stress are higher than those for decreases. By 2050, climate change could expose an additional 951 million people in sub-Saharan Africa to water stress while also reducing exposure to water stress by 459 million people. Compared to population in 2000, human displacement due to river flooding in sub-Saharan Africa is projected to triple for a scenario of low population growth and 1.6°C global warming. Changing rainfall distributions together with warming temperatures will alter the distributions of disease vectors like mosquitoes and midges. Malaria vector hotspots and prevalence are projected to increase in east and southern Africa and the Sahel under even moderate greenhouse gas emissions scenarios by the 2030s, exposing an additional 50.6–62.1 million people to malaria risk.

Increases in the number of hot days and nights, as well as in heatwave intensity and duration, have had negative impacts on agriculture, human health, water availability, energy demand and livelihoods. By some estimates, African countries' Gross Domestic Product per capita is on average 13.6% lower since 1991 than if human-caused global warming had not occurred. In the future, high temperatures combined with high humidity exceed the threshold for human and livestock tolerance over larger parts of Africa and with greater frequency. Increased average temperatures and lower rainfall will further reduce economic output and growth in Africa, with larger negative impacts than on other regions of the world.

Resilient infrastructure and technologies are required to cope with the increasing climate variability and change (Figure FAQ9.1.1). These include improving housing to limit heat and exposure, along with improving water and sanitation infrastructure. Such interventions to ensure that the most vulnerable are properly protected from climate change have many co-benefits, including for pandemic recovery and prevention.

Box FAQ 9.1 (continued)

A schematic illustration of the interconnectedness of different sectors and impacts

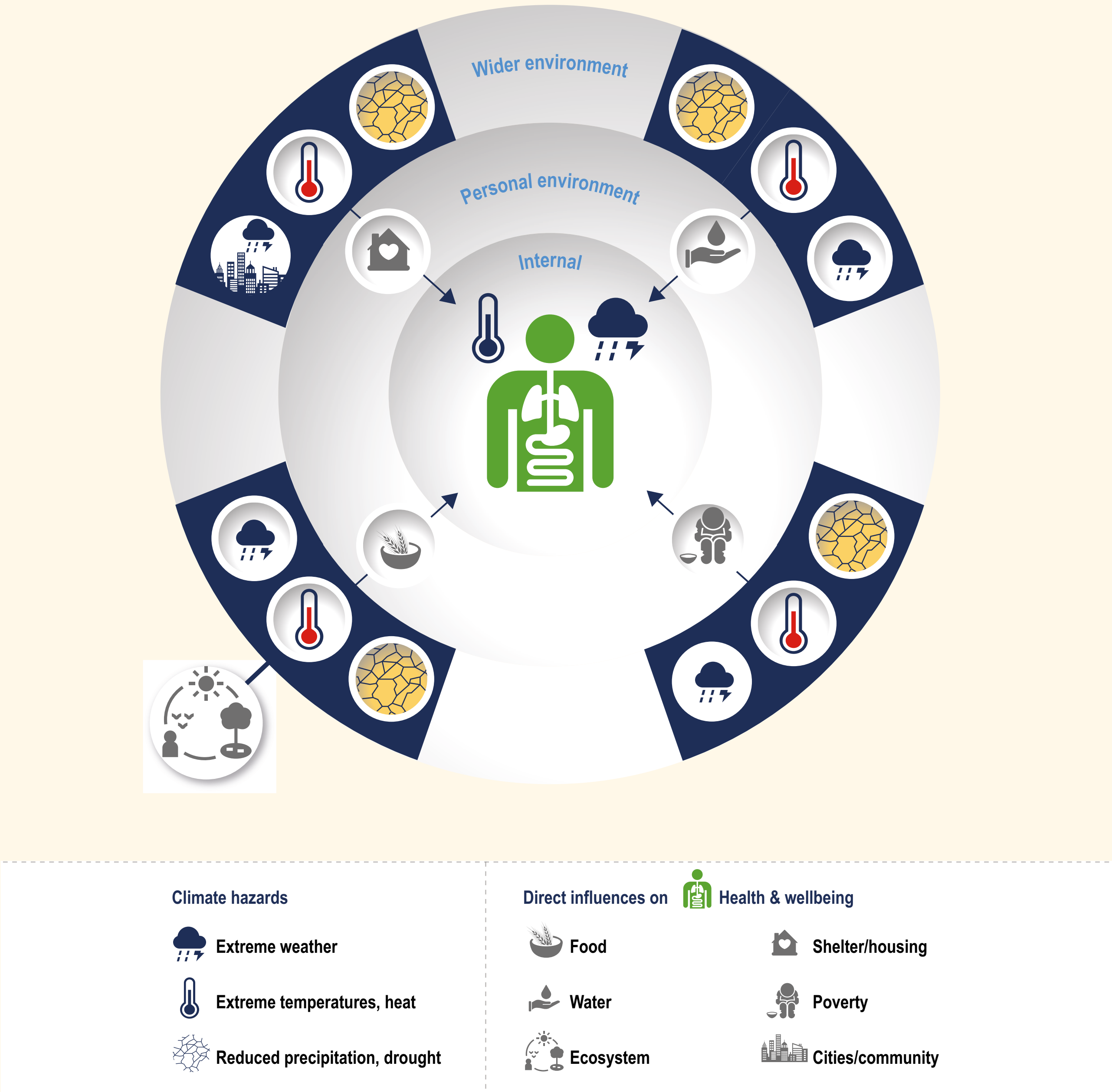

Figure FAQ9.1.1 | A schematic illustration of the interconnectedness of different sectors and impacts that spillover to affect the health and well-being of African people.

FAQ

Frequently Asked Questions

FAQ 9.2 | What are the limits and benefits of climate change adaptation in Africa?

The capacity for African ecosystems to adapt to changing environmental conditions is limited by a range of factors, from heat tolerance to land availability. Adaptation across human settlements and food systems are further constrained by insufficient planning and affordability. Integrated development planning and increasing finance flows can improve African climate change adaptation.

With increasing warming, there is a lower likelihood species can migrate rapidly enough to track shifting climates, increasing extinction risk across more of Africa. At 2°C global warming more than 10% of African species are at risk of extinction. Species ability to disperse between areas to track shifting climates is limited by fencing, transport infrastructure, and the transformation of landscapes to agriculture and urban areas. Many species will lose large portions of their suitable habitats due to increases in temperature by 2100. Coupled with projected losses of Africa's protected areas, higher temperatures will also reduce carbon sinks and other ecosystem services. Many nature-based adaptation measures (e.g., for coral reefs, mangroves, marshes) are less effective or no longer effective above 1.5°C of global warming. Human-based adaptation strategies for ecosystems reach their limits as availability and affordability of land decreases, resulting in migration, displacement and relocation.

The limits to adaptation for human settlements arise largely from developmental challenges associated with Africa's rapid urbanisation, poor development planning, and increasing numbers of urban poor residing in informal settlements. Further limits arise from insufficient consideration of climate change in adaptation planning and infrastructure investment and insufficient financial resources. There are also limits to adaptation for food production strategies. Increasing climate extreme events—droughts and floods—impose specific adaptation responses which poorer households cannot afford. For instance, the use of early maturing or drought-tolerant crop varieties may increase resilience, but adoption by smallholder farmers is hindered by the unavailability or unaffordability of seed.

Adaptation in Africa can reduce risks at current levels of global warming. However, there is very limited evidence for the effectiveness of current adaptation at increased global warming levels. Ambitious, near-term mitigation would yield the largest single contribution to successful adaptation in Africa.

Current adaptation finance flows are billions of USD less than the needs of African countries and around half of finance commitments to Africa reported by developed countries remain undisbursed. Increasing adaptation finance flows by billions of dollars (including public and private sources), removing barriers to accessing finance and providing targeted country support can improve climate change adaptation across Africa.

Frequently Asked Questions

FAQ 9.3 | How can African countries secure enough food in changing climate conditions for their growing populations?

Climate change is already impacting African food systems and will worsen food insecurity in sub-Saharan Africa in the future. An integrated approach to adaptation planning can serve as a flexible and cost-effective solution for addressing African food security challenges.

Maize and wheat yields have decreased an average of 5.8% and 2.3%, respectively, in sub-Saharan Africa due to climate change. Among the 135 million acutely food-insecure people in crisis globally, more than half (73 million) are in Africa. This is partly due to the growing severity of drought with increasing temperatures also a severe risk factor. Adding to these challenges, Africa has the fastest-growing population in the world that is projected to grow to around 40% of the world's population by 2100.

Sustainable agricultural development combined with enabling institutional conditions, such as supportive governance systems and policy, can provide farmers with greater yield stability in uncertain climate conditions. It is also widely acknowledged that an integrated approach for adaptation planning that combines (a) climate information services, (b) capacity building, (c) Indigenous and local knowledge systems and (d) strategic financial investment can serve as a flexible and cost-effective solution for addressing African food security challenges.

Frequently Asked Questions

FAQ 9.4 | How can African local knowledge serve climate adaptation planning more effectively?

A strong relationship between scientific knowledge and local knowledge is desirable, especially in developing contexts where technology for prediction and modelling is least accessible.

In many African settings, farmers use the local knowledge gained over time—through experience and passed on orally from generation to generation—to cope with climate challenges. Indigenous Knowledge systems of weather and climate patterns include early warning systems, agroecological farming systems and observation of natural or non-natural climate indicators. For instance, biodiversity and crop diversification are used as a buffer against environmental challenges: if one crop fails, another could survive. Local knowledge of seasons, storms and wind patterns is used to guide and plan farming and other activities.

Collaborative partnerships between research, agricultural extension services and local communities would create new avenues for the co-production of knowledge in climate change adaptation to better inform adaptation policies and practices across Africa.

Frequently Asked Questions

FAQ 10.1 | What are the current and projected key risks related to climate change in each sub-region of Asia?

Climate-change-related risks are projected to increase progressively at 1.5°C, 2°C and 3°C of global warming in many parts of Asia. Heat stress and water deficit are affecting human health and food security. Risks due to extreme rainfall and sea level rise are exacerbated in vulnerable Asia.

Climatologically, the summer surface air temperature in South, Southeast and Southwest Asia is high, and its coastal area is very humid. In these regions, heat stress is already a medium risk for humans. Large cities are warmer by more than 2°C compared with the surroundings due to heat island effects, exacerbating heat stress conditions. Future warming will cause more frequent temperature extremes and heatwaves especially in densely populated South Asian cities, where working conditions will be exacerbated and daytime outdoor work will become dangerous. For example, incidence of excess heat-related mortality in 51 cities in China is estimated to reach 37,800 deaths per year over a 20-year period in the mid-21st century (2041–2060) under the RCP8.5 scenario.

Asian glaciers are the water resources for local and adjacent regions. Glaciers are decreasing in Central, Southwest, Southeast and North Asia, but are stable or increased in some parts of the Hindu Kush Himalaya region. The glacier melt water in the southern Tibetan Plateau increased during 1998–2007, and the total amount and area of glacier lakes has increased during recent decades. In the future, maximum glacial runoff is projected in High Mountain Asia. Glacier collapses and surges, together with glacier lake outburst flood due to the expansion of glacier lakes, will threaten the securities of the local and down streaming societies.

With much of the Asian population living in drought-prone areas, water scarcity is a prevailing risk across Asia through water and food shortage leading to malnutrition. Populations vulnerable to impacts related to water are going to increase progressively at 1.5°C, 2°C and 3°C of global warming. Aggravating drought condition is projected in Central Asia. Water quality degradation also has profound impact on human health.

Extreme rainfall causes floods in vulnerable rivers. Observed changes in extreme rainfall vary considerably by region in Asia. Extreme rainfall events (such as heavy rainfall >100 mm per day) have been increasing in South and East Asia. In the future, most of East and Southeast Asia are projected to experience more intense rainfall events as soon as by the middle of the 21st century. In those regions, the flood risk will become more frequent and severe. It is estimated that over one-third of Asian cities and about 932 million urban dwellers are living in areas with high risk of flooding.

Sea level rise is continuing. Higher than the global mean sea level rise is projected on Asian coasts. Storm surge and high wave by tropical cyclones of higher intensity are high risk for a large number of Asian megacities facing the ocean: China, India, Bangladesh, Indonesia and Vietnam have the highest numbers of coastal populations exposed and thus are most vulnerable to disaster-related mortality.

Changes in terrestrial biome have been observed that are consistent with warming, such as an upward move of treeline position in mountains. Climate change, human activity, lightning and quality of forest governance and management have increased wildfire severity and area burned in North Asia in recent decades. Changes in marine primary production also have been observed: a decrease up to 20% over the past six decades in the western Indian Ocean, due to ocean warming and stratification, has restricted nutrient mixing. The risk of irreversible loss of many ecosystems will increase with global warming.

The likelihood of adverse impacts to agricultural and food security in many parts of developing Asia will progressively escalate with the changing climate. The potential of total fisheries production in South and Southeast Asia is also projected to decrease.

FAQ 10.1 (continued)

Figure FAQ10.1.1 | Key risks related to climate change in Asia.

FAQ 10.2 | What are the current and emerging adaptation options across Asia?

Mirroring the heterogeneity across Asia, different countries and communities are undertaking a range of reactive and proactive strategies to manage risk in various sectors. Several of these adaptation actions show promise, reducing vulnerability and improving societal well-being. However, challenges remain around scaling up adaptation actions in a manner that is effective and inclusive while simultaneously meeting national development goals.

Asia exhibits tremendous variation in terms of ecosystems, economic development, cultures and climate risk exposure. Mirroring this variation, households, communities and governments have a wide range of coping and adaptation strategies to deal with changing climatic conditions, with co-benefits for various non-climatic issues such as poverty, conflict and livelihood dynamics.

Currently, Asian countries have rich evidence on managing risk, drawing on long histories of dealing with change. For example, to deal with erratic rainfall and shifting monsoons, farmers make incremental shifts such as changing what and when they grow or adjusting their irrigation practices. Communities living in coastal settlements are using Early warning systems to prepare for cyclones or raising the height of their houses to minimise flood impacts. These types of strategies, seen across all Asian sub-regions, based on local social and ecological contexts, are termed *autonomous adaptations* that occur incrementally and help people manage current impacts.

Currently and in the future, Asia is identified as one of regions most vulnerable to climate change, especially on extreme heat, flooding, sea level rise and erratic rainfall. All these climatic risks, when overlaid on existing development deficits, show us that incremental adaptation will not be enough; transformational change is required. Recognising this, at subnational and national levels, government and non-governmental actors are also prioritising *planned adaptation strategies* which include interventions like 'climate-smart agriculture' as seen in South and Southeast Asian countries, or changing labour laws to reduce exposure to heat as seen in West Asia. These are often sectoral priorities governments lay out through national or subnational policies and projects, drawing on various sources of funding: domestic, bilateral and international. Apart from these planned adaptation strategies in social systems, Asian countries also report and invest in adaptation measures in natural systems such as expanding nature reserves to enable species conservation or setting up habitat corridors to facilitate landscape connectivity and species movements across climatic gradients.

Overall, the fundamental challenges that Asia will see exacerbated under climate change are around water and food insecurity, poverty and inequality, and increased frequency and severity of extreme events. In some places and for some people, climate change, even at 1.5°C and more so at 2°C, will significantly constrain the functioning and well-being of human and ecological systems. Asian cities, villages and countries are rising to this current and projected challenge, albeit somewhat unevenly.

Some examples of innovative adaptation actions are China's 'Sponge Cities' which are trying to protect ecosystems while reducing risk for people, now and in the future. Another example is India's Heat Action Plans that are using 'cool roofs' technologies and awareness-building campaigns to reduce the impacts of extreme heat. Across South and Southeast Asia, climate-smart agriculture programmes are reducing GHG emissions associated with farming while helping farmers adapt to changing risks. Each country is experimenting with infrastructural, nature-based, technological, institutional and behavioural strategies to adapt to current and future climate change with local contexts shaping both the possibility of undertaking such actions as well as the effectiveness of these actions to reduce risk. What works for ageing cities in Japan exposed to heatwaves and floods may not work for pastoral communities in the highlands of Central Asia, but there is progress on understanding what actions work and for whom. The challenge is to scale current adaptation action, especially in the most exposed areas and for the most vulnerable populations, as well as move beyond adapting to single risks alone (i.e., adapt to multiple coinciding risks such as flooding and water scarcity in coastal cities across South Asia or extreme heat and flash floods in West Asia). In this context, funding and implementing adaptation is essential, and while Asian countries are experimenting with a range of autonomous and planned adaptation actions to deal with these multiple and often concurrent challenges, making current development pathways climate resilient is necessary and, some might argue, unavoidable.

FAQ 10.2 (continued)

Table FAQ10.2.1 | System transitions, sectors and illustrative adaptation options

System transitions	Sectors	Illustrative adaptation options
Energy and industrial systems	Energy and industries	Diversifying energy sources Improving energy access, especially in rural areas Improving resilience of power infrastructure Rehabilitation and upgrading of old buildings
Land and ecosystems	Terrestrial and freshwater ecosystems	Expanding nature reserves Assisted species migration Introducing species to new regions to protect them from climate-induced extinction risk Sustainable forest management including afforestation, forest fuel management, fire management
	Ocean and coastal ecosystems	Marine protected areas Mangrove and coral reef restoration Integrated coastal zone management Sand banks and structural technologies
	Freshwater	Integrated watershed management Transboundary water management Changing water access and use practices to reduce/manage water demand High-efficiency water-saving technology Aquifer storage and recovery
	Agriculture, fisheries and food	Changing crop type and variety, improving seed quality Water storage, irrigation and water management Climate-smart agriculture Early warning systems and use of climate information services Fisheries management plans (e.g., seasonal closures, limited fishing licenses, livelihood diversification)
Urban systems	Cities and settlements	Flood protection measures and sea walls sustainable land-use planning and regulation Protecting urban green spaces, improving permeability, mangrove restoration in coastal cities Planned relocation and migration Disaster management and contingency planning
	Key infrastructures	Climate-resilient highways and power infrastructure Relocating key infrastructure
Health systems		Reducing air pollution Changing dietary patterns

Frequently Asked Questions

FAQ 10.3 | How are Indigenous knowledge and local knowledge being incorporated in the design and implementation of adaptation projects and policies in Asia?

Indigenous People, comprising about 6% of the global population, play a crucial role in managing climate change for two important reasons. First, they have a physical and spiritual connection with land, water and associated ecosystems, thus making them most vulnerable to any environmental and climatic changes. Second, their ecological and local knowledge are relevant to finding solutions to climate change.

Indigenous knowledge and local knowledge (IKLK) play an important role in the formulation of adaptation governance and related strategies (IPCC 2007), and best quality, locality-specific knowledge can help address the serious lack of education on climate change and uncertainties surrounding quality, salience, credibility and the legitimacy of the available knowledge base.

Key findings across Asia underline the importance of building, sustaining and augmenting local capacity through addressing inadequacies in terms of resource base, climate-change awareness, government–community partnerships and vulnerability assessment. Furthermore, inclusion of Indigenous knowledge and local knowledge as well as related practices will improve adaptation planning and decision-making processes concerning climate change.

In climate-sensitive livelihoods, an integrated approach informed by science that examines multiple stressors, along with Indigenous knowledge and local knowledge, appears to be of immense value. For instance, in building farmers' resilience, enhancing climate-change adaptation, ensuring cross-cultural communication and promoting local skills, Indigenous People's intuitive thinking processes and geographic knowledge of remote areas are very important.

There is also a widespread recognition that Indigenous knowledge and local knowledge are important in ensuring successful ecosystem-based adaptation (EbA). However, this recognition requires more practical application and translation into IKLK-driven EbA projects. For instance, in the Coral Triangle region, creating historical timelines and mapping seasonal calendars can help to capture Indigenous knowledge and local knowledge while also feeding this information into climate science and climate adaptation planning. Identifying indigenous crop species for agriculture by using Indigenous knowledge and local knowledge is already identified as an important way to localise climate adaptation: an example is Bali's vital contribution of moral economies to food systems which have long built resilience among groups of communities in terms of food security and sovereignty, even with the challenges faced due to modernising of local food systems.

Many of the pressing problems of Asia, including water scarcity, rapid urbanisation, deforestation, loss of species, rising coastal hazards and agricultural loss can be effectively negated, or at least minimised, through proper adoption of suitable science and technological methods. Climate-change adaptation is greatly facilitated by science, technology and innovation. This ranges from application of existing science, new development on scientific tools and methods, application of Indigenous knowledge and local knowledge and citizen sciences. Deploying Knowledge Quality Assessment Tool found significant co-relation between science-based and IKLK framing would help to address, acknowledge and utilise by an integrated approach the wisdom of Indigenous knowledge and local knowledge, a valuable asset for climate adaptation governance. The IKLK-based environmental indicators need to be seen as part of a separate system of knowledge that coexists with, but is not submerged into, another conventional knowledge system.

In the context of education and capacity development of climate change, an integrated approach of embracing both the importance of climate science and IKLK is acknowledged. The Indigenous knowledge and local knowledge is increasingly recognised as a powerful tool for compiling evidence of climate change over time. Such as knowledge of climate-change adaptation and disaster risk reduction provide a range of complementary approaches in building resilience and reducing the vulnerability of natural and human systems. Developing knowledge and utilising existing Indigenous knowledge and local knowledge, skills and dispositions to better cope with already evident and looming climate impacts. Engaging communities in the process of documenting and understanding long-term trends and practices will enable both Indigenous knowledge and local knowledge as well as Western scientific assessments of climate change to contribute in designing appropriate climate adaptation measures.

FAQ 10.4 | How can Asia meet multiple goals of climate-change adaptation and sustainable development within the coming decades?

Asian countries are testing ways to develop in a climate-resilient manner to meet the goals related to climate change and sustainable development simultaneously. Some promising examples exist, but the window of opportunity to put some of these plans in place is small and closing fast, highlighting the need for urgent action across and within countries.

In order to achieve the multiple goals of climate-change adaptation, mitigation and sustainable development, critical are rapid, system transitions across (a) energy systems, (b) land and ecosystems and (c) urban and infrastructural systems. This is especially important across Asia, which has the largest population exposed to current climate risks and high sub-regional diversity, and where risks are expected to rise significantly and unevenly under higher levels of global warming. However, such transformational change is deeply challenging because of variable national development imperatives; differing capacities and requirements of large, highly unequal and vulnerable populations; and socioeconomic and ecological diversity that requires very contextual solutions. Furthermore, issues such as growing transboundary risks, inadequate data for long-term adaptation planning, finance barriers, uneven institutional capacity and non-climatic issues, such as increasing conflict, political instability and polarization, constrain rapid, transformational action across systems.

Despite these challenges, there are increasing examples of actions across Asia that are meeting climate adaptation goals and Sustainable Development Goals (SDGs) simultaneously, such as through climate-smart agriculture, disaster risk management and nature-based solutions. To enable these system transitions, vertical and horizontal policy linkages, active communication and cooperation between multiple stakeholders, and attention to the root causes of vulnerability are essential. Furthermore, rapid systemic transformation can be enabled by policies and finances to incentivise capacity building, new technological innovation and diffusion. The effectiveness of such technology-centred approaches can be maximised by combining them with attention to behavioural shifts such as by improving education and awareness, building local capacities and institutions, and leveraging Indigenous knowledge and local knowledge.

Obviously, time is of the essence. If system transitions are delayed, there is *high confidence* that climatic risks will increase human and natural system vulnerability, as well as increase inequality and erode the achievements of multiple SDGs. Thus, urgent systemic change that is suited to national and subnational social–ecological contexts

FAQ 10.4 (continued)

across Asia is imperative.

Adaptatation option	Mitigation impacts	Implications on SDGs: Positive	Implications on SDGs: Negative
Wetland protection, restoration	Medium synergy (carbon sequestration through mangroves)	8 DECENT WORK AND ECONOMIC GROWTH; 14 LIFE BELOW WATER; 15 LIFE ON LAND	
Solar drip irrigitation	High synergy (shift to cleaner energy)	2 ZERO HUNGER; 7 AFFORDABLE AND CLEAN ENERGY; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION	10 REDUCED INEQUALITIES
Climate-smart agriculture	High synergy (no till practices and improved residue management can reduce soil carbon emissions)	2 ZERO HUNGER; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION	
Integrated smart water grids	High synergy (reduced energy needs for supplying water)	6 CLEAN WATER AND SANITATION; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 11 SUSTAINABLE CITIES AND COMMUNITIES	
Disaster risk management (including early warning systems)	Not applicable	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 11 SUSTAINABLE CITIES AND COMMUNITIES	5 GENDER EQUALITY; 10 REDUCED INEQUALITIES
Aquifer storage and recovery	Low synergy	6 CLEAN WATER AND SANITATION; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION	
Nature-based solutions in urban areas: green infrstructure	High synergy (blue-green infrastructure act as carbon sinks)	3 GOOD HEALTH AND WELL-BEING; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 11 SUSTAINABLE CITIES AND COMMUNITIES	
Coastal green infrastructure	High synergy	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE; 11 SUSTAINABLE CITIES AND COMMUNITIES; 14 LIFE BELOW WATER; 15 LIFE ON LAND	

Figure FAQ10.4.1 | Adaptation options, mitigation impacts and implications on Sustainable Development Goals.

Frequently Asked Questions

FAQ 11.1 | How is climate change affecting Australia and New Zealand?

Climate change is affecting Australia and New Zealand in profound ways. Some natural systems of cultural, environmental, social and economic significance are at risk of irreversible change. The socioeconomic costs of climate change are substantial, with impacts that cascade and compound across sectors and regions, as demonstrated by heatwaves, wildfire, cyclone, drought and flood events.

Temperature has increased by 1.4°C in Australia and 1.1°C in New Zealand over the last 110 years, with more extreme hot days. The oceans in the region have warmed significantly, resulting in longer and more frequent marine heatwaves. Sea levels have risen and the oceans have become more acidic. Snow depths have declined and glaciers have receded. Northwestern Australia and most of southern New Zealand have become wetter, while southern Australia and most of northern New Zealand have become drier. The frequency, severity and duration of extreme wildfire weather conditions have increased in southern and eastern Australia and northeastern New Zealand.

The impacts of climate change on marine, terrestrial and freshwater ecosystems and species are evident. The mass mortality of corals throughout the Great Barrier Reef during marine heatwaves in 2016–2020 is a striking example. Climate change has contributed to the unprecedented south-eastern Australia wildfires in the spring and summer of 2019–2020, loss of alpine habitats in Australia, extensive loss of kelp forests, shifts further south in the distribution of almost 200 marine species, decline and extinction in some vertebrate species in the Australian wet tropics, expansion of invasive plants, animals and pathogens in New Zealand, erosion and flooding of coastal habitats in New Zealand, river flow decline in southern Australia, increased stress in rural communities, insurance losses for floods in New Zealand, increase in heatwave mortalities in Australian capital cities and fish deaths in the Murray-Darling River in the summer of 2018–2019.

Frequently Asked Questions

FAQ 11.2 | What systems in Australia and New Zealand are most at risk from ongoing climate change?

The nine key risks to human systems and ecosystems in Australia and New Zealand from ongoing climate change are shown in Figure FAQ 11.2.1. Some risks, especially on ecosystems, are now difficult to avoid. Other risks can be reduced by adaptation if global mitigation is effective.

Risk is the combination of hazard, exposure and vulnerability. For a given hazard (e.g., fire), the risk will be greater in areas with high exposure (e.g., many houses) and/or high vulnerability (e.g., remote communities with limited escape routes). The severity and type of climate risk varies geographically (Figure FAQ11.2.1). Everyone will be affected by climate change, with disadvantaged and remote people and communities the most vulnerable.

The risks to natural and human systems are often compounded by impacts across multiple spatial and temporal scales. For example, fires damage property, farms, forests and nature with short- and long-term effects on biodiversity, natural resources, human health, communities and the economy. Major impacts across multiple sectors can disrupt supply chains to industries and communities and constrain delivery of health, energy, water and food services. These impacts create challenges for the adaptation and governance of climate risks. When combined, they have far-reaching socioeconomic and environmental impacts.

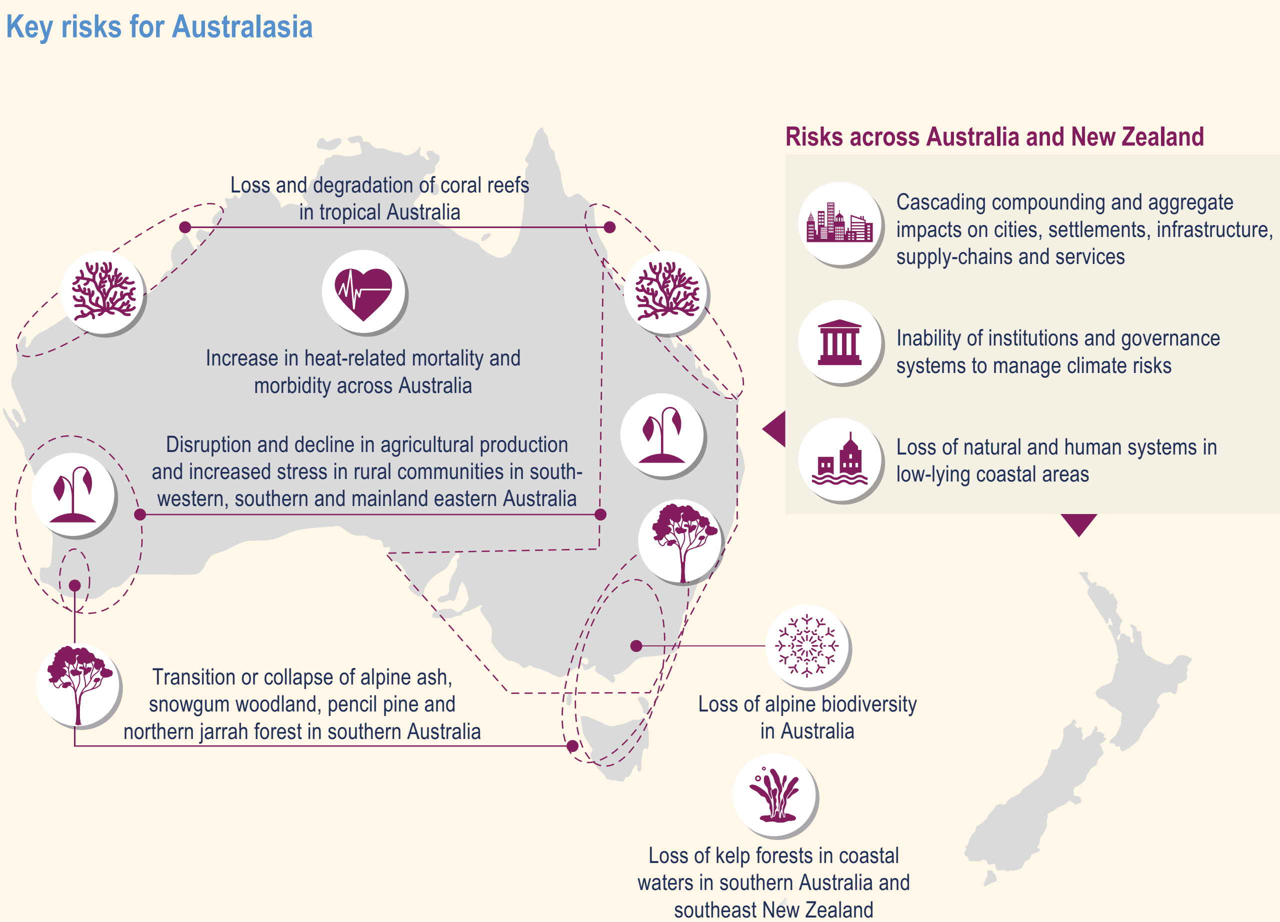

Figure FAQ11.2.1 | Key risks from climate change

Frequently Asked Questions

FAQ 11.3 | How can Indigenous Peoples' knowledge and practice help us understand contemporary climate impacts and inform adaptation in Australia and New Zealand?

In Australia and New Zealand, as with many places around the world, Indigenous Peoples with connections to their traditional country and extensive histories hold deep knowledge from observing and living in a changing climate. This provides insights that inform adaptation to climate change.

Indigenous Australians—Aboriginal and Torres Strait Islanders—maintain knowledge regarding previous sea level rise, climate patterns and shifts in seasonal change associated with the flowering of trees and emergence of food sources, developed over thousands of generations of observation of their traditional country. Knowledge of localised contemporary adaptation is also held by many Indigenous Australians with connections to traditional lands. With assured free and prior informed consent, this provides a means for Indigenous-guided land management, including for fire management and carbon abatement, fauna studies, medicinal plant products, threatened species recovery, water management and weed management.

Tangata Whenua Māori in New Zealand are grounded in Mātauranga Māori knowledge, which is based on human–nature relationships and ecological integrity and incorporates practices used to detect and anticipate changes taking place in the environment. Social-cultural networks and conventions that promote collective action and mutual support are central features of many Māori communities and these customary approaches are critical to responding to, and recovering from, adverse environmental conditions. Intergenerational approaches to planning for the future are also intrinsic to Māori social-cultural organisation and are expected to become increasingly important, elevating political discussions about conceptions of rationality, diversity and the rights of non-human entities in climate change policy and adaptation.

Frequently Asked Questions

FAQ 11.4 | How can Australia and New Zealand adapt to climate change?

There is already work under way by governments, businesses, communities and Indigenous Peoples to help us adapt to climate change. However, much more adaptation is needed in light of the ongoing and intensifying climate risks. This includes coordinated laws, plans, guidance and funding that enable society to adapt and the information, education and training that can support it. Everyone has a part to play working together.

We currently mainly react to climate events such as wildfires, heatwaves, floods and droughts and generally rebuild in the same places. However, climate change is making these events more frequent and intense, and ongoing sea level rise and changes in natural ecosystems are advancing. Better coordination and collaboration between government agencies, communities, Aboriginal and Torres Strait Islanders and Tangata Whenua Indigenous Peoples, not-for-profit organisations and businesses will help prepare for these climate impacts more proactively, in combination with future climate risks integrated into their decisions and planning. This will reduce the impacts we experience now and the risks that will affect future generations.

Some of the risks for natural systems are close to critical thresholds and adaptation may be unable to prevent ecosystem collapse. Other risks will be severe, but we can reduce their impact by acting now, for example coastal flooding from sea level rise, heat-related mortality and managing water stresses. Many of the risks have the potential to cascade across social and economic sectors with widespread societal impacts. In such cases, really significant system-wide changes will be needed in the way we currently live and govern. To facilitate such changes, new governance frameworks, nationally consistent and accessible information, collaborative engagement and partnerships with all sectors, communities and Indigenous Peoples and the resources to address the risks are needed (Figure FAQ11.4.1).

However, our ability to adapt to climate change impacts also rests on every region in the world playing its part in reducing greenhouse gas emissions. If mitigation is ineffective, global warming will be rapid and adaptation costs will increase, with worsening losses and damages.

Box FAQ 11.4 (continued)

Adaptation pathways for Australia and New Zealand

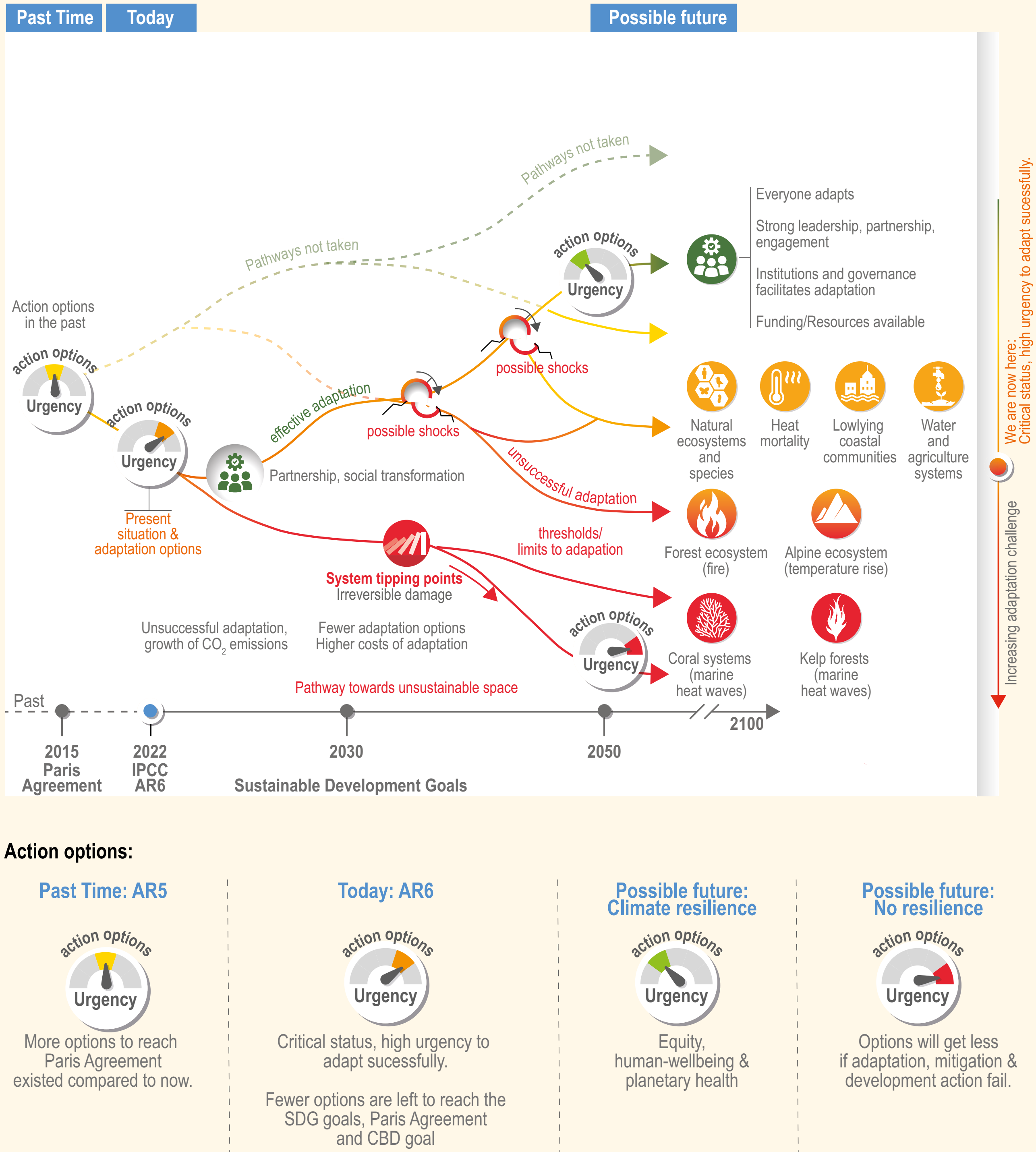

Figure FAQ11.4.1 | Developing adaptation plans in the solutions space showing system tipping points, thresholds and limits to adaptation, unsustainable pathways, critical systems and enablers to climate resilient development

FAQ

Frequently Asked Questions

FAQ 12.1 | How are inequality and poverty limiting options to adapt to climate change in Central and South America?

Poverty and inequality decrease human capacity to adapt to climate change. Limited access to resources may reduce the ability of individuals, households and societies to adapt to the impacts of climate change and variability because of the narrow response portfolio. Inequality limits responses available to vulnerable segments as most adaptation options are resource-dependent.

Though poverty in Central and South America has decreased over the last 12 years, inequality remains as a historic and structural characteristic of the region. In 2018, 29.5% of Latin America's population (including Mexico) were poor (182 million) and 10.2% were extremely poor (63 million), more than half of them living in urban areas. In 2020, due to COVID crisis Gini coefficient projection of increases is ranging from 1.1% to 7.8%, poverty increased to 33.7% (209 millions) and extreme poverty to 12.5% (78 millions).

Poor populations have little or no access to good-quality education, information, health systems and financial services. They have fewer chances to access resources, such as land and water, good-quality housing, risk-reducing infrastructure, and services, such as running water, sanitation and drainage. Their lack of political clout and endowments limits their access to assets for withstanding and recovering from shocks and stresses. Poverty, inequality and high vulnerability to the impacts of climate change are interrelated processes. Poor populations are highly vulnerable to the impacts of climate change and are usually located in areas of high exposure to extreme events. The constant loss of assets and livelihoods in both urban and rural areas drives communities into chronic poverty traps, exacerbating local poverty cycles and creating new ones.

For instance, climate-related reduced yields in crops, fisheries and aquaculture have a substantial impact on the livelihoods and food security of families and affect their options for coping with and adapting to climate change and variability. The impact of climate change in agriculture for Central and South America depends on determinants such as the availability of natural resources, access to markets, diversity of inputs and production methods, quality and coverage of infrastructure and socioeconomic characteristics of the population. Impacts from climate change on small-scale farmers compromise the livelihoods and food security of rural areas and, consequently, the food supply for urban areas.

Governments in the region have implemented several poverty-reduction programmes. However, policies of income redistribution and poverty alleviation do not necessarily improve climate risk management, so complementary policies integrating both social and material conditions are required. A study in northern Brazil showed that risk management strategies for droughts and food insecurity did not change poverty rates between 1997–1998 and 2011–2012. Major shocks, such as climate and extreme weather events (e.g., floods, heavy rains, droughts, frost), reduce and destroy public and private property. For instance, the ENSO event of 2017 in Peru caused losses estimated between USD 6 and 9 billion, affected more than a million inhabitants and generated 370,000 new poor. In total, losses by unemployment, deaths, destruction and damage to infrastructure and houses were around 1.3% of the Gross Domestic Product of Peru.

Low government spending on social infrastructure (e.g., health, education), ethnic discrimination and social exclusion reduce healthcare access, leaving poor people in entire regions mostly undiagnosed or untreated. In a context of privatisation policies of healthcare systems, research shows that marginal people lack identifying documents needed to access public services in Buenos Aires (Argentina), Mexico City (Mexico) and Santiago de Chile (Chile), some of the most developed cities in the region. The consequences of this situation are underreporting, low diagnosis and low treatment of diseases such as vector-borne diseases such as dengue and risk of diarrhoeal diseases originating from frequent flooding in Amazonian riverine communities. Bias in reporting on access to healthcare and the incidence of diseases in marginal populations is usually region-dependent. For example, in Brazil's Amazonian north in 2018, there were 2.2 medical doctors per 1000 inhabitants, while 4.95 medical doctors per 1000 inhabitants and 9.52 doctors in São Paulo and Santa Catarina respectively. Another example is pregnant women in remote Amazonian municipalities, who receive less prenatal care than women in urban areas. These social inequities underlie systemic biases in health data quality, hindering reliable estimation of disease burdens such as the distribution of disease or birth and death registrations. For example, in Guatemala, alternative Indigenous healthcare systems are responding to local needs in Mayan communities. However, this remains unrecognised. The existence of health institutions based on IK can reinforce the lack of universal coverage by central government healthcare, addressing the miscalculation of morbidity, mortality and cause of death among disadvantaged groups.

FAQ 12.1 (continued)

Inequality, informality and precariousness are particularly relevant barriers to adaptation. A significant part of the construction sector in the region is informal and does not follow regulations for land use and construction safety codes, and there is a lack of public strategies for housing access. Adaptive construction is based on up-to-date regulation and codes, appropriate design and materials, and access to infrastructure and services. Decreasing inequality and eradicating poverty are crucial for achieving proper adaptation to climate change in the region. Some anti-poverty initiatives, such as savings groups, microfinance for improving housing or assets and community enterprises, may also support specific adaptive measures. These mechanisms should be widely accessible to poor groups and be complemented by comprehensive poverty alleviation programmes that include climate-change adaptation.

Frequently Asked Questions

FAQ 12.2 | How have urban areas in Central and South America adapted to climate change so far, which further actions should be considered within the next decades and what are the limits of adaptation and sustainability?

Cities are becoming focal points for climate-change impacts. Rapid urbanisation in Central and South America, together with accelerating demand for housing, resource supplies and social and health services, has put pressure on the already stretched physical and social infrastructure. In addition, migration is negatively affecting the opportunities of cities to adapt to climate change.

Central and South America is the second most urbanised region in the world after North America, with 81% of its population being urban. In addition, 129 secondary cities with 500,000 inhabitants are home to half of the region's urban population (222 million). Another 65 million people live in megacities of over 10 million each. The population migrates among cities, resulting in more secondary cities and creating mega regions and urban corridors.

Rapid growth in cities has increased the urban informal housing sector (e.g., slums, marginal human settlements and others), which increased from 6% to 26% of the total residences from 1990 to 2015. Coastal areas in Central and South America increasingly concentrate more urban centres. Researchers indicate that between 3 and 4 million inhabitants will experience coastal flooding and erosion from SLR in all emission scenarios by 2100 considering South America alone.

A study on cities with more than 100,000 inhabitants showed that the number of coastal cities significantly increased from 42 to 420 between 1945 and 2014; they are located close to fragile ecosystems such as bays, estuaries and mangrove forests, resulting in higher concentrations of population and economic activities. This process degraded the ability of coastal ecosystems, such as mangroves, to reduce risks and provide essential ecosystem services, which help to prevent coastal erosion or maintain fish stocks. Moreover, it reduced ports and tourism, along with income opportunities.

Climate-change impacts on cities in Central and South America are strongly influenced by ENSO, which is associated with an increase in more-extreme rainfall events. Urban areas are increasingly dealing with floods, landslides, storms, tropical cyclones, water stress, fires, spread of vector-borne and infectious diseases, damaging infrastructure, economic activities, built and natural environments and the population's overall well-being.

Glacier retreat in the mountains will affect water runoff and water provision to metropolitan areas such as Lima, La Paz, Quito and Santiago, which rely on rivers that originate in the high Andes. Lima, the second driest capital city in the world, is vulnerable to drought and heavy rain peak events associated with climate change. In Bogota, lower precipitation levels and a tendency towards increasing extreme events are expected in the coming decades. Hence, the protection of fragile ecosystems such as paramo (fields at 3000 to 4000 meters above sea level) will be crucial for supplying water to the city.

Sea level rise impacts cities located in low elevation coastal zones, not only because of direct coastal flooding, coastal erosion and subsidence, but also because it aggravates the impact of storm surges, heat wave energy and saltwater intrusion. In Suriname and Guyana 68% and 31% of the population respectively live below 5 metres above sea level, while many sectors of Georgetown, the capital of Guyana, are below sea level. Floods with increased frequency and severity of storm surges will also impact the River Plate estuary and lower delta of the Parana River where metropolitan Buenos Aires is located.

Over 80% of losses associated with climate-related risks are concentrated in urban areas, and between 40% and 70% of losses occur in cities with less than 100,000 inhabitants, most likely as a result of limited capacities to manage disaster risks and low levels of investment.

Despite consistent political and economic barriers, many cities in the region have adopted sustainable local development agendas, which work to bring about balanced urban development. The shortcomings of poor development patterns remain prominently on display in cities and present important obstacles to adaptation investment, as public investment in basic needs (mainly housing and sanitation) must be prioritised.

FAQ 12.2 (continued)

Cities struggle to address the immediate needs of their population while addressing longer-term needs associated with climate adaptation, emissions reduction and sustainable development. Some cities are moving forward to transformative adaptation, addressing drivers of vulnerability, building robust systems and anticipating impacts. Besides government-led adaptation planning and action, individuals, communities and enterprises have been incrementally adapting to climate change autonomously over time. Municipalities from Argentina, Peru, Chile, Equator, Brazil and Costa Rica are developing and implementing their Local Climate Action Plans, experimenting with and revealing best practices in adaptation. Both anticipatory adaptation measures—choosing safe locations, building structurally safe houses, choosing elevated places to store valuables, building on stilts—and reactive adaptation measures are used, the latter incorporating measures such as relocation, slope stabilisation, afforestation and greening of riverbanks. With variations, these cities have included mechanisms to work across sectors and actors on the understanding that it is collective planning and actions that will ensure that long-term programmes continue independently of particular city administrations.

Cities are interconnected systems operating beyond administrative boundaries. Improved collaboration and coordination are needed for integrated responses. Aside from good planning, cities need access to external adaptation funds. Climate-change adaptation requires long-term funding and investments, which are beyond cyclical political considerations. It is crucial to rethink how to ensure that international adaptation funds will reach cities and innovate. For example, member cities of Global Covenant of Mayors for Climate & Energy in the region, together with Cities for Life Forum in Peru, the Red Argentina de Municipios por el Cambio Climático (RAMCC), the Capital Cities of the Americas facing Climate Change (CC35) and others, are pursuing this goal and applying directly for international grants. New funding sources are required to help local governments and civil society. Cities and locally driven adaptation initiatives can be funded by national governments and international organisations.

Frequently Asked Questions

FAQ 12.3 | How do climatic events and conditions affect migration and displacement in Central and South America, will this change due to climate change, and how can communities adapt?

Migration and displacements associated with climatic hazards are becoming more frequent in CSA, and they are expected to continue to increase. These complex processes require comprehensive actions in their places of origin and reception, to improve both adaptation in more affected places and the conditions of mobilisation.

The migration, voluntary and involuntary, of individuals, families and groups is common in Central and South America. People migrate nationally and internationally, temporarily or permanently, predominantly from rural areas—often immersed in poverty—to urban areas. Common social drivers of migration in the region are the economy, politics, land tenure and land management change, lack of access to markets, lack of infrastructure, and violence; environmental drivers include loss of water, crops and livestock, land degradation and sudden or gradual onset of climate hazards.

The increasing frequency and magnitude of droughts, tropical storms, hurricanes and heavy rains producing landslides and floods have amplified internal movements, overall rural to urban. For instance, rural-to-urban migration in northern Brazil and international migration from Guatemala, Honduras and El Salvador to North America are partly a consequence of prolonged droughts, which have increased the stress of food availability in these highly impoverished regions. Diminished access to water is also a result of privatisation of that resource. In Central America, the majority of migrants are young men, reducing the labour force in their places of origin. However, the migrants send back substantial amounts of money, which have become the main source of foreign exchange for their countries and the main source of income for their families.

Because poor people have fewer resources to adapt to changing conditions, they are usually the most impacted by climate hazards since they are already struggling to survive under normal conditions. These populations are the most likely to migrate, chiefly because of the loss of their livelihoods, their precarious housing and settlements and the lack of money and international aid. Other important factors are the minimal governmental support and assistance through social safety nets and extension services, the scarcity and low quality of education and health services, their isolation and marginality and the insecurity of land rights. These same conditions, though, may hinder their mobility or even render them immobile. Nevertheless, in some cases, despite worsening conditions, people decide not to move.

The magnitude and frequency of droughts and hurricanes are projected to keep increasing by 2050, which may force millions of people to leave their homes. Climate models show some dry regions becoming even dryer in the coming decades, increasing the stress on small farmers who rely on rainfall to water their fields. Glacier retreat and water scarcity are becoming strong drivers of migration in the Andes. Sea level rise affects activities such as fishing and tourism, which will foster further migration. In Brazil, at least 0.9 million more people will migrate interregionally under future climate conditions.

Addressing migration and displacement requires diverse interventions: in dry regions it is recommended to improve water management in the places of origin of migration, including storage, distribution and irrigation. Wet regions, lowlands and floodplains will benefit from preventing construction in areas prone to landslides and flooding. Government and international aid are also important for improving people's options to adapt and enhance their resilience to climate impacts. In northern Brazil, for example, government financial support has significantly reduced drought-related migration. There exists between Guatemala and Canada a temporary migration programme to bring in migrant workers during the harvest season. The United States is also increasing these types of legal temporary migration.

Frequently Asked Questions

FAQ 12.4 | How is climate change impacting and how is it expected to impact food production in Central and South America in the next 30 years, and what effective adaptation strategies are and can be adopted in the region?

Agriculture is a fundamental sector in the development of societies from economic and social perspectives, and so it is a major component of Central and South American countries' adaptive strategies. Implementation of sustainable agriculture practices, such as improved management on native grasslands or agroforestry systems for crop and livestock production, can increase productivity while improving adaptability.

Over the last two decades, countries throughout Central and South American have been developing rapidly. The agricultural sector is fundamental to this development from economic and social perspectives. Some countries in the region are major global food exporters:

- Corn: three of the top 10 exporters are Brazil, Argentina and Paraguay;
- Soybean exports: Brazil and Argentina are among the top 5 and Paraguay and Bolivia rank in the top 12;
- Coffee exports: 5 of the top 10 export countries are Brazil, Colombia, Honduras, Peru and Guatemala;
- Fruits: 2 of the top 10 fresh fruit exporting countries are Chile and Ecuador;
- Fishmeal exports globally are led by Peru, Chile and Ecuador;
- Beef: four of the top exporting countries are from this region: Brazil, Argentina, Uruguay and Paraguay.

Central and South American is among the regions with the highest potential to increase food supplies, particularly to more densely populated regions in Asia, the Middle East and Europe. A better understanding of the impact of the economy on the environment and the contribution of the environment to the economy is critical for identifying opportunities for innovation and promoting activities that could lead to sustainable economic growth without depleting natural resources and increasing sensitivity to climate change and climate variability. The consideration of food as a commodity instead of a common resource leads to the accumulation of underpriced food resources at the expense of natural capital. Without serious emissions reduction measures, climate models project an average 1°C to 4°C increase in maximum temperatures and a 30% decrease in rainfall up to 2050, across CSA. Tropical South America is projected to warm at higher rates than the southern part of South America. Given these circumstances, some regions in Central and South America (Andes region and Central America) will just meet or fall below the critical food supply/demand ratio for their population. Meanwhile, the temperate southern-most region of South America is projected to have agricultural production surplus. The challenge for this region will be to retain the ability to feed and adequately nourish its internal population as well as make an important contribution to food supplies available to the rest of the world.

The Nationally Determined Contributions (NDCs) of most Central and South American countries expressly include agriculture as a major component of their adaptive strategy. From the recommendations presented, five general adaptive themes, or imperatives, emerge: (a) inclusion of climate-change projections as a key element for ministries of agriculture and research institutes in their decision-making processes, (b) support of research on and adoption of drought- and heat-tolerant crop varieties, (c) promotion of sustainable irrigation as an effective adaptive strategy, (d) recovery of degraded lands and sustainable intensification of agriculture to prevent further deforestation, and (e) implementation of climate-smart practices and technologies to increase productivity while improving adaptability.

Climate-smart practices provide a framework to operationalise actions aimed at understanding synergies among productivity, adaptation and mitigation. A significant amount of evidence supports the potential for climate-smart-practice technologies to produce such triple wins as natural pastoral systems in the southern region of South America. Such systems allow for the combination of food production and environmental sustainability. The production of meat based on native grasslands with grazing management that optimises forage allowance can achieve high production levels while providing multiple ecosystem benefits. Optimal forage allowance means offering animals enough forage in order to meet requirements while avoiding overgrazing. This management practice simultaneously increases productivity, reduces greenhouse gas emissions while improving soil carbon sequestration and minimises other environmental impacts such as excess of nutrients, fossil-based energy use and biodiversity loss. Pastoral farming systems that manage grazing and feeding efficiently are an example of the integration of food security, environmental conservation and nature-based adaptation to climate change.

FAQ 12.4 (continued)

Agroforestry systems are present in the tropical region of Central and South America. Trees are present in a large part of the agricultural landscape of this region, either dispersed or in lines, supporting the production of coffee, cocoa, fruits, pastures and livestock in various agroforestry configurations. In Central America, shade-grown coffee reduces weed control and improves the quality and taste of the product. Agroforestry uses nitrogen-fixing trees (*Leguminosae*), such as *Leucaena* in Colombia and *Inga* in Brazil, to restore soil nitrogen fertility. Tropical forest soils are generally nutrient-poor and unsuited to long-term agricultural use. Land converted to agriculture by cutting and burning natural vegetation tends to remain productive for only a few years. Agroforestry and so-called silvopastoral systems, which incorporate trees into crop and livestock systems, have been shown to have a dramatic impact on the maintenance and restoration of long-term productivity in agricultural landscapes, including degraded and abandoned land. Agroforestry systems can provide major benefits through enhanced food security, stronger local economies and increased ecosystem services such as carbon storage, regulation of climate and water cycles, control of pests and diseases and maintenance of soil fertility. Because of these multiple goods and services, agroforestry practices are considered one of the key strategies for the development of climate-smart agriculture.

Frequently Asked Questions

FAQ 12.5 | How can Indigenous knowledge and practices contribute to adaptation initiatives in Central and South America?

Indigenous Peoples have knowledge systems and practices that allow them to adapt to many climatic changes. Adaptation initiatives based on Indigenous knowledge and practices are more sustainable and legitimate among local communities. It is important to build effective and respectful partnerships among Indigenous and non–Indigenous researchers to co-produce climate-relevant knowledge to enhance adaptation planning and action in the region.

There are 28 million Indigenous Peoples in Central and South America (around 6.6% of the total population of the region). They belong to more than 800 groups living in territories covering a wide range of ecosystems—from drylands to tropical rainforests to savannahs, coasts to mountains—and that share the land with many other cultural and ethnic groups. In the region, Indigenous Peoples are often categorised as groups that are highly vulnerable to climate change because they are frequently affected by socioeconomic inequalities and the dominance of external powers. They often experience internal and external pressures on their communal lands in the forms of pollution, oil and mining, industrial agriculture and urbanisation. On the other hand, it is important to recognise that Indigenous Peoples have knowledge systems and practices that allow them to adapt to many climatic changes. Increasing scientific evidence shows that adaptation initiatives based on Indigenous knowledge and practices are more sustainable and legitimate among local communities.

The wide range of adaptation practices based on Indigenous knowledge in the region include, among others, increasing species and genetic diversity in agricultural systems through community seed exchanges; promotion of highly diverse crop systems; ancient systems to collect and conserve water; fire prevention strategies; observing and monitoring changes in communal ecological–agricultural calendar cycles; recognising changes in ecological indicators like migration patterns in birds, the behaviour of insects and other invertebrates and the phenology of fruit and flowering species; and systematisation and knowledge exchange among communities. These practices represent a valuable cultural and biological heritage.

The Kichwa in the Ecuadorian Amazon cultivate Chakras (plots) within the rainforest. These plots combine crops and medicinal herbs for both self-consumption and selling. Similar systems, like the Chakras in the high Andes, the Milpas in Central America, and the Conucos in northern South America, have been resilient to social and environmental disturbances due to their outstanding agrobiodiversity (more than 40 species and varieties can be present in one plot), microhabitat management and the associated knowledge and institutions.

Traditional fire management among Indigenous Peoples of Venezuela, Brazil and Guyana is another adaptation strategy based on a fine-tuned understanding of environmental indicators associated with their culture and worldviews. In these countries, Indigenous lands have the lowest incidence of wildfires, significantly contributing to maintaining and enhancing biodiversity. These traditional practices have helped to prevent large-scale and destructive wildfires, reducing the risks posed by rising temperature and dryness due to climate change.

The traditional agriculture of Mapuche Indigenous Peoples in Chile includes a series of practices that result in a system that is more resilient to climate and non-climate stressors. Practices include water management, native seed conservation and exchange with other producers (trafkintu), crop rotation, polyculture and tree–crop association. Similar practices can be found in Mayan communities in Guatemala at the other end of the sub-continent.

Despite the increasing recognition and integration of Indigenous knowledge in adaptation practices and policies in the region, important barriers for a more effective and transformative integration remain. Some of the most relevant barriers include limited participation of Indigenous Peoples and local communities in adaptation planning and the lack of sufficient consideration of non-climatic socioeconomic drivers of vulnerability such as poverty and inequality. Also, scientific knowledge is commonly prioritised over traditional Indigenous knowledge and local knowledge. However, some transformative efforts are emerging. Bolivian Indigenous organisations represent a notable example by contesting normative conceptions of development as economic growth and replacing them with more comprehensive views like harmony with Mother Earth and 'Sumak Kawsay' or 'Good Living'.

Several strategies have been proposed to overcome existing barriers, including building effective and respectful partnerships among Indigenous and non-Indigenous researchers, co-producing climate-change-relevant knowledge and recognising Indigenous Peoples as active participants in the continual development of autonomous strategies to preserve their practices, beliefs and knowledge. The implementation of these and other strategies can significantly enhance adaptation planning and action in the region.

Frequently Asked Questions

FAQ 13.1 | How can climate change affect social inequality in Europe?

The poor and those practising traditional livelihoods are particularly exposed and vulnerable to climate change. They rely more often on food self-provisioning and settle in flood-prone areas. They also often lack the financial resources or the rights to successfully adapt to climate-driven changes. Good practice examples demonstrate that adaptation can reduce inequalities.

Social inequalities in Europe arise from disparities in income, gender, ethnicity, age as well as other social categorisations. In the European Union (EU), about 20% of the population (109 million people) live under conditions of poverty or social exclusion. Moreover, poverty is unequally distributed across Europe, with higher poverty levels in Eastern Europe. The oldest and youngest in society are often most vulnerable.

The poor and those practising traditional livelihoods are particularly vulnerable and exposed to climate risks. Many depend on food self-provisioning from lakes, the sea and the land. With higher temperatures, the availability of these sources of food is *likely* to be reduced, particularly in Southern Europe. Poorer households often settle in flood-prone areas and are therefore more exposed to flooding. Traditional pastoralist and fishing practices are also negatively affected by climate change across Europe. Semi-migratory reindeer herding, a way of life among Indigenous and traditional communities (i.e., Komi, Sámi, Nenets) in the European Arctic, is threatened by reduced ice and snow cover. Almost 15% of the EU population (in some countries more than 25%) already cannot meet their health care needs for financial reasons, while they are at risk of health impacts from warming.

In addition to being more exposed to climate risks, socially vulnerable groups are also less able to adapt to these risks, because of financial and institutional barriers. More than 20% of people in Southern Europe and Eastern Europe live in dwellings that cannot be cooled to comfortable levels during summer. These people are particularly vulnerable to risks from increasing heatwave days in European cities (e.g., when they already face energy poverty). They may also lack the means to protect against flooding or heat (e.g., when they do not own the property). Risk-based insurance premiums, which are intended to help people reduce climate risks, are potentially unaffordable for poor households. The ability to adapt is also often limited for Indigenous people, as they often lack the rights and governance of resources, particularly when in competition with economic interests such as resource mining, oil and gas, forestry and expansion of bioenergy.

Adaptation actions by governments can both increase and decrease social inequality. The installation of new, or the restoration of existing, green spaces may increase land prices and rents due to a higher attractiveness of these areas, leading to potential displacement of population groups who cannot afford higher prices. On the other hand, rewilding and restoration of ecosystems can improve the access of less privileged people to ecosystem services and goods, such as the availability of freshwater. At city level, there are examples of good practice in climate resilient development that consider social equity which integrate a gender-inclusive perspective in its sustainable urban planning, including designing public spaces and transit to ensure that women, persons with disabilities and other groups can access, and feel safe using, these public amenities.

Frequently Asked Questions

FAQ 13.2 | What are the limits of adaptation for ecosystems in Europe?

Land, freshwater and ocean organisms and ecosystems across Europe are facing increasing pressures from human activities. Climate change is rapidly becoming an additional and, in the future, a primary threat. Ongoing and projected future changes are too severe and happen too fast for many organisms and ecosystems to adapt. More expensive and better implemented environmental conservation and adaptation measures can slow down, halt, and potentially reverse biodiversity and ecosystem declines, but only at low or intermediate warming.

Ecosystem degradation and biodiversity loss have been evident across Europe since 1950, mainly due to land use and overfishing; however, climate change is becoming a key threat. The unprecedented pace of environmental change has already surpassed the natural adaptive capability of many species, communities and ecosystems in Europe. For instance, the space available for some land ecosystems has shrunk, especially in Europe's polar and mountain areas, due to warming and thawing of permafrost. Across Europe, heatwaves and droughts, and their impacts such as wildfires, add further acute pressures, as seen in the 2018 heatwave, which impacted forest ecosystems and their services. In the Mediterranean Sea, plants and animals cannot shift northward and are negatively affected by marine heatwaves. Food-web dynamics of European ecosystems are disrupted as climate change alters the timing of biological processes, such as spawning and migration of species, and ecosystem composition. Moreover, warming fosters the immigration of invasive species that compete with–and can even out-compete–the native flora and fauna.

In a future with further and even stronger warming, climate change and its many impacts will become increasingly more important threats. Several species and ecosystems are projected to be already at high risk at 2°C global warming level, including fishes and lake and river ecosystems. At 3°C global warming level, many European ecosystems, such as coastal wetlands, peatlands and forests, are projected to be at much higher risk of being severely disrupted than in a 2°C warmer world. For example, Mediterranean seagrass meadows will *very likely* become extinct due to more frequent, longer and more severe marine heatwaves by 2050. Several wetland and forest plants and animals will be at high risk to be replaced by invasive species that are better adapted to increasingly dry conditions, especially in boreal and Arctic ecosystems.

Current protection and adaptation measures, such as the Natura 2000 network of protected areas, have some positive effects for European ecosystems; however, these policies are not sufficient to effectively curb overall ecosystem decline, especially for the projected higher risks above 2°C global warming level. Nature-based solutions, such as the restoration of wetlands, peatlands and forests, can serve both ecosystem protection and climate-change mitigation through strengthening carbon sequestration. Some climate-change mitigation measures, such as reforestation and restoration of coastal ecosystems, can strengthen conservation measures. These approaches are projected to reduce risks for European ecosystems and biodiversity, especially when internationally coordinated.

Not all climate-change adaptation options are beneficial to ecosystems. When planning and implementing adaptation options and nature-based solutions, trade-offs and unintended side effects should be considered. On one hand, engineering coastal protection measures (seawalls, breakwaters and similar infrastructure) in response to sea level rise reduce the space available for coastal ecosystems. One the other hand, nature-based solutions can also have unintended side effects, such as increased methane release from larger wetland areas and large-scale tree planting changing the albedo of the surface.

Frequently Asked Questions

FAQ 13.3 | How can people adapt at individual and community level to heatwaves in Europe?

Heatwaves will become more frequent, more intense and will last longer. A range of adaptation measures are available for communities and individuals before, during and after a heatwave strikes. Implementing adaptation measures are important to reduce the risks of future heatwaves.

Heatwaves affect people in different ways; risks are higher for the elderly, pregnant women, small children, people with pre-existing health conditions and low-income groups. By 2050, about half of the European population may be exposed to high or very high risk of heat stress during summer, particularly in Southern Europe and increasingly in Eastern Europe and Western and Central Europe. The severity of heat-related risks will be highest in large cities, due to the UHI effect.

In Southern Europe, people are already aware of the risks of heat extremes. Consequently, governments and citizens have implemented a range of adaptation responses to reduce the impacts of heatwaves; however, there are limits to how much adaptation can be implemented. At 3°C global warming level, there will be substantial risks to human lives and productivity, which cannot be avoided. In the parts of Europe where heatwaves are a relatively new phenomenon, such as many parts of Northern Europe and Western and Central Europe, public awareness of heat extremes is increasing and institutional capacity to respond is growing.

Preparing for heatwaves is an important first step. Implementing and sustaining effective measures, such as national or regional early warning and information systems, heatwave plans and guidelines, and raising public awareness through campaigns, are successful responses. Evidence suggests that such measures have contributed to reduced mortality rates in Southern Europe and Western and Central Europe. At city level, preparing for heatwaves can sometimes require urban re-design. For example, green–blue spaces, such as recreational parks and ponds in cities, have been shown to reduce the average temperature in cities dramatically and to provide co-benefits, such as improved air quality and recreational space. The use of cool materials in asphalt, increasing reflectivity, green roofs and building construction measures are being considered in urban planning for reducing heat risks. Citizens can prepare themselves by using natural ventilation, using approaches to stay cool in heatwaves, green roofs and green façades on their buildings.

During heatwaves, public information that is targeted at people and social care providers is critical, particularly for the most vulnerable citizens. Governments and NGOs play an important role in informing people about how to prepare and what to do to avoid health impacts and reduce mortality. Coordination between vital emergency and health services is critical. Individuals can take several actions to effectively protect themselves from heat including (a) decrease exposure to high temperatures (e.g., avoid outdoor during hottest times of the day, access cool areas, wear protective and appropriate clothing), (b) keep hydrated (e.g., drink enough proper fluids, avoid alcohol, etc.) and (c) be sensitive to the symptoms of heat illness (dizziness, heavy sweating, fatigue, cool and moist skin with goosebumps when in heat, etc.).

Once the heatwave has ended, evaluation of what worked well and how improvements can be made is key to prepare for the *next* heatwave. Governments can, for example, evaluate whether the early warning systems provided timely and useful information, whether coordination went smoothly and assess the estimated number of lives saved, to determine the effectiveness of the measures implemented. Sharing these lessons learned is critical to allow other cities and regions to plan for heat extremes. After the heatwave, citizens can reflect if their responses were sufficient, whether investments are needed to be better prepared and draw key lessons about what (not) to do when the next heatwave strikes.

Frequently Asked Questions

FAQ 13.4 | What opportunities does climate change generate for human and natural systems in Europe?

Not all climate-change impacts across Europe pose challenges and threats to natural communities and human society. In some regions, and for some sectors, opportunities will emerge. Although these opportunities do not outweigh the negative impacts of climate change, considering these in adaptation planning and implementation is important to benefit from them. Nevertheless, Europe will face difficult decisions balancing the trade-offs between the adaptation needs of different sectors, regions and adaptation and mitigation actions.

Opportunities of climate change can be (a) positive effects of warming for specific sectors and regions, such as agriculture in Northern Europe, and (b) co-benefits of transformation of cities or transport measures that reduce the speed and impact of climate change while improving air quality, mental health and well-being. Windows of action for transformation opportunities for large-scale transitions and transformation of our society may be accelerated through new policy initiatives in response to the COVID-19 crisis, such as the European New Green Deal and Building Back Better.

As warming and droughts impact Southern Europe most strongly, direct opportunities from climate change are primarily in northern regions, thereby increasing existing inequalities across Europe. Across Europe, positive effects of climate change are fewer than negative impacts and are typically limited to some aspects of agriculture, forestry, tourism and energy sectors. In the food sector, opportunities emerge by the northward movement of food production zones, increases in plant growth due to CO_2 fertilisation and reduction of heating costs for livestock during cold winters. In the energy sector, positive effects include increased wind energy in the southwest Mediterranean and reduced energy demand for heating across Europe. While climatic conditions for tourist activities are projected to decrease for winter tourism (e.g., insufficient snow amount) and summer tourism in some parts of Europe (e.g., too much heat), conditions may improve during spring and autumn in many European locations. Fewer cold waves will reduce risks on transport infrastructure, such as cracking of road surface, in parts of Northern Europe and Eastern Europe particularly by the end of the century.

Indirect opportunities emerge from the co-benefits of implementing adaptation actions. Some of these co-benefits are widespread but need careful consideration in order to be utilised. For example, an nature-based solution approach to adaptation can make cities and settlements more liveable, increase the resilience of agriculture and protect biodiversity. Ecosystem-based adaptation can attract tourists and create recreational space. There are opportunities to mainstream adaptation into other developments and transitions, including the energy or agricultural transitions as well as COVID-19 recovery plans. Transformative solutions to achieve sustainability may be accelerated through larger changes of, for example, behaviour, energy, food or transport, to better exploit new opportunities and co-benefits. Implementation of adaptation actions can also help to make progress towards achieving the Sustainable Development Goals (SDGs).

Inclusive, equitable and just adaptation is critical for climate resilient development considering SDGs, gender as well as Indigenous knowledge and local knowledge and practices. Implementation requires political commitment, persistence and consistent action across scales of government. Upfront mobilisation of political, human and financial capital in implementation of adaptation actions is key, even when the benefits are not immediately visible.

Frequently Asked Questions

FAQ 14.1 | How has climate change contributed to recent extreme events in North America and their impacts?

Multiple lines of evidence indicate that climate change is already contributing to more intense and more frequent extreme events across North America. The impacts resulting from extreme events represent a huge challenge for adapting to future climate change.

Extreme events are a fundamental part of how we experience weather and climate. Exceptionally hot days, torrential rainfall and other extreme weather events have a direct impact on people, communities and ecosystems. Extreme weather can lead to other impactful events such as droughts, floods or wildfires. In a changing climate, people frequently ask whether extreme events are generally becoming more severe or more frequent, and whether an actual extreme event was caused by climate change.

Because really extreme events occur rarely (by definition), it can be very difficult to assess whether the overall severity or frequency of such events has been affected by changing climate. Nevertheless, careful statistical analysis shows that record-setting hot temperatures in North America are occurring more often than record-setting cold temperatures as the overall climate has gotten warmer in recent decades. The area burned by large wildfires in the western USA has increased in recent decades. Observed trends in extreme precipitation events are more difficult to detect with confidence, because the natural variability of precipitation is so large and the observational database is limited.

Our understanding of how individual extreme weather events have been influenced by climate change has improved greatly in recent years. Climate scientists have developed a formal technique ('event attribution', described in WGI FAQ 11.3) for assessing how climate change affects the severity or frequency of a particular extreme event, such as a record-breaking rainfall event or a marine heatwave. This is a challenging task, because any particular event can be caused by a combination of natural variability and climate change. Event attribution is typically carried out using models to compare the probability of a specific event occurring in today's climatic environment relative to the probability that the same event might have occurred in a modelled climate in which atmospheric greenhouse gases have not risen due to human activities. Using this strategy, multiple studies have estimated that the historically extreme rainfall amount that fell across the Houston area from Hurricane Harvey (2017) was three to ten times more *likely* as the result of climate change.

The *impacts* from extreme events depend not just on physical climate system hazards (temperature, precipitation, wind, etc.), but also on the exposure and vulnerability of humans or ecosystems to these events. For example, damage from land-falling hurricanes along the coast of the Gulf of Mexico is expected to increase as very strong hurricanes become more frequent and intense due to climate change. But damage would also increase with additional construction along the shoreline, because coastal development increases *exposure* to hurricanes. And if some structures are constructed to poor building standards, as was the case when hurricane Andrew made landfall in Florida in 1992, then *vulnerability* to hurricane-caused impacts is increased.

Climate change also contributes to impacts from extreme events by making some building codes and zoning restrictions inadequate or obsolete. Many North American communities limit development in areas known to be flood-prone, to minimise exposure to flooding. But as climate change expands the areas at risk of exposure to flooding beyond historical floodplains, the impacts of potential flooding are increased, as Hurricane Harvey demonstrated. Adapting to climate change may require retrofits for existing structures and revised zoning for new construction. Some structures and neighbourhoods may need to be abandoned altogether to accommodate expanded flooding risk.

Climate change can be an *added stress* that increases impacts from extreme events, combined with other non-climatic stressors. For example, climate change in western North America has contributed to more extreme fire weather. The devastating impacts of recent wildfire outbreaks, such as occurred across western Canada in 2016 and 2017, the western United States in 2018 and 2020, and both countries in 2021, are to some extent associated with expanded development and forest management practices (such as policies to suppress low-intensity fires, allowing fuel to accumulate). The effects of development and forest management have dramatically increased the exposure and vulnerability of communities to intense wildfires. Climate change has added to these stressors: warming temperature leads to more extreme weather conditions that are conducive to increasingly severe wildfires.

Biodiversity is affected by climate change in this way too. For example, numerous bird populations across North America are estimated to have declined by up to 30% over the past half-century. Multiple human-related factors, including habitat loss and agricultural intensification, contribute to these declines, with climate change as an added stressor. Increasingly extreme events, such as severe storms and wildfires, can decimate local populations of birds, adding to existing ecological threats.

FAQ

Frequently Asked Questions

FAQ 14.2 | What can we learn from the North American past about adapting to climate change?

The archaeology and history of Indigenous Peoples and Euroamerican farmers show that climate variability can have severe impacts on livelihoods, food security and personal safety. Traditional societies developed numerous methods to cope with variability but have always expanded to the limits of what those adaptations permit. Current knowledge and technology can buffer societies from many negative effects of climate change already experienced but will be severely challenged by the novel conditions we are now creating.

People came into North America more than 15,000 years ago and have experienced both massive and minor shifts in climate ever since. At the end of the last very cold phase of the most recent Ice Age, about 11,500 years ago, temperatures rose extremely rapidly—as much as 10°C (18°F) in a decade in some regions. This undoubtedly contributed to the extinction of large mammals like mammoths and mastodons that people hunted alongside many other resources (see Cross-Chapter Box PALEO in Chapter 1). There were so few people on the land, though, and other resources were so abundant, that the long-standing human means of coping with climate variability—switching foods and moving on—were sufficient.

Following the end of the Ice Age, populations across North America grew for the next few thousand years, at a rate that increased once people began to domesticate corn (maize), beans and squash (the 'three sisters') as well as other crops. However, more people meant less mobility, and farmers traditionally are also more invested in their fields and remaining in place than foragers are to hunting grounds. Other means of coping with vulnerability to food shortage caused by climate variability included some continued hunting and gathering of wild resources, planting fields in multiple locations and with different crops, storage in good years, and exchange with neighbours and neighbouring groups.

According to archaeological evidence, however, these adaptation strategies were not always sufficient during times of climate-induced stress. Human remains showing the effects of malnutrition are fairly common, and conflict caused in part by climate-induced shortfalls in farming has left traces that include fortified sites, sites placed in defensible locations and trauma to human bone. Larger and more hierarchical groups emerged, first in Mesoamerica and then in the southwest and southeast USA as well as the Midwest USA. These groups offered the possibility of buffering poor production in one area with surplus from another, but they also tended to increase inequality within their borders and often attempted to expand at the expense of their neighbours, introducing new sources of potential conflict. Dense hierarchical societies also arose in other areas such as the northwest coast where agriculture was not practised but resources, such as salmon and roots, were abundant and either relatively constant or storable.

These societies were not immune to climate hazards despite their greater population and more formal organisation. Archaeological evidence strongly suggests that drought, or growing conditions that were too hot or cold, contributed to the decline of groups ranging from Classic-period Maya states in Mesoamerica, to the somewhat less hierarchical societies of Chaco in the southwest USA and Cahokia in the Midwest USA (Figure FAQ14.2.1). The usual pattern seems to be that climatic variability compounded social and environmental problems that were already challenging these societies.

If societies in North America prior to the Euroamerican colonisation were vulnerable to climate variability, surely were not the more recent and technologically advanced societies of North America at lower risk? The 20th century Dust Bowl created in the US and Canadian prairies suggests otherwise. Severe drought conditions throughout the 1930s—which, to make matters worse, peaked during the Great Depression—did not cause either the USA or Canada to collapse. But both countries suffered massive economic losses, regional loss of topsoil and regional human strife (including loss of crops, income and farms) leading to migration. Yet anthropogenic global climate change was of little or no consequence in the 1930s. While farming practices made climate stress worse, the climate variability itself was either completely, or mostly, within the envelope of historical climate variability that earlier human societies had experienced.

Indigenous Peoples and Euroamerican farmers and ranchers have a long history of mostly successful adaptation to changing weather patterns. The wisdom held by Indigenous Peoples deep knowledge of how plants, animals and atmospheric conditions provide early warning signals of approaching weather shifts, and stories about how past communities have tried to cope with climate-related resource shortfalls. Long-standing community-level management of resources also helps prevent shortfalls, and institutions such as kin groups, church groups, clubs and local governments (which exist in communities of both Euroamericans and Indigenous Peoples, in different forms) can be powerful aids in ameliorating shortfalls and resolving conflict.

Box FAQ 14.2 (continued)

Examples of areas where past climate variability has contributed to crises

Figure FAQ14.2.1 | Examples of areas where past climate variability has contributed to crises. Climatic variability is most likely to lead to crisis when it is accompanied by social, demographic and political conditions or environmental mismanagement that compound climatic impacts on societies.

Box FAQ 14.2 (continued)

Still, Indigenous knowledge and traditional knowledge among Euroamerican farming communities provide guidelines for how to cope with *traditional* problems. Contemporary governmental restrictions (such as legal water-rights allocations, international borders and tribal-lands boundaries) have limited the adaptive capacity that Indigenous societies have developed over the centuries. Now human-caused climate forcing, if not mitigated by reducing heat-trapping greenhouse gases, is expected to produce climates in North America that have no local analogues in human history even as it destroys heritage sites that are sources of knowledge about palaeoclimates and the diverse ways of coping with them that past peoples have discovered. Just as past peoples often *avoided* local climate change by moving on, in a world where mobility options are severely limited, a lesson from archaeology and history is that we should use our hard-won knowledge of the causes of climate change to avoid creating futures with no past analogues to provide useful guidance.

Frequently Asked Questions

FAQ 14.3 | What impacts do changes in the North American Arctic have within and outside the region?

The North American Arctic is warming at nearly three times the global average, creating a cascading web of local, regional and global impacts within and beyond polar regions. Changes in the Arctic not only effect global ocean circulation and climate regulation, but also facilitate new Arctic transportation routes and support transboundary resources with geopolitical, environmental and cultural implications as conditions change.

Rapid warming and extreme temperatures in the Arctic is leading to unprecedented seasonal sea ice loss, permafrost thaw and increasing ocean temperatures. Cascading from these biophysical changes are cultural, socioeconomic and political consequences that are widespread and largely unprecedented in human history. Changes in sea ice create safety hazards for Indigenous Peoples and northerners who rely on frozen seas and rivers for transportation between remote communities and to subsistence hunting areas. Thawing permafrost, especially that of ice-rich permafrost, creates challenges and costs for a region with low population density and a small tax base to support major infrastructure investments. Warmer ocean temperatures induce large-scale distributional shifts and reduced productivity and access to the largest North American fisheries. Ice-associated marine mammals, such as polar bears, seals and walruses, have declined precipitously with decreasing sea ice in the Bering Sea, and widespread ecosystem changes from fish through birds and marine mammal species have altered the system with uncertain outcomes for these productive ice-driven ecosystems. Newly ice-free shipping routes are increasing regional and geopolitical tensions and may facilitate novel threats like the spread of invasive species and safety hazards to local hunters and fishers. The local and regional impacts of climate change in the North American Arctic are profound and span social, cultural, health, economic and political imperatives.

Although the region is remote, changes in the Arctic impact the rest of the world. The Arctic serves as a regulator of global climate and other ecological processes through large-scale patterns related to air and ocean circulation. These vitally important processes are nearing points beyond which rapid and irreversible (on the scale of multiple human generations) changes are possible. The magnitude of cascading changes over the next two centuries includes regional warming and temperature extremes, permafrost declines and sea ice loss beyond that experienced in human existence. This includes macro-scale risks related to sea level rise from the melting of glaciers and thermal expansion of oceans. Changes in the Arctic are more pronounced than elsewhere and portend climate-change impacts in other areas of the globe.

Adaptation in the Arctic is underway and lessons learned on what works and what is effective and feasible to implement can provide global insights. Successful adaptation in the North American Arctic region has been attributed, in part, to the explicit and meaningful inclusion of Indigenous knowledge and Indigenous self-determination, and diverse perspectives in decision-making processes, strong local leadership, co-management approaches, technological investment in integrated climate modelling and projections, and multilateral cooperation.

Frequently Asked Questions

FAQ 14.4 | What are some effective strategies for adapting to climate change that have been implemented across North America, and are there limits to our ability to adapt successfully to future change?

Climate adaptation is happening across North America. These efforts are differential across sectors, scale and scope. Without more integrative and equitable approaches across broad scales, known as transformational adaptation, the continent may face limits to the future effectiveness of adaptation actions.

Across North America, progress in introducing climate adaptation is steady, but incremental. Adaptation is typically limited to planning, while implementation is often hindered by 'soft' limits, such as access to financial resources, disparate access to information and decision-making tools, the existence of antiquated policies and management frameworks, lack of incentives and highly variable political perceptions of the urgency of climate change.

Cities and other state and local entities are taking the lead in adaptation efforts, particularly in terms of mainstreaming the use of many approaches to adaptation. These approaches include a suite of efforts ranging from assessment of impacts and vulnerability (relative to individuals, communities, jurisdictions, economic sectors, natural resources, etc.), planning processes, implementation of identified strategies and evaluation of the effectiveness of these strategies. Other institutions (e.g., NGOs, professional societies, private engineering and architecture businesses) also are making significant progress in the adaptation arena, particularly at local to regional levels.

The water management and utilities sectors have made significant progress towards implementation of adaptation strategies using broad-based participatory planning approaches. Consideration of climate change is now folded into some ongoing watershed-wide planning efforts. An example is provided by the One-Water-One-Watershed (OWOW) approach followed by the Santa Ana Watershed Project Authority (SAWPA) in southern California. SAWPA is a joint powers authority comprising five regional water districts that provide drinking water to more than 6 million people as well as industrial and irrigation water across the 2400-square-mile watershed. The OWOW perspective focuses on integrated planning for multi-benefit projects and explicit consideration of the impacts of any planning option across the entire watershed. Planning is supported by stakeholder-driven advisory bodies organised along themes that consider a full suite of technical, political, environmental and social considerations. SAWPA provides member agencies with decision-support tools and assistance to implement water conservation policies and pricing regimes, and one member agency is an industry leader on potable water recycling.

The marine and coastal fisheries sector also has shown considerable progress in climate adaptation planning, particularly in terms of assessing impacts and vulnerability of fisheries. Along the Pacific Northwest coast of the USA and Alaska, seasonal and sub-seasonal forecasts of ocean conditions exacerbated by warming (e.g., O_2, pH, temperature, sea ice extent) already have informed fisheries and aquaculture management. Similarly, forecasts and warnings have reduced human exposure to the increased risk of toxins from harmful algal blooms in the Gulf of Mexico, the Great Lakes, California, Florida, Texas and the Gulf of Maine.

Professional organisations and insurance play an important part in mainstreaming climate adaptation. Government and private-sector initiatives can help address adaptation efforts through building-design guidelines and engineering standards, as well as insurance tools that reflect the damages from climate impacts. Through the identification of climate risks and proactive adaptation planning, the private sector can contribute to reducing risks throughout North America by securing operations, supply chains and markets.

Indigenous Peoples and rural community efforts across the continent show great potential for enhancing and accelerating adaptation efforts particularly when integrated with Western-based natural resource management approaches, such as cultural burning and other traditional practices that reduce the buildup of fuels, in addition to prescribed fire and mechanical thinning. In the agricultural sector, examples include planting and cultivation of culturally significant plants, as a traditional practice of soil conservation, in addition to food crops or in lieu of synthetic or mechanical soil treatments.

Future changes in climate (e.g., more intense heatwaves, catastrophic wildfire and post-fire erosion, sea level rise and forced relocations) could exceed the current capacity of human and natural systems to successfully adapt (or 'hard limits'). The inclusion and equitable contribution of Indigenous Peoples and rural communities in decision-making and governance processes—including recognition of the interdependencies between cities and surrounding areas—increases the likelihood of building adaptive capacity at a pace that is commensurate with present and future climate-change risks.

Box FAQ 14.4 (continued)

Large-scale, equitable transformational adaptation likely will be required to respond to the growing rate and magnitude of changes before crossing tipping points where hard limits exist, beyond which adaptation may no longer be possible. Increasingly, there are calls for accelerating and scaling up adaptation efforts, in addition to aligning policies and regulatory legislation at multiple levels of government. Improved processes for adaptation decision making, governance and coordination, across sectors and jurisdictions, could enhance North America's capacity to adapt to rapid climatic change. These actions include a focused societal shift, across governments, institutions and transnational boundaries, from primarily technological approaches to NbS that help foster changes in perception of risk and, ultimately, human behaviour.

Frequently Asked Questions

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

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

Observed changes—including increases in air and ocean temperatures, increases in storm surges, heavy rainfall events, and possibly more intense tropical cyclones—are already reducing the number and quality of ecosystem services, thereby causing the disruption of human livelihoods, damage to buildings and infrastructure, and loss of economic activities and cultural heritage on small islands. Widespread observed impacts include severe coral reef bleaching events, such as that associated with the 2015–2016 El Niño season, the most damaging on record worldwide. Additionally, the 2017 Atlantic hurricane season was unusually characterised by sequential severe tropical cyclones that resulted in widespread cyclone-induced damage to ecosystems from the very interior of small islands to those of the ocean waters that surround them as well as damage to human settlements and economic activities within the whole Caribbean region. Although knowledge is limited regarding long-term increases in tropical cyclone intensity, studies have shown that heavy rainfall and intense wind speed of individual tropical cyclones were increased by climate change. The combination of various climate events, such as tropical cyclones, extreme ocean waves, and El Niño or La Niña phases, with sea level rise causes increased coastal flooding, especially on low-lying atoll islands of the Indian and Pacific oceans.

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

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

Frequently Asked Questions

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

Faced with rising sea levels and storm surges along their coastal areas which have significantly threatened people's safety, buildings, infrastructure and livelihoods, small island communities have already embarked on the use of different adaptation strategies. These include reactive adaptation, which deals with short-term measures, and anticipatory adaptation, which takes action in advance to lessen climate change impacts in the long run. Reactive measures have not always proven to be effective. By contrast, anticipatory measures hold much promise for future adaptation.

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

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

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

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

Where relocation is successful, it is most commonly driven and funded by governments and non-government organisations, often within a specially designed policy framework. The Government of Fiji, for example, has introduced a relocation framework that specifically develops guidance on relocation processes, with several villages already having relocated. Evaluations to date recommend thorough cost–-benefit analyses of relocation be undertaken before this strategy is pursued. Relocation is often viewed as a 'last resort' adaptation option because of high cost and because some sociocultural aspects of life cannot be maintained in locations separated from customary land. The Bahamas relocated a community on Family Island from the shoreline to an inland location and the community of Boca de Cachón in the Dominican Republic was relocated to higher ground. The Navunievu community (Bua, Fiji) has mandated that every young adult building their family home in the village should do so upslope rather than on the regularly flooded coastal flat where the existing village is located. Over the next few decades, this will result in the gradual upslope migration of the community, an example of autonomous adaptation. Such creative community-grounded solutions hold great promise for future adaptation on small islands, where they are undertaken inclusively.

FAQ 15.2 (continued)

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

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

FAQ 15.2 (continued)

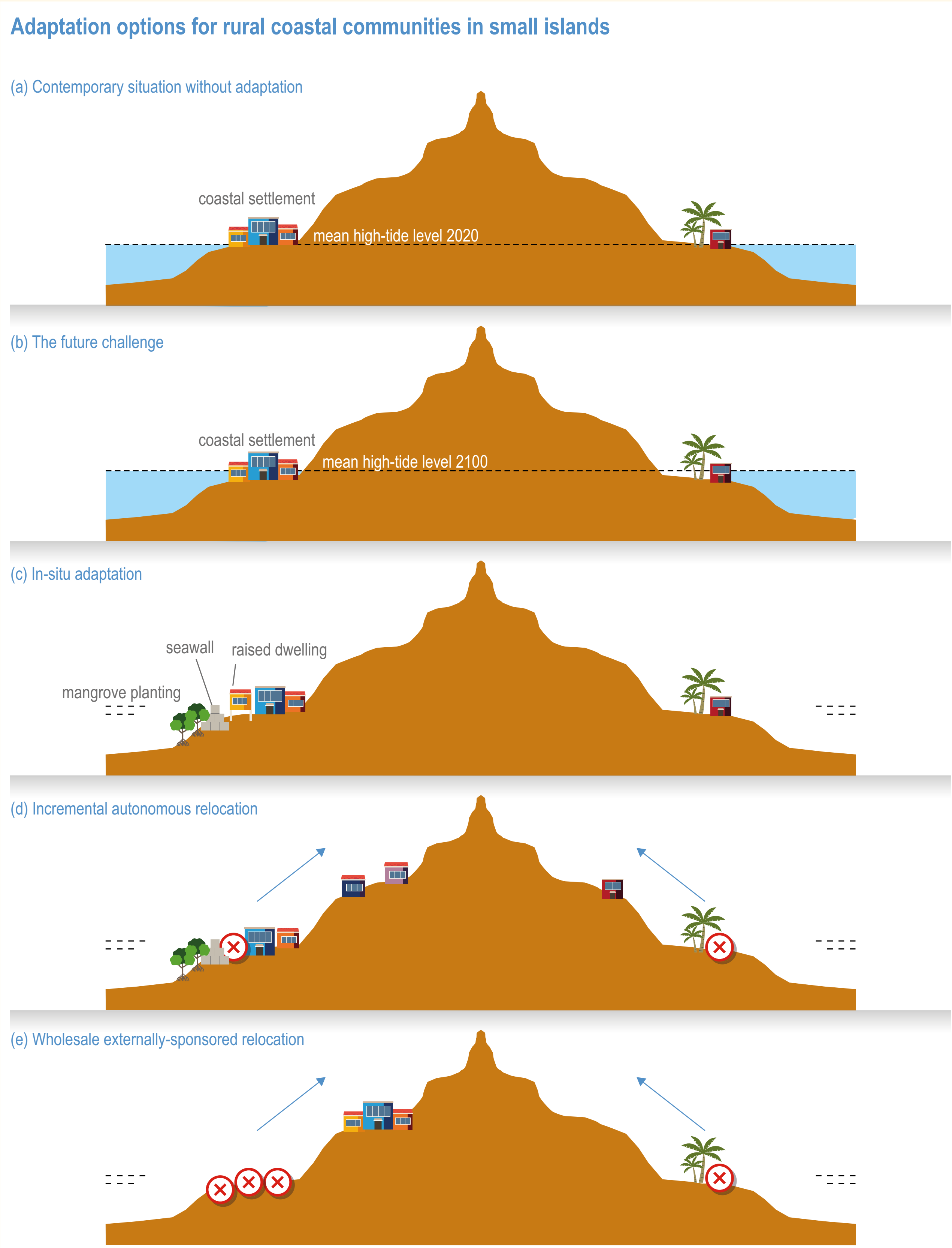

Figure FAQ15.2.1 | Adaptation options for rural coastal communities in small islands.

FAQ 15.2 (continued)

a: In many places today, coastal communities which have been established for hundreds of years are being more regularly inundated than ever before as a result of rising sea level.
b: By the end of this century, sea level in such places may have risen 1 m or more, making many such settlements (largely) uninhabitable, underscoring the need for effective (anticipatory) adaptation.
c: One option is in situ adaptation, popular because it is cheaper and less disruptive than other options; it is typically characterised by mangrove replanting, seawall construction and raising of dwellings.
d: A second option is for communities to incrementally relocate upslope by building all new houses further inland.
e: A third option is complete relocation of a vulnerable coastal community with external support upslope and inland.

Frequently Asked Questions

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

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

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

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

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

Impacts of climate change on fisheries in small islands result from ocean temperature change, sea level rise, extreme weather patterns such as cyclones, reducing ocean oxygen concentrations and ocean acidification. These combined pressures are leading to the widespread loss or damage to marine habitats such as coral reefs but also mangroves and seagrass beds and consequently of important fish species that depend on these habitats and are crucial both to the food security (a high proportion of dietary protein is derived from seafood) and incomes of island communities. Shifting ocean currents and warming waters are also changing the distribution of pelagic fish stocks, especially of open-water tuna, with further consequences for both local food security and national economies, where they are often highly dependent on income from fishing licenses (e.g., 98% of Gross Domestic Product in Tokelau, 66% of national income in Kiribati).

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

Frequently Asked Questions

FAQ CCP1.1 | Why are biodiversity hotspots important?

Biodiversity hotspots are regions that are exceptionally rich in species, ecologically unique and which may contain geographically restricted species. They are thus priority targets for nature conservation.

Recognising that the Convention on Biological Diversity definition of biodiversity includes the variation within and between species and of ecosystems, different schemes have been applied to define hotspots, leading to hundreds of different areas being proposed as hotspots. However, all identify a set of priority areas that cover a small portion of the Earth, but house an exceptionally high proportion of its biodiversity. Because biodiversity underpins all life on Earth, these hotspots have significant global value as they contain species and habitats that are found nowhere else. Their loss would mean loss of species and habitats that provide wild and farmed food, medicine and other materials, and services such as climate regulation, pollination and water purification, all of which maintain the health of the ecosystems we depend upon.

Healthy ecosystems, with flourishing biodiversity in natural conditions, are more resilient to disturbances, whether natural or human in origin. Environmentally sustainable development inside and outside hotspots could help reverse human impacts on biodiversity. The hotspots also capture and store carbon, thereby helping to mitigate climate change. Prioritisation of protecting biodiversity in hotspots thus benefits nature conservation and helps mitigate climate change. A global network of protected areas and restoration initiatives inside biodiversity hotspots can also help increase resilience to the effects of climate change on biodiversity.

Frequently Asked Questions

FAQ CCP1.2 | How can society ensure conservation of biodiversity in climate policies?

To reduce the effects of climate change on biodiversity, it is first essential to address direct human impacts that are already leading to a loss of biodiversity. This can be achieved by protecting biodiversity in conservation areas, restoring biodiversity everywhere possible and promoting sustainable development. Climate policies should thus integrate with policies to protect and restore nature.

Avoiding further loss of biodiversity is implicit in sustainable development. This needs to happen on land, rivers, lakes and in the oceans. It is especially important in 'biodiversity hotspots' (FAQ 1.1) and protected areas to minimise species losses. Hence calls by the International Union for the Conservation of Nature, Convention on Biological Diversity, United Nations Sustainable Development Goals (SDGs) to increase the size and connectivity of fully protected areas (which aim to have biodiversity in a near natural condition) and include in them the biodiversity hotspots, need to be immediately implemented.

Five of the SDGs are life on land, life below water, good health and well-being, food security and climate action. They underpin and interact with many other SDGs. Healthy ecosystems play a role in mitigating greenhouse gas emissions, not only protecting areas to prevent the release of carbon through land conversion activities but also restoring otherwise degraded land. The United Nations has declared 2021–2030 as the Decade on Ecosystem Restoration and the Decade of Ocean Science for Sustainable Development. Restoration means actively or passively allowing habitat to return to its natural state (e.g., grassland, forest, peatland, oyster beds), including replanting native vegetation. This can benefit the recovery of biodiversity, help remove carbon dioxide from the atmosphere and improve the delivery of nature's contributions to people, such as climate regulation, water purification, pollination, and pest and disease control. Thus, protecting biodiversity helps to meet two SDGs directly, and three indirectly.

On land, the loss of natural forests and grasslands not only means a loss of carbon and many of their associated species, but exposes soils to erosion, affecting food production, and can affect the climate by altering the water cycle. Sustainable development, even within hotspots, involves active restoration of natural biodiversity, reducing poaching and trafficking of wildlife (UN SDG 15), and needs to include agriculture. This includes working to ensure biodiverse soils and supporting healthy pollinator populations. Biodiversity includes not only wild species but also genetic diversity, including crops and wild crop relatives. These wild relatives may contain important genes that could help farmed crops survive better in a changed climate. At least some of these wild relatives come from areas designated as hotspots. In the ocean, sustainable development means reducing pollution, carefully managed aquaculture development, increased protected areas (from the present 2.5% of the ocean area), enforcement of fisheries regulations, and removal of fishery subsidies that perpetuate overfishing within Exclusive Economic Zones and on the High Seas (UN SDG 14). Generally, the use of freshwaters, rivers, lakes and groundwaters, has not been sustainable and there is a need to restore biodiversity and water quality by eliminating pollution and to better manage abstraction, river flows, fishing and invasive species. Thus, as is the case with land and oceans, climate policies must prioritise the restoration of freshwater biodiversity, and reduction of the current negative impacts of human activities.

Frequently Asked Questions

FAQ CCP2.1 | Why are coastal cities and settlements by the sea especially at risk in a changing climate, and which cities are most at risk?

Coastal cities and settlements (C&S) by the sea face a much greater risk than comparable inland cities and settlements because they concentrate a large proportion of the global population and economic activity, whilst being exposed and vulnerable to a range of climate- and ocean-compounded hazard risks driven by climate change. Coastal cities and settlements range from small settlements along waterways and estuaries, to small island states with maritime populations and/or beaches and atolls that are major tourist attractions, large cities that are major transport and financial hubs in coastal deltas, to megacities and even megaregions with several coastal megacities.

The concentration of people, economic activity and infrastructure dynamically interacts with coast-specific hazards to magnify the exposure of these cities and settlements to climate risks. While large inland cities and coastal settlements can be exposed to climate-driven hazards, such as urban heat islands and air pollution, the latter are also subject to distinctive ocean-driven hazards, such as sea level rise (SLR), exposure to tropical cyclones and storm surges, flooding from extreme tides and land subsidence from decreased sediment deposition along coastal deltas and estuaries. With climate change increasing, the intensity and frequency of hazards under all future warming levels and thus the risks to lives, livelihoods and property are especially acute in cities and settlements by the sea.

Coastal cities are diverse in shape, size, growth patterns and trajectories, and in terms of access to cultural, financial and ecosystem resources and services. Along deltaic and estuarine archetypes, cities most vulnerable to a changing climate have relatively high levels of poverty and inequality in terms of access to resources and ecosystem services, with large populations and dense built environments translating into higher exposure to coastal climate risks.

These climate risks at the coast can also be magnified by compounding and cascading effects due to non-climate drivers directly affecting vulnerable peri- and ex-urban areas inland. These risks include disruption to transport supply chains and energy infrastructure from airports and power plants sited along the coastline, as occurred in New York City, USA, during Hurricane Sandy in 2012. The impacts can be felt around the world through globalised economic and geopolitical linkages, for example through maritime trade and port linkages.

For open coasts, settlements on low-lying small island states and the Arctic are especially vulnerable to climate change, and sea level rise impacts in particular, well before 2100. While the economic risks may not compare to the scale of those faced in coastal megacities with high per capita Gross Domestic Product, the existential risks to some nations and an array of distinctive livelihoods, cultural heritage and ways of life in these settlements are great, even with modest sea level rise.

Frequently Asked Questions

FAQ CCP2.2 | What actions can be taken by coastal cities and settlements to reduce climate change risk?

Sea level rise (SLR) responds to climate change over long timeframes and will continue even after successful mitigation. However, rapid global mitigation of greenhouse gases significantly reduces risks to coastal cities and settlements (C&S), and, crucially, buys time for adaptation.

Appropriate actions to reduce climate change risks in coastal cities and settlements depend on the scale and speed of coastal change interacting with unfolding local circumstances, reflecting the hazards, exposure, vulnerability and response to risks.

'Hard' protection, like dikes and seawalls, can reduce the risk of flooding for several metres of sea level rise in some coastal cities and settlements. These are most cost effective for densely populated cities and some islands, but may be unaffordable for poorer regions. Although these measures reduce the likelihood of coastal flooding, residual risk remains, and hard protection typically has negative consequences for natural systems. In low-lying protected coastal zones, draining river and excess water will increasingly be hampered, eventually requiring pumping or transferring to alternative strategies.

Whereas structures can disrupt natural beach morphology processes, sediment-based protection replenishes beaches. These have lower impact on adjacent beaches and coastal ecology and lower costs for construction and maintenance compared to hard structures. Another form of 'soft' protection involves establishing, rehabilitating and preserving coastal ecosystems, like marshes, mangroves, seagrass, coral reefs and dunes, providing 'soft' protection against storm surges, reducing coastal erosion and offering additional benefits including food, materials and carbon sequestration. However, these are less effective where there is limited space in the coastal zone, limited sediment supply and under higher rates of sea level rise.

Coastal settlements can 'avoid' new flood and erosion risks by preventing development in areas exposed to current and future coastal hazards. Where development already exists, settlements can 'accommodate' climate change impacts through, among other things, land-use zoning, raising ground or buildings above storm surge levels, installing flood-proofing measures within and outside properties, and early warning systems. Improving the capacity of urban drainage, incorporating nature-based solutions within urban areas and managing land upstream of settlements to reduce runoff from the hinterland reduces the risk of compound flood events. More radically, land can also be reclaimed from the sea, which offers opportunities for further development but has impacts on the natural system and wider implications for the trajectory of development.

Coastal risks and impacts such as floods, loss of fisheries or tourism, or salinization of groundwater require people to change behaviour to adapt, such as diversifying livelihoods or moving away from low-lying areas. Currently, most of these practices are reactive and help people adjust to/cope with current impacts. While a critical part of coastal adaptation, changing behaviour can be enabled by supportive policies and financial structures aligned with sociocultural values and worldviews.

Where risks are very high or resources are insufficient to manage risks, submergence or erosion of coastal cities and settlements will be inevitable, requiring 'retreat' from the coastline. This is the outlook for millions of people in the coming decades, including those living in river deltas, Arctic communities, small islands and low-lying small settlements in poor and wealthy nations. Whilst the impacts of retreat on communities can be devastating, the prospect of many cities and settlements and even whole nations being permanently inundated in the coming centuries underscores the imperative for urgent action.

Crucial to making choices about how to mitigate greenhouse gas emissions and adapt to climate change in coastal cities and settlements is to establish institutions and governance practices supporting climate resilient development—a mix and sequence of mitigation and adaptation actions—that are fair, just and inclusive as well as technically and economically effective across successive generations.

Frequently Asked Questions

FAQ CCP2.3 | Considering the wide-ranging and interconnected climate and development challenges coastal cities and settlements face, how can more climate resilient development pathways be enabled?

Coastal cities and settlements (C&S) are on the frontline of the climate change challenge. They are the interface of three interconnected realities. First, they are critical nodes of global trade, economic activity and coast-dependent livelihoods, all of which are highly and increasingly exposed to climate- and ocean-driven hazards (FAQ CCP2.1). Second, coastal C&S are also sites where some of the most pressing development challenges are at play (e.g., trade-offs between expanding critical built infrastructure while protecting coastal ecosystems, high economic growth coupled with high inequality in some coastal megacities). Third, coastal C&S are also centres of innovation and creativity, thus presenting a tremendous opportunity for climate action through a range of infrastructural, nature-based, institutional and behavioural solutions (FAQ CCP2.2). Given these three realities of high climate change risks, rapid but contested and unequal development trajectories, and high potential for innovative climate action, C&S are key to charting pathways for climate resilient development (CRD).

Three key levers can enable pathways that are climate resilient and meet goals of inclusive, sustainable development. One key enabler involves flexible, proactive, and transparent governance systems, built on a bedrock of accountable local leadership, evidence-based decision-making—even under uncertainty—and inclusive institutions that consider different stakeholder voices and knowledge systems. Another key enabler is acknowledging the sociocultural and psychological barriers to climate action and incentivising people to change to lifestyles and behaviours that are pro-climate and aligned with community-oriented values and norms. In practice, coastal cities and settlements are experimenting with different strategies to change practices and behaviours, such as using subsidies and zoning policies, tax rebates and public awareness campaigns to promote individual and collective action. Finally, enabling climate resilient development needs dedicated short- and long-term financing to reorient current trajectories of unsustainable and unequal development towards climate mitigation and adaptation action that reduces current and predicted losses and damages, especially in highly vulnerable coasts such as the small island states, the Arctic and low-lying cities and settlements. Currently, adaptation finance is concentrated in coastal megacities and tends to be deployed for risk-proofing high-value waterfront properties or key infrastructures. Addressing these financial imbalances (globally, regionally and sub-nationally) remains a critical barrier to inclusive climate resilient coastal development.

Notwithstanding the many interconnected challenges faced, from more frequent and intense extreme events to the COVID-19 pandemic, many coastal cities and settlements are experimenting with ways to pivot towards climate resilient development. Critical enablers have been identified and lesson learned, which, if translated into practice, will enhance the prospects for advancing the Sustainable Development Goals and charting pathways for climate resilient development that are appropriate to local contexts and foster human well-being and planetary health.

Frequently Asked Questions

FAQ CCP3.1 | How has climate change already affected drylands and why are they so vulnerable?

Human-caused climate change has so far had mixed effects across the drylands, leading to fewer trees and less biodiversity in some areas and increased grass and tree cover in others. In those dryland areas with increasing aridity, millions of people face difficulties in maintaining their livelihoods, particularly where there is water scarcity.

Drylands include the hottest and most arid areas on Earth. Human-caused climate change has been intensifying this heat and aridity in some places, increasing temperatures more across global drylands than in humid areas. In areas which are hotter and drier, tree death has occurred and in some locations bird species have been lost. Climate change has reduced rainfall in some dryland areas and increased rainfall in other areas. Increased rainfall, combined with the plant-fertilizing effect of more carbon dioxide in the atmosphere, can increase grass and shrub production in dryland areas. Because water is scarce in drylands and aridity limits the productivity of agriculture, millions of people living in drylands have faced severe difficulties in maintaining their livelihoods. This challenge is exacerbated by non-climate change factors, such as low levels of infrastructure, remoteness and limited livelihood options that are less dependent on scarce natural resources. High temperatures in drylands increase the vulnerability of people to potential heat-related illnesses and deaths from heat under continued climate change.

Frequently Asked Questions

FAQ CCP3.2 | How will climate change impact the world's drylands and their people?

Climate change is projected to lead to higher temperatures across global drylands. Many drylands also risk more irregular rainfall leading to increased irregularity in crop yields and increased water insecurity where less rainfall is projected, which may have profound implications for both dryland ecosystems and their human inhabitants.

There is, however, considerable uncertainty about the changes that may occur in drylands in the future and how people and ecosystems will be affected. In some drylands, higher temperatures and declining rainfall have increased aridity. However, this is not a global trend as many drylands are experiencing increases in vegetation cover and rainfall. Both the amount of rainfall and its seasonality have changed in many dryland areas, associated with natural variability and warming.

Most climate models project increased rainfall in tropical drylands, but more variability. High natural climatic variability in drylands makes predictions uncertain. Understanding future impacts is further complicated by many interacting factors such as land use change and urbanisation that affect the condition of drylands. Future trends in sand and dust storm activity are also uncertain and will not be the same everywhere, but there will likely be increases in some regions (e.g., the USA) in the long term. The impacts of climate change in deserts and semiarid areas may have substantial implications globally: for agriculture, biodiversity, health, trade and poverty, as well as potentially, for conflicts and migration. Increasing temperatures and more irregular rainfall are expected to affect soil and water and contribute to tree death and loss of biodiversity. In other places, woody encroachment onto savannas may increase, in response to the combination of land use change, changes in rainfall, fire suppression and CO_2 fertilization. Crop yields are projected to decline in some areas, with adverse impacts on food security. The potential for conflicts and migration is primarily associated with socioeconomic development, while links to climate change remain uncertain and lack evidence.

Frequently Asked Questions

FAQ CCP3.3 | What can be done to support sustainable development in desert and semiarid areas, given projected climate changes?

Water is a major limiting factor in drylands. Many efforts to support sustainable development aim to improve water availability, access and quality, ranging from large engineering solutions that move or desalinise water, to herders' migrations with their animals to locations that have water, to land management and water harvesting practices that conserve water and support land cover. These solutions draw on IKLK and innovative science, and can help to address multiple Sustainable Development Goals.

Different desert and semiarid areas can benefit from different incremental and transformational solutions to move toward sustainable development under climate change. In some dryland areas facing critical water shortages, transformational adaptations may be needed; for example, large-scale water desalination when they have access to sea water, despite high energy use and negative environmental impacts of waste brine. In dryland agricultural areas across the world, incremental adaptations include water conservation measures, use of improved crop varieties or increasing herd mobility. What counts as a transformational change in some places may be incremental in others.

Often solutions can target multiple development goals. For example, water harvesting can make water available during drought, buffering water scarcity impacts, while also supporting food production, agricultural livelihoods and human health. Land-based approaches, e.g. restoration of grassland, shrubland, and savanna ecosystems, are important for ensuring ecological integrity, soil protection and preventing livelihoods from being undermined as a result of growing extreme weather events.

It is important that policies, investments and interventions that aim to support sustainable development take into account which groups are likely to be most affected by climate change. Those people directly dependent on natural resources for their survival are generally most vulnerable but least able to adapt. The capacity to translate Indigenous knowledge and local knowledge and experience into actions can require external support. Governments and other stakeholders can help by investing in early warning systems, providing climate information, realigning policies and incentives for sustainable management, investing in supporting infrastructures, alongside developing alternative livelihood options that are less exposed and sensitive to climate change. Involving all relevant stakeholders is important. For example, in China, the Grain for Green programme secured local engagement by paying people to manage the environment more sustainably. At a global level, important groups have emerged to cooperate and offer solutions around issues such as sand and dust storms, and integrated drought management. Efforts are needed across all scales from local to global to support sustainable development in desert and semiarid areas, given projected climate changes.

Frequently Asked Questions

FAQ CCP4.1 | Is the Mediterranean Basin a 'climate change hotspot'?

Is the Mediterranean 'a geographical area characterised by high vulnerability and exposure to climate change'? Climate change projections for the Mediterranean Basin indicate with very high consistency that the region will experience higher temperatures, less rainfall and continued sea level rise during the coming decades. Given that summers are already comparatively dry, these factors together will likely cause substantially drier and hotter conditions as well as coastal flooding, impacting people directly but also harming ecosystems on land and in the ocean.

For the Mediterranean Basin, climate models consistently project regional warming at rates about 20% above global means and reduced rainfall (–12% for global warming of 3°C). While it is not the region with the highest rate of expected warming on Earth, the Mediterranean Basin is considered particular in comparison to most other regions due to the high exposure and vulnerability of human societies and ecosystems to these changes: a 'climate change hotspot'.

Rising temperatures trigger extensive evaporation of water from all wet surfaces, notably the sea, lakes and rivers, but also from soils. Along with decreasing rainfall, this evaporation leads to shrinking water resources on land, drier soils, reduced river flow, and significantly longer and more intensive drought spells. Since the Mediterranean climate is already relatively dry and warm in the summer, any additional drought (and also heat) will affect plants, animals and people significantly, and ultimately entire societies and economies.

In general, increasing temperatures and more intensive heat waves in the basin threaten human well-being, economic activities, and also many ecosystems on land and in the ocean. Extreme rainfall events, which despite the lower total rainfall are expected to increase in intensity and frequency in some regions, generate significant risks for infrastructure and people through flash floods. Warming also affects the ocean and its ecosystems, jointly with acidification caused by atmospheric carbon dioxide. Finally, sea level rise, currently accelerating because of global ice loss, threatens coastal ecosystems, historical sites and a growing human population.

Key risks in the Mediterranean and their location for SSP5-RCP8.5 by 2100

Figure FAQ CCP4.1.1 | Key risks across the Mediterranean region by 2100. The symbols above the map highlight risks enhanced by climate change which apply to the entire region with *high confidence*. Other risks are localised in the map.

FAQ

FAQ CCP4.1(continued)

Risks associated with projected climate change are particularly high for people and ecosystems in the Mediterranean Basin due to the unique combination of many factors, including:

- A large and growing urban population exposed to heat waves, with limited access to air conditioning
- A large and growing number of people living in settlements impacted by rising sea level
- Important and increasing water shortages, already experienced by 180 million people today
- Growing demand for water by agriculture for on irrigation
- High economic dependency on tourism, which is likely to suffer from increasing heat but also from the consequences of international emission reduction policies on aviation and cruise-ship travel
- Loss of ecosystems in the ocean, wetlands, rivers and also uplands, many of which are already endangered by unsustainable practices (e.g., overfishing, land use change).

Frequently Asked Questions

FAQ CCP4.2 | Can Mediterranean countries adapt to sea level rise?

The rates of observed and projected sea level rise in the Mediterranean are similar to the Northeast Atlantic, potentially reaching 1.1 metres at the end of the present century. Erosion, flooding and the impacts of salinisation are projected to be particularly severe due to the special conditions of the coastal zones in the region. Beyond a few tens of centimetres, adaptation to sea level rise will require very large investments and may be impossible in some regions.

Sea level in the Mediterranean has been rising by only 1.4 mm yr^{-1} during the 20th century, more recently by 2.4±0.5 mm yr^{-1} from 1993 to 2012, and it is bound to continue rising in the future. Future rates are projected to be similar to the global mean (within an uncertainty of 10–20 cm), potentially reaching 1.1 m or more around 2100 in the event of 3°C of global warming (Figure FAQ CCP4.2; Table SMCCP4.4). Due to the ongoing ice loss in Greenland and Antarctica, this trend is expected to continue in coming centuries. Sea level rise already impacts extreme coastal waters around the Mediterranean and it is projected to increase coastal flooding, erosion and salinisation risks. These impacts would affect agriculture, fisheries and aquaculture, urban development, port operations, tourism, cultural sites and many coastal ecosystems.

Most of the Mediterranean Sea is a micro-tidal environment, which means that the difference between regular high and mean water levels (astronomical tides) is very small. Storm surges and waves can produce coastal floods that persist for several hours, causing particularly large impacts on sandy coasts and eventually also on coastal infrastructure. Mediterranean coasts are also characterised by narrow sandy beaches that are highly valuable for coastal ecosystems and tourism. These beaches are projected to be increasingly affected by erosion and eventually disappear where sedimentary stocks are small.

Overall, Mediterranean low-lying areas of significant width occur along 37% of the coastline and currently host 42 million inhabitants. The coastal population growth projected until 2050 mostly occurs in southern Mediterranean countries, with Egypt, Libya, Morocco and Tunisia being the most exposed countries to future sea level rise. The area at risk also hosts 49 cultural World Heritage sites, including the city of Venice and the early Christian monuments of Ravenna. The Mediterranean also includes areas subjected to sinking of the land (subsidence), including the eastern Nile Delta (Egypt) and the Thessaloniki flood plain (Greece), where local relative sea level rise can exceed 10 mm yr^{-1} today.

Mediterranean mean sea level rise from 2020–2150

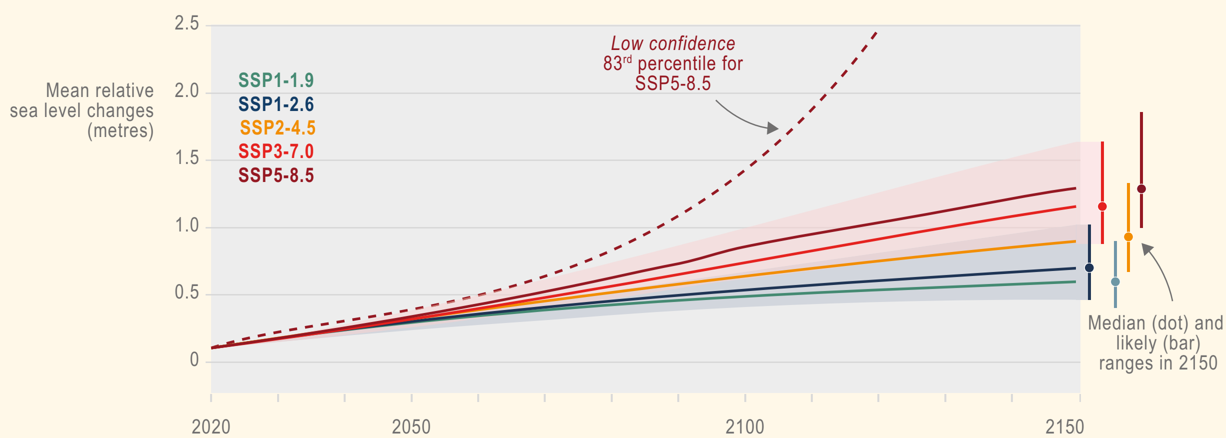

Figure FAQ CCP4.2.1 | Mediterranean Sea level projections. These projections translate the global estimates in WGI AR6 Chapter 9 to the Mediterranean Basin (Fox-Kemper et al., 2021). They assume that sea level change in the Mediterranean continues to be forced by Atlantic Sea level change seen at the Gibraltar Strait (Section CCP4.1) and thus follow the global mean beyond 2100. Vertical ground motions induced by glacial isostatic adjustments are also included, but not those due to other natural or anthropogenic processes such as tectonics or groundwater extractions. Intra-basin sea level changes are not included. Data available as supplementary material.

FAQ

FAQ CCP4.2 (continued)

Adaptation to sea level rise in the Mediterranean includes engineering or soft/ecosystem-based protection, accommodation, and retreat or managed realignment. Despite various limitations, adaptation already happens today to some extent, as for example the coastal flood and erosion protections along the subsiding Nile Delta coast. Only massive coastal protection and other sustainable development policies could reduce the growing number of people exposed to sea level rise by 20%. It appears therefore *likely* that the number of people exposed could increase by up to 130% by 2100.

Without drastic mitigation of climate change, sea level rise is projected to accelerate and will require additional coastal engineering protection projects (e.g., dykes or groynes). Despite their efficiency for the few next decades, these engineering options have also adverse impacts for coastal ecosystems and may not ensure that the recreative value of Mediterranean coasts can be sustained (see Box 13.1 on Venice on the movable barriers protecting the Venice Lagoon). Among nature-based solutions, there are immediate benefits of restoring dunes and coastal wetlands to restore a buffer zone between coastal infrastructure and the sea and therefore reduce coastal risks (Cross-Chapter Box SLR in Chapter 3). Yet, this kind of protection is not feasible everywhere, particularly in urbanised areas, where it faces its limits. The limits for adaptation in the Mediterranean to further acceleration of sea level rise have stimulated ideas of large-scale geoengineering projects such as surface height control dams at Gibraltar. However, such projects come with unknown risks for humans and ecosystems.

Frequently Asked Questions

FAQ CCP4.3 | What is the link between climate change and human migration in the Mediterranean Basin?

Climate change already influences conflict and migrations occurring within countries or regions. However, climate is only one of the multiple factors affecting conflict and migration decisions across countries and regions. It is currently not possible to attribute particular conflicts or migrations to climate change and also in the future migration will most likely depend on the economic, social and governance context.

The Mediterranean Sea is the world's most dangerous place for migrants, with more than 20,000 deaths reported since 2014. Although empirical evidence indicates that migration related to climate impacts is mostly internal to national borders, climate change is likely to contribute to migration in the Mediterranean Basin as one out of several factors. Climate impacts contribute to migration flows particularly by affecting the economic and political drivers of migration.

Many migrants attempting to cross the Mediterranean to Europe originate from sub-Saharan Africa, a region heavily affected by climate change. In West Africa, for example, migration decisions are heavily influenced by perceptions of climate change and of its economic impact on resources and income. However, projections are uncertain, because climate impacts in Africa might both increase human suffering and thus enhance mobility, but they could also limit mobility of people through lack of financial resources.

The impacts of climate change on conflicts and security are increasingly documented, especially in Africa. Climate impacts may not in itself have caused social and political unrest but can contribute to them. The conflict in Syria has occurred after the drought that marred the country in the years before, but there is no evidence for direct causal linkage. There is, however, high agreement that food insecurity and land degradation, which can be induced by climate change, are major drivers of political upheavals and instability in northern and sub-Saharan Africa.

Frequently Asked Questions

FAQ CCP5.1 | How is freshwater from mountain regions affected by climate change, and what are the consequences for people and ecosystems?

Sources of freshwater from mountains, such as rainfall, snow and glacier melt, and groundwater are strongly affected by climate change, leading to important changes in water supply in terms of quantity and, partly, quality and timing (e.g., shifts and changes in seasonality). In many cases, the effects on ecosystems and people are negative, e.g., creating or exacerbating ecosystem degradation, water scarcity or competition or conflict over water.

River flow is a main source of freshwater both in mountain regions and downstream areas. Various sources contribute to it, including rainfall, snow and glacier melt and groundwater. Climate change affects these different sources in different ways. Climate change affects rainfall patterns, such as long-term increase or decrease, seasonal shifts or changes in rainfall intensity. Rising temperatures strongly influence snowmelt- and glacier-melt-generated river discharge; the snowmelt season starts earlier, less snow mass is available for melt, and snowmelt contribution to river flow thus decreases over the year. Whether rising temperatures produce meltwater from glaciers depends on the state and characteristics of the glaciers and the catchment basin. The concept of 'peak water' implies that, first, as glaciers shrink in response to a warmer climate, more meltwater is released until a turning point (peak water), after which glaciers melt, and so its contribution to river flow decreases. In many mountain regions worldwide, glaciers and their basins have already passed peak water, and the runoff contribution of glaciers is on the decline. Glacier shrinkage not only influences river discharge but also water quality. In the Andes of Peru, for instance, it has been observed that retreating glaciers expose bedrock, resulting in more acid water because of minerals that dissolve from the rock. Mountain ecosystems are also affected by changing freshwater availability. For instance, high-elevation wetlands in the tropical Andes critically depend on glacier meltwater during the dry season, and the disappearance of this freshwater source results in ecosystem degradation.

The effect of climate change on groundwater in mountains is insufficiently understood. Infiltrating water from glaciers and snowmelt plays an important role in groundwater recharge. Groundwater recharge is expected to decrease with continued climate change in several mountain regions. In the Himalaya many springs have already been observed to be in decline.

The availability of freshwater is a function of water supply and water demand, with the latter being determined by sectors such as agriculture, energy, industry or domestic use, as well as by competition among these sectors. Formal and informal water extraction and use prevail, and competition includes issues of inequality, power relations and asymmetry. Consequently, the effects of climate change on water resources, people and ecosystems are strongly modulated and often exacerbated by socioeconomic development and related water resource management. For example, the increasing frequency and intensity of droughts in the European Alps, combined with declines and seasonal shifts of river runoff from snowmelt and glacier melt, are expected to result in growing competition among different sectors, such as hydropower, agriculture and tourism. Similar developments are projected or have already been observed in many other mountain regions. This situation calls for strengthening and improving negotiation formats for water management that are transparent, equitable and socially and environmentally just. Management of water demand and strategies that entail multiple uses of water will become increasingly important in this context.

Frequently Asked Questions

FAQ CCP5.2 | Do people in mountain regions, and further downstream, face more severe risks to water-related disasters due to climate change, and how are they coping?

Mountain regions have always been affected by either too much or too little water. Because of climate change, hazards are changing rapidly and becoming even more unpredictable. Whether or not these changes will result in more disasters locally and further downstream depends on several factors, not least the fact that more people are settling in exposed locations. People in mountains have a history of developing skills to live in a dangerous and dynamic environment, which will be invaluable in the future when combined with inclusive and long-term disaster risk reduction measures.

Water-related hazards in mountains include rainfall (pluvial) and river (fluvial) floods, extreme rainfall-induced landslides, debris flows, ice and snow avalanches and droughts. When people are exposed and vulnerable to these hazards, disasters can result. Floods and landslides in mountains contribute to and count among the most devastating disasters globally, often resulting in significant losses such as high numbers of fatalities and economic and property damage. Climate change may alter rainfall frequency/intensity distributions, potentially leading to floods and droughts. Climate change may also lead to shifts in precipitation type, with more precipitation falling as rain rather than snow in the future, which will further impact both short- and long-term water storage and, therefore, will impact downstream ecosystems and cities.

Although climate change directly affects water-related hazards, studies indicate that above and beyond natural hazards, disaster risk and disasters are influenced to a major extent by vulnerability and exposure. This is of relevance in mountains, where disaster risk is influenced by population growth, induced displacements, land use changes and inefficient water distribution systems. For example, current trends suggest that more people are settling in exposed locations, with more infrastructure being built and activities such as tourism and recreation being promoted, exacerbating this exposure.

Experiences in dealing with water-related disasters provide a basis on which to build adequate responses to increasing risks in the future. For example, upgrading infrastructure like dams and embankments can help address water shortages, but diversification of income-generating activities, such as subsistence farming moving away from certain drought-sensitive crops, can also help.

The risk perceptions of people also shape their behaviours in coping with disaster risks. For example, based on their longstanding observations and local knowledge, communities in the southern part of the Peruvian Andes identified the shrinking of glaciers, more frequent and intense extreme weather events, more extreme temperatures and shortened rainy seasons as key challenges. The recognition of local knowledge is key to addressing these challenges, as well as providing a basis for the transformation of current systems. A lack of community involvement and participation in decision making on how to address disaster risk can contribute to mismatches between perceptions and behaviours in face of those risks, and the actions needed to reduce losses. Therefore, measures which are flexible, address the objectives and needs of all those affected by disasters and bring long-term benefits have more chances of being successful in dealing with future disaster risks.

Frequently Asked Questions

FAQ CCP5.3 | Does climate change pose a risk to mountain species and ecosystems, and will this affect people?

Treeline position, bioclimatic zones and species ranges move up in elevation as the climate warms, increasing the risk of extinction for species isolated on mountain tops as a result of exceeding their physiological limits, loss of habitat or competition from colonising species. Additionally, climate change may alter the quality and quantity of food and natural products on which the livelihood of many mountain communities depends.

Mountain regions cover about a quarter of the Earth's land surface, are scattered around the globe and may support a wide range of climates within short horizontal distances. Mountains have experienced above-average warming, and this trend is expected to continue. Mountains provide a variety of goods for people, are home to many Indigenous Peoples and are attractive for tourism and recreational activities. Mountain regions support many different ecosystems, and some are very species rich. Mountain regions can be vast and diverse, and climate change and its impacts on ecosystems vary greatly from location to location.

With increasing average global temperatures, the climatic conditions under which plants and animals can thrive are shifting to higher elevations. The movement of some plant taxa towards mountain tops has been observed in recent decades. However, for species restricted to the highest elevations, there is nowhere to move to, meaning they are increasingly at risk of extinction. Climatic conditions may exceed the physiological limits for species and habitats may become unsuitable for others. There is also a risk from competition with colonising native species and invading non-native species, spreading to higher elevations, and some species cannot move quickly enough to keep pace with changes in the climate. The most vulnerable species are those that reproduce and disperse slowly and those that are isolated on mountain tops, including endemic species, which may face global extinction. In other cases, species will be lost from some parts of their current range. Mountains can, however, allow other species to survive in areas where they otherwise would not because of small-scale variations in climate with elevation or different aspects of slopes.

Changes in snow cover and snow duration are related to changes in temperature and precipitation and are also critical for plants and animals. In particular, glacier retreat and changing snow patterns affect both streamflow dynamics (including extremes) and soil moisture conditions and can cause moisture shortages during the growing season. A change in snow patterns can critically affect animal movements in mountains. Other processes creating stresses on mountain ecosystems are direct human impacts, such as the influence of grazing, tourism, air pollution and nitrogen deposition on alpine vegetation. In some cases, these impacts can be so large on the goods and services provided by alpine ecosystems that they can overshadow the effects of climate change or exacerbate its effects.

In many mountain regions, multiple sources of evidence point to tree expansions into treeless areas above (and in some cases below) the forest belt. This may increase forest productivity at the upper treeline. Treelines have moved up in the last 30–100 years in many mountain regions, including, for example, the Andes, Urals and Altai. At the same time, since the 1990s, treeline responses in different parts of the Himalaya have been highly variable, in some places advancing upslope, in others demonstrating little change and in yet others moving downwards. This can be explained by site-specific complex interactions of the positive effects of warming on tree growth, drought stress, change in snow precipitation, land use change, especially grazing, and other factors. Treelines are affected by land use and management around the globe, and changing land use practices can supersede climate change effects in some mountain regions. An upward shift in the elevation of bioclimatic zones, decreases in the area of the highest elevation zones and an expansion of the lower zones can be expected by mid-century, for example in regions such as the Himalaya.

In some regions, the livelihoods of many local mountain communities depend on access to firewood, pastures, edible plants and mushrooms, and medicinal and aromatic plants. Climate change can alter the quality and quantity of these ecosystem services; however, the degree and direction of change are context specific. The appeal and feasibility of mountains for tourism and recreational activities are also affected by climate change.

Frequently Asked Questions

FAQ CCP5.4 | What types of adaptation options are feasible to address the impacts of climate change in mountain regions under different levels of warming, and what are their limits?

The feasibility of adaptation to address risks in mountain regions is influenced by numerous factors, many of which are unique to mountain people and their environment. Adaptation efforts in mountains mainly consist of small, largely autonomous steps. Robust and flexible adaptation measures have a better chance of addressing risks, but eventually large systemic transformation will be needed in the face of higher levels of warming. Empirical evidence on what works and what does not is largely absent but urgently needed.

The term feasibility refers to climate goals and adaptation options that are possible and desirable. Feasibility is influenced by factors such as economic viability, availability of technical resources, institutional support, social capital, ecological and adaptive capacity and biophysical conditions. Establishing the feasibility of options under changing climatic and socioeconomic conditions is not an easy task, mostly because even present feasibility is difficult to assess in mountains due to a lack of systematic information on opportunities and challenges of adaptation in practice.

Underlying environmental conditions, such as limited space, shallow soils, exposure to numerous hazards, climate-sensitive ecosystems and isolation, make it particularly difficult to implement adaptation at scales relevant for implementation. Common adaptation options are often implemented at the individual, household or community level. These options are incremental and have generated observable results and outcomes. Adaptation actions that involve partial changes that do not dramatically alter established practices and behaviours seem to have better chances of being implemented than systemic or structural changes. Formal or planned adaptation efforts that are more institutionally driven constitute only a small proportion of observed adaptation in mountain regions. Where adaptation options are implemented, they often target not only climate change but an array of other issues, priorities and pressures experienced by and in those communities (e.g., livelihood diversification in farming practices).

Whether or not adaptation options are feasible says little about their effectiveness, i.e., the degree to which adaptation has been or will be successful in reducing the risks of negative impacts. Adaptation is difficult to disentangle from other factors that contribute to both increasing and decreasing risks. Since adaptation in mountains is often autonomous and unplanned, measuring its effectiveness is complex and missed by more conventional, formal or structured monitoring and evaluation frameworks.

Evidence suggests that promising measures undertaken in mountains are those that are robust under uncertain futures, allow for adaptive planning and management and respond to multiple interests and purposes. For example, multi-purpose water reservoirs can alleviate multiple stressors and address several risks, such as those from natural hazards and water shortages. Capacity-building and awareness-raising can go a long way towards ensuring that these measures are also socially acceptable if combined with more structural and systemic changes. Indeed, transformations happen slowly in mountains and it is unlikely that small steps and incremental measures will be able to cope with more severe and pervasive risks.

Overall, empirical evidence on the effectiveness of adaptations at reducing risk is largely lacking but is urgently needed to better understand what works and what does not under certain circumstances.

Frequently Asked Questions

FAQ CCP5.5 | Why are regional cooperation and transboundary governance needed for sustainable mountain development?

Regional cooperation and transboundary governance are key to managing our vast mountain resources because they do not necessarily share political boundaries. Mountain countries need to come together, share data and information, form joint management committees, jointly develop policies and take decisions that benefit all countries equitably. A lack of cooperation may lead to missed opportunities to address climate risks and adequately manage mountain resources, which could cause social unrest and spark conflict within and between countries.

Mountains are climate change hotspots that are highly susceptible to climate change. Due to rapidly changing climatic conditions, climate change is one of the major issues that would benefit from regional cooperation. The transboundary management of mountains means shared legal and institutional frameworks for sharing the benefits and costs of managing mountain ranges across boundaries, whether local or district jurisdictions within countries or indeed across national boundaries.

The IPCC's Special Report on Oceans and Cryosphere refers to governance as an 'effort to establish, reaffirm or change formal and informal institutions at all scales to negotiate relationships, resolve social conflicts and realise mutual gains'. Governance is an act of governments, NGOs, private-sector institutions and civil society in establishing rules and norms for restricting the use of common goods. Institutions can guide, constrain and shape human interaction through direct control, incentives, and processes of socialisation. How do we apply the definitions of governance and institutions in the context of mountains? Since governance not only refers to government, which is a formal arm of the state, the report also talks about other agencies such as community organisations, non-profit organisations or businesses that play a vital role in society and influence individual or collective decisions and help in preventing the overexploitation of resources.

To comprehend the processes of governance in mountain areas, we need to recognise how each of these agencies adds to the enduring task of enabling and managing change at the system level but also to preserving social structures and reconciling disputes. For the sustainable and resilient development of mountain regions, governance mechanisms may be different than those applied to the management of other resources, such as coastal zones or rivers. Mountains are also mostly transboundary and do not necessarily follow political boundaries. Mountain governance, therefore, is about managing resources across political boundaries for the benefit of all countries. This includes downstream countries that also rely on resources such as water, silt and others from these mountain regions. These include high rangelands, biodiversity hotspots, forests and glaciers, for example.

There are several examples of regional cooperation in connection with the governance of shared resources in mountains. Some examples come from the Arctic (bottom-up and science-based evolution of Arctic cooperation), Southeast Europe (regionalisation of environmental benefits) and the Hindu Kush Himalaya region (intergovernmental scientific institution for research and data sharing). Mountains share resources, so their management will benefit from cooperation among countries. Transboundary cooperation is needed not only to address transboundary climate risks and regional adaptation to climate change in mountains but also to work across countries to reduce greenhouse gas emissions.

Frequently Asked Questions

FAQ CCP6.1 | How do changes in ecosystems and human systems in the polar regions impact everyone around the globe? How will changes in polar fisheries impact food security and nutrition around the world?

Polar regions are commonly known to be experiencing particularly fast and profound climate change, which strongly affects areas and people all around the world in several ways. Physical processes taking place in these regions are critically important for the global climate and sea level. Less known is that regional climate-driven changes of ecosystems and human communities will also have far-reaching impacts on a number of sectors of human societies at lower latitudes.

Climate change has triggered rapid, unprecedented and cascading changes in polar regions that have profound implications for ecosystems and people globally. Although physically remote from the largest population centres, polar systems are inextricably linked to the rest of the world through interconnected ocean currents, atmospheric interactions and weather, ecological and social systems, commerce and trade. The nutrient-rich waters of the polar regions fuel some of the most productive marine ecosystems on earth, which in turn support fisheries for species packed with vital macronutrients that are essential for human health and well-being. The largest most sustainable fisheries in the world are located in polar waters, where a mix of ice, seasonal light and cold nutrient-rich waters fuel schools of millions of fish that swell and retract in numbers across the years, reflecting interlaced cycles of icy cold waters, lipid-rich prey and abundant predators. Polar systems thus exist in a productive balance that has supported vibrant ecocultural connections between Indigenous Peoples and the Arctic for millennia and has supported global food production and trade for centuries.

Climate change increasingly destabilises this balance with uncertain outcomes for Indigenous Peoples and local residents in the Arctic as well as for the rest of the world. Triggered by warming oceans and air temperatures, accelerated melting of sea ice, glaciers and IS in polar regions in turn impacts ocean salinity, sea levels and circulation throughout the global ocean. Warming waters have also pushed cold-adapted species poleward, eroded the cold barrier between boreal and Arctic species, and induced rapid reorganisation of polar ecosystems. Studies increasingly indicate that the complex web of physical and biological connections that have fuelled these productive regions will falter without the strong regulating influence of cryospheric change. At the same time, the global demand for food is increasing, particularly the demand for highly nutritious marine protein, placing increasing importance on stabilising polar ecological systems and minimising climate change impacts and risks.

Frequently Asked Questions

FAQ CCP6.2 | Is sea ice reduction in the polar regions driving an increase in shipping traffic?

The polar seas have captured the imagination of global nations for centuries for its natural resource, tourism, scientific, and maritime trade potential. As the polar regions are warming at two to three times the rate of the global average leading to rapid reductions in sea ice extent and thickness, international attention has been reinvigorated and investments are being made by Arctic and non-Arctic nations alike with a view to utilise newly accessible seaways. Between 2013 and 2019, ship traffic entering the Arctic grew by 25% and the total distance travelled increased by 75%. Similar shipping growth trends are evident in the Antarctic, albeit to a lesser extent. Expected growth in Arctic shipping will influence a suite of cascading environmental and cultural risks with implications for Indigenous Peoples.

There has been debate among shipping stakeholders, rightsholders and experts about the extent to which climate change and sea ice change is directly influencing increases in shipping activity in the polar regions relative to other social, technological, political and economic factors such as commodity prices, tourism demand, global economic trends, infrastructure support and service availability. Understanding the connection between climate change and polar shipping activity will allow for more reliable projections of possible future traffic trends and will aid in identifying appropriate adaptation and infrastructure needs required to support future management of the industry.

Recent studies have observed increasing statistical correlations between sea ice change and shipping trends in the polar regions, and many have concluded that although economic factors remain the main driver of shipping activities, followed by infrastructure availability, climate change does indeed play a varying but important role in influencing operator intentions. The 'opening of polar seaways' due to sea ice reduction is indeed 'enabling' opportunities for polar shipping among all types of vessels due to increasingly accessible areas that were previously covered by multi-year ice, but the extent to which climate change will specifically 'drive' an increase in shipping demand remains highly dependent on the vessel type and the reasons for operation.

There are certain vessel types, such as those supporting international trade, mining operations or community re-supply, where analysis shows no correlation or weak correlations with sea ice change, suggesting that climate change is enabling these types of ships via increased open water areas and season lengths but that it is not necessarily driving demand. Conversely, there are certain vessel types, such as yachts and cruise ships, where correlations between sea ice change and traffic increases are stronger, and where there is evidence to suggest that these vessels are indeed driven to visit the polar regions because they perceive waterways as exotic and exciting due to being newly accessible or they want to have a Polar experience before it disappears or is irreversibly changed as is the case with last chance tourists. As sea ice recedes and polar shipping opportunities grow, there will be an increased need to better identify and implement Indigenous self-determined and equitable shipping governance frameworks that facilitate benefits and minimise risks.

Box FAQ CCP6.2 (continued)

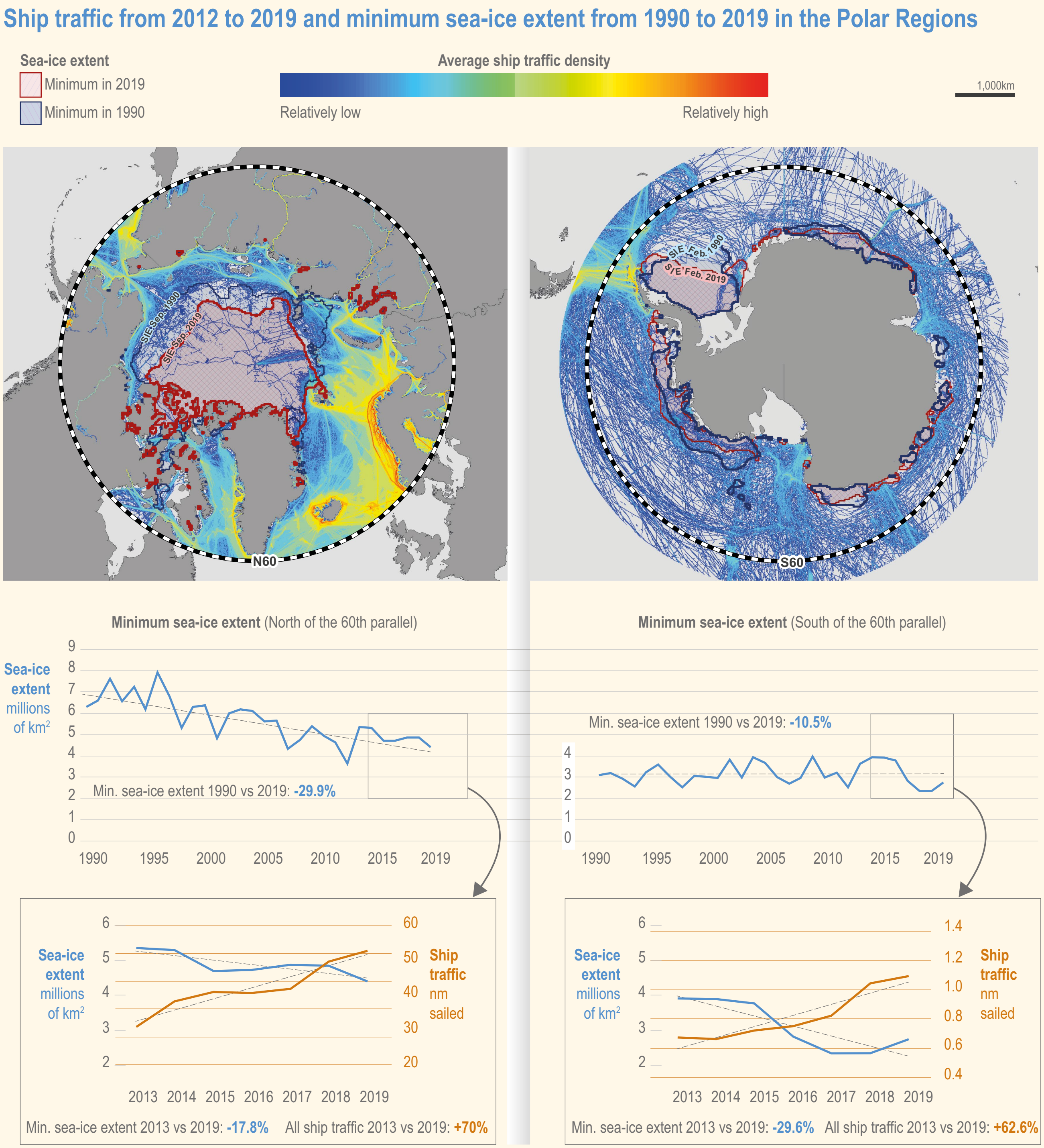

Figure FAQ CCP6.2.1 | Projected operational accessibility along Arctic maritime trade routes (Northwest Passage, Transpolar Route and Northern Sea Route) under future warming (left) and observed increases in commercial ship traffic along the routes from 2012 to 2019.

FAQ

Frequently Asked Questions

FAQ CCP6.3 | How have arctic communities adapted to environmental change in the past and will these experiences help them respond now and in the future?

For thousands of years, Arctic Indigenous Peoples and local communities have survived several major changes to the ecosystems on which they rely; however, the present changes in climate are more challenging than pre- and early historic changes in the Arctic, and polar communities will now face new unprecedented risks.

The challenges for responding to present change are due to the multiple imposed and simultaneous drivers combined with elimination and/or removal of endemic capacity to respond in culturally and locally appropriate ways. Adapting in the past may therefore inform and produce novel solutions for the present and convey baselines of important contextual information on significance of change. Arctic communities, especially Indigenous Peoples, have been marginalised in terms of their autonomous responses spaces and self-assessment that could be made without external pressures. Therefore, to increase the possibility of community-led adaptation, colonialism and the resultant lack of upheld rights, resources and equity need to be solved simultaneously with the present climate change impacts. New research, governance, policy and collaborations are needed to effectively adapt to risks that are projected to emerge in the polar regions as a result of rapid climate change.

Frequently Asked Questions

FAQ CCP6.4 | When will climate change impacts in polar regions surpass our ability to adapt?

When environmental variability is within the range of the current adaptive management approaches, the social–ecological system can thrive. However, the rapidly changing polar systems are causing disruptions to societies, economies and ecosystems. The current management systems are yet to develop procedures for managing rapid change being experienced in warming waters, sea ice declines, permafrost thaw and erosion, and poleward shifts in species. These challenges are expected to become more pronounced within a few decades rather than later this century.

Polar regions are naturally dynamic environments. Ecosystems in polar regions, and the people who rely on them, have adapted to natural variability and dynamic nature of polar environments. Fish populations in polar regions are known to exhibit cycles of productivity, and shift their distribution across hundreds of kilometres in response to changes in winter sea ice cover and concomitant summer ocean conditions. Management of the productive fisheries in polar regions is also designed to allow for these changes, using adaptive and ecosystem-based approaches that buffer populations from overexploitation and also stabilise fisheries, livelihoods and food resources. Indigenous Peoples diversify their subsistence harvest across species and resources and, therefore, similarly stabilise food and nutritional security.

When environmental variability is within the range of these adaptive measures, the social–ecological system can thrive. Thus, there are fundamental components in place in polar regions already to help ecosystems and people adapt to some degree of climate change. However, as climate change impacts like warming waters, sea ice loss, permafrost thaw and erosion systematically alter components of the system, shift species increasingly poleward, and disrupt linkages between species and people, the ability to adapt is reduced. There are critical tipping points (e.g., sea ice melt, permafrost thaw) where changes may cascade, self-reinforce and accelerate, outpacing adaptation actions and force natural and human systems irreversibly (on the scale of human existence) into novel regimes. The risk of crossing tipping points is greater and the probability much increased after mid-century under scenarios without global carbon mitigation (SSP5 8.5), where changes are largest and most rapid.

Frequently Asked Questions

FAQ CCP7.1 | How is climate change affecting tropical forests and what can we do to protect and increase their resilience?

Global warming, droughts, extreme rainfalls and sea level rise cause significant impacts on tropical forests.

In addition to climate change, tropical forests are experiencing non-climatic stressors. Conversion of forest into large-scale agriculture land and exploitation of timber and non-timber forest products are increasing pressure and amplifying the impacts of climate change on the remaining areas of tropical forests. These include biodiversity decline, increases of fires, large-scale ecosystem transformation (e.g., into savannah in southeastern Amazon) and increasing carbon emissions due to deforestation, forest conversion and forest degradation. Further, loss of forest resources leads to the decline of livelihoods of Indigenous Peoples and local communities. All nations need to collaborate to implement collective actions to protect tropical forests.

Tropical forests are essentially important for the health of planet Earth. Tropical forests in Asia, Africa and South America regulate carbon, water and chemical cycles, which maintain a healthy climate and nutrient cycles for supporting life. Tropical forests are home to two-thirds of our world's biodiversity, although they cover only about 13% of the land on Earth, but it is not known exactly how many millions of living creatures, such as microorganisms, insects, amphibians, snakes, fish, birds, mammals and primates, live in tropical forests.

Approximately 1.3 billion people directly depend upon tropical forest resources to survive. Others are indirectly dependent upon the health and provisioning of ecosystem services and goods from tropical forests. The forests provide many kinds of economic products, such as timber, medicines and food, and recreational services, such as nature trekking, bird and wildlife watching, to mention a few. Indigenous People and other forest-dependent communities have shown extraordinary knowledge on how to manage forest resources to meet their subsistence needs without causing forest degradation. This forest culture and wisdom are broken when the rate of forest extraction changes into unplanned and unsustainable large-scale transformation.

Deforestation and land-use changes in tropical forests cause not only physical and biological changes on flora and fauna, but also rapid changes in cultures harming forest peoples. A degraded tropical forest is prone and more vulnerable to climate change. An increase in temperature in lowlands creates an unfavourable condition for optimum growths of many kinds of plant species which also affects several agricultural plants. Coffee farmers, for example, are forced to open new forest frontiers in highland areas to meet an optimum temperature for the growth of coffee.

The onset and duration of dry and rainy seasons also changes. A prolonged wet season has excessive rains which cause flash floods and substantially disturbs the fruiting cycle of many plant species. Due to high rainfall and high humidity, most flowers of forest trees fail to mature, and hence essentially deplete fruit production. Most trees in tropical forests require a short period of a dry season to have a mass fruiting season. On the other hand, a prolonged dry season causes soils to dry in deeper layers, higher atmospheric demand for water vapour and enhanced forest fires. In the tropical humid forests, the majority of forest fires are anthropogenic. In Southeast Asia, peat fires cause large carbon emissions and haze pollution which harms locals and people in neighbouring countries. The impact on tropical forest comes also from the sea level rise which is due to changes in salinity and sedimentation rates, and the expansion of inundated areas leads to the decline of mangrove productivity.

Projected impacts of climate change on the tropical forest might be detrimental to safeguards of local communities and a significant number of flora and fauna in the tropics. In southeastern Amazon, reduction in precipitation, due to changes in the climate pattern, associated with intense deforestation and land cover change are leading to reduction of productivity in the remaining forest areas, and might lead to a large-scale change in the forest structure which can become a savannah. In Southeast Asia, in particular in Indonesia and Malaysia, prolonged dry seasons associated with the El Niño phenomenon cause extensive peat fires, releasing large amounts of carbon dioxide and creating various health problems related to haze pollution. Furthermore, climate change interacts with deforestation for agriculture (crops, livestock and plantation forestry), logging, mining or infrastructure development, exacerbating temperature and rainfall changes resulting in more degradation.

Box FAQ CCP7.1 (continued)

Climate change, together with forest fragmentation and deforestation, also harms wildlife. For example, the orangutan, an endemic species to tropical peat forests in Kalimantan and Sumatra, is classified as critically endangered. Many other endemic and unknown species of flora in tropical forests are in the same condition and could experience a mass extinction at a more rapid rate than the previous five mass extinctions on Earth. About 1.3 million Indigenous Peoples depending on the natural resources of the tropical forest would suffer from cultural disruption and livelihood change due to forest loss.

To protect tropical forests a collective action of all nations is needed. It requires a global effort to stop deforestation and the conversion of tropical forests. The role of Indigenous Peoples and local communities as forest keepers must be strengthened. Economic incentives for protecting tropical forests, among other strategies, could facilitate collective actions towards a sustainable management of tropical forests. Sustainable, effective and just strategies to increase the resilience of tropical forests need to consider the complex political, social and economic dynamics involved, including the goals, identity and livelihood priorities of Indigenous Peoples and local communities beyond natural resource management. Strategies can benefit from integrating knowledge and know-how from traditional cultures, fostering transitions towards more sustainable systems.

Frequently Asked Questions

FAQ 16.1 | What are key risks in relation to climate change?

A few clusters of key risks can be identified which have the potential to become particularly severe and pose significant challenges for adaptation worldwide. These risks, therefore, deserve special attention. They include risks to important resources such as food and water, risks to critical infrastructures, economies, health and peace, as well as risks to threatened ecosystems and coastal areas.

The IPCC defines key risks related to climate change as potentially severe risks that are relevant to the primary goal of the United Nations Framework Convention on Climate Change treaty to avoid 'dangerous human interference with the climate system', and whatever the scale considered (global to local). What constitutes 'dangerous' or 'severe' risks is partly a value judgement and can therefore vary widely across people, communities or countries. However, the severity of risks also depends on criteria like the magnitude, irreversibility, timing, likelihood of the impacts they describe, and the adaptive capacity of the affected systems (species or societies). The Working Group II authors use these criteria in various ways to identify those risks that could become especially large in the future owing to the interaction of physical changes to the climate system with vulnerable populations and ecosystems exposed to them. For example, some natural systems may be at risk of collapsing, as is the case for warm-water coral reefs by mid-century, even if global warming is limited to +1.5°C. For human systems, severe risks can include increasing restriction of water resources that are already being observed; mortality or economic damages that are large compared with historical crises; or impacts on coastal systems from sea level rise and storms that could make some locations uninhabitable.

More than 120 key risks across sectors and regions have been identified by the chapters of this report, which have then been clustered into a set of 8 overarching risks, called representative key risks, which can occur from global to local scales but are of potential significance for a wide diversity of regions and systems globally. As shown in Figure 16.1.1, the representative key risks include risks to (a) low-lying coastal areas, (b) terrestrial and marine ecosystems, (c) critical infrastructures and networks, (d) living standards, (e) human health, (f) food security, (g) water security and (h) peace and human mobility.

These representative key risks are expected to increase in the coming decades and will depend strongly not only on how much climate change occurs, but also on how the exposure and vulnerability of society changes, as well as on the extent to which adaptation efforts will be effective enough to substantially reduce the magnitude of severe risks. The report finds that risks are highest when high warming combines with development pathways with continued high levels of poverty and inequality, poor health systems, lack of capacity to invest in infrastructure, and other characteristics making societies highly vulnerable. Some regions already have high levels of exposure and vulnerability, such as in many developing countries as well as communities in small islands, Arctic areas and high mountains; in these regions, even low levels of warming will contribute to severe risks in the coming decades. Some risks in industrialised countries could also become severe over the course of this century, for example if climate change affects critical infrastructure such as transport hubs, power plants or financial centres. In some cases, such as coral reef environments and areas already severely affected by intense extreme events (e.g., recent typhoons or wildfires), climate risks are already considered severe.

Box FAQ 16.1 (continued)

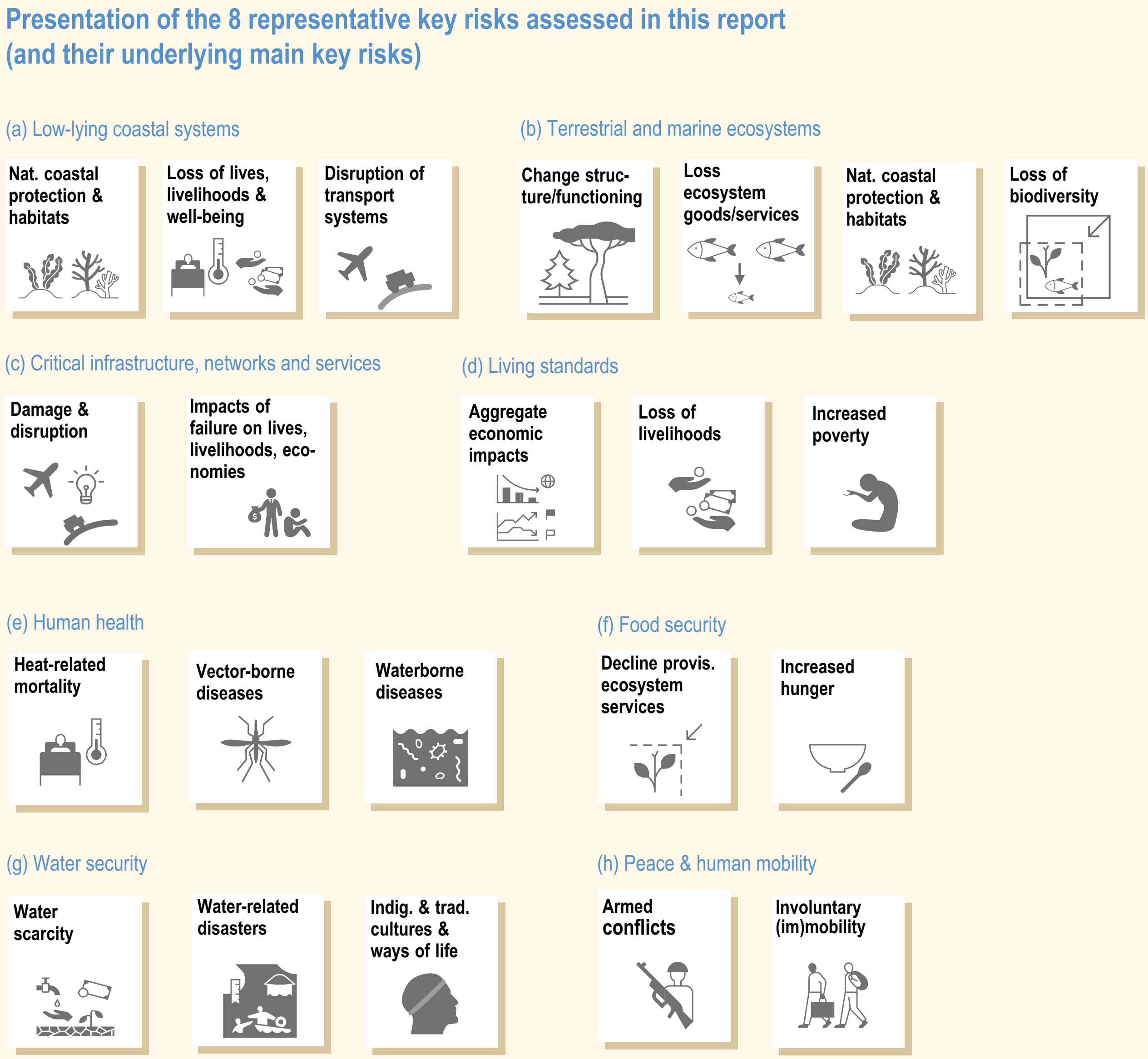

Figure FAQ16.1.1 | Presentation of the eight representative key risks assessed in this report (and their underlying main key risks).

Frequently Asked Questions

FAQ 16.2 | How does adaptation help to manage key risks and what are its limits?

Adaptation helps to manage key risks by reducing vulnerability or exposure to climate hazards. However, constraining factors make it harder to plan or implement adaptation and result in adaptation limits beyond which risks cannot be prevented. Limits to adaptation are already being experienced, for instance by coastal communities, small-scale farmers and some natural systems.

Adaptation-related responses are actions that are taken with the intention of managing risks by reducing vulnerability or exposure to climate hazards. While mitigation responses aim to reduce greenhouse gas emissions and slow warming, adaptations respond to the impacts and risks that are unavoidable, either due to past emissions or failure to reduce emissions. However, while these responses intend to reduce risks, it is difficult to determine precise levels of risk reduction that can be attributed to adaptation. Changing levels of risk as well as other actions—such as economic development—make it challenging to definitively connect specific levels of risk reduction with adaptation. Although it is not feasible to assess the adequacy of adaptation for risk reduction at global or regional levels, evidence from specific localised adaptation projects do show that adaptation-related responses reduce risk. Moreover, many adaptation measures offer near-term co-benefits related to mitigation and to sustainable development, including enhancing food security and reducing poverty.

Adaptation responses can occur in natural systems without the intervention of humans, such as species shifting their range, time of breeding, or migration behaviour. Humans can also assist adaptation in natural systems through, for example, conservation activities such as species regeneration projects or protecting ecosystem services. Other adaptation-related responses by humans aim to reduce risk by decreasing vulnerability and/or exposure of people to climate hazards. This includes infrastructural projects (e.g., upgrading water systems to improve flood control), technological innovation (e.g., early-warning systems for extreme events), behavioural change (e.g., shift to new crop types or livelihood strategies), cultural shifts (e.g., changing perspectives on urban greenspace, or increased recognition of Indigenous knowledge and local knowledge) and institutional governance (e.g., adaptation planning, funding and legislation).

While adaptation is important to reduce risk, adaptation cannot prevent all climate impacts from occurring. Adaptation has soft and hard limits, points at which adaptive actions are unable to prevent risks. Soft limits can change over time as additional adaptation options become available, while hard limits will not change as there are no additional adaptive actions that are possible. Soft limits occur largely due to constraints—factors that make it harder to plan and implement adaptation, such as lack of financial resources or insufficient human capacity. Across regions and sectors, the most challenging constraints to adaptation are financial and those related to governance, institutions and policy measures. Limited funding and ineffective governance structures make it difficult to plan and implement adaptation-related responses which can lead to insufficient adaptation to prevent risks. Small-scale farmers and coastal communities are already facing soft limits to adaptation as measures that they have put in place are not enough to prevent loss. If constraints that are limiting adaptation are addressed, then additional adaptation can take place and these soft limits can be overcome. Evidence on limits to adaptation is largely focused on terrestrial and aquatic species and ecosystems, coastal communities, water security, agricultural production, and human health and heat.

Adaptation is critical for responding to unavoidable climate risks. Greater warming will mean more and more severe impacts requiring a high level of adaptation which may face greater constraints and reach soft and hard limits. At high levels of warming, it may not be possible to adapt to some severe impacts.

Frequently Asked Questions

FAQ 16.3 | How do climate scientists differentiate between impacts of climate change and changes in natural or human systems that occur for other reasons?

We can already observe many impacts of climate change today. The large body of climatic impact data and research confirms this. To decide whether an observed change in a natural or human system is at least partly an impact of climate change, we systematically compare the observed situation with a theoretical situation without observed levels of climate change. This is detection and attribution research.

Global mean temperature has already risen by more than 1°C, and that also means that the impacts of climate change become more visible. Many natural and human systems are sensitive to weather conditions. Crop yields, river floods and associated damages, ecosystems such as coral reefs, or the extent of wildfires are affected by temperatures and precipitation changes. Other factors also come into play. So, for example, crop yields around the world have increased over the last decades because of increasing fertilizer input, improved management and varieties. How do we detect the effect of climate change itself on these systems, when the other factors are excluded? This question is central for impact attribution. 'Impact of climate change' is defined as the difference between the observed state of the system (e.g., level of crop yields, damage induced by a river flood, coral bleaching) and the state of the system assuming the same observed levels of non-climate-related drivers (e.g., fertilizer input, land use patterns or settlement structures) but no climate change.

So:

'Impact of climate change' is defined as the difference between the observed state of the system and the state of the system assuming the same observed levels of non-climate-related drivers but no climate change. For example, we can compare the level of crop yields, damage induced by a river flood, and coral bleaching with differences in fertilizer input, land use patterns or settlement structures, without climate change and with climate change occurring.

While this definition is quite clear, there certainly is the problem that, in real life, we do not have a 'no climate change world' to compare with. We use model simulations where the influence of climate change can be eliminated to estimate what might have happened without climate change. In a situation where the influence of other non-climate-related drivers is known to be minor (e.g., in very remote locations), the non-climate-change situation can also be approximated by observation from an early period where climate change was still minor. Often, a combination of different approaches increases our confidence in the quantification of the impact of climate change.

Impacts of climate change have been identified in a wide range of natural, human and managed systems. For example, climate change is the major driver of observed widespread shifts in the timing of events in the annual cycle of marine and terrestrial species, and climate change has increased the extent of areas burned by wildfires in certain regions, increased heat-related mortality, and had an impact on the expansion of vector-borne diseases.

In some other cases, research has made considerable progress in identifying the sensitivity of certain processes to weather conditions without yet attributing observed changes to long-term climate change. Two examples of weather sensitivity without attribution are observed crop price fluctuations and waterborne diseases.

Finally, it is important to note that 'attribution to climate change' does not necessarily mean 'attribution to anthropogenic climate change'. Instead, according to the IPCC definition, climate change means any long-term change in the climate system, no matter where it comes from.

Frequently Asked Questions

FAQ 16.4 | What adaptation-related responses to climate change have already been observed, and do they help reduce climate risk?

Adaptation-related responses are the actions taken with the intention of managing risks by reducing vulnerability or exposure to climate hazards. Responses are increasing and expanding across global regions and sectors, although there is still a lot of opportunity for improvement. Examining the adequacy and effectiveness of the responses is important to guide planning, implementation and expansion.

The most frequently reported adaptation-related responses are behavioural changes made by individuals and households in response to drought, flooding and rainfall variability in Africa and Asia. Governments are increasingly undertaking planning, and implementing policy and legislation, including, for example, new zoning regulations and building codes, coordination mechanisms, disaster and emergency planning, or extension services to support farmer uptake of drought tolerant crops. Local governments are particularly active in adaptation-related responses, particularly in protecting infrastructure and services, such as water and sanitation. Across all regions, adaptation-related responses are strongly linked to food security, with poverty alleviation a key strategy in the Global South.

Overall, however, the extent of adaptation-related responses globally is low. On average, responses tend to be local, incremental, fragmented, and consistent with Business-As-Usual practices. There are no global regions or sectors where the overall adaptation-related response has been rapid, widespread, substantial and has overcome or challenged key barriers. The extent of adaptation thus remains low globally, with significant potential for increased scope, depth, speed and the challenging of adaptation limits. Examples of low-extent adaptations include shifts by subsistence farmers in crop variety or timing, household flood barriers to protect houses and gardens, and harvesting of water for home and farm use. In contrast, high-extent adaptation means that responses are widespread and coordinated, involve major shifts from normal practices, are rapid, and challenge existing constraints to adaptation. Examples of high-extent adaptations include planned relocation of populations away from increasingly flood-prone areas, and widely implemented social support to communities to prevent migration or displacement due to climate hazards.

Increasing the extent of adaptation-related responses will require more widespread implementation and coordination, more novel and radical shifts from Business-As-Usual practices, more rapid transitions, and challenging or surmounting limits—key barriers—to adaptation. This might include, for example, best-practice programmes implemented in a few communities being expanded to a larger region or country, accelerated implementation of behaviours or regulatory frameworks, coordination mechanisms to support deep structural reform within and across governments, and strategic planning that challenges fundamental norms and underlying constraints to change.

We have very little information on whether existing adaptation-related responses that have already been implemented are reducing climate risks. There is evidence that risks due to extreme heat and flooding have declined, though it is not clear if these are due to specific adaptation-related responses or general and incremental socioeconomic development. It is difficult to assess the effectiveness of adaptation-related responses, and even more difficult to know whether responses are adequate to adapt to rising climate risk. These remain unknown but important questions in guiding implementation and expansion of adaptation-related responses.

Frequently Asked Questions

FAQ 16.5 | How does climate risk vary with temperature?

Climate risk is a complex issue, and communicating it is fraught with difficulties. Risk generally increases with global warming, though it depends on a combination of many factors such as exposure, vulnerability and response. To present scientific findings succinctly, a risk variation diagram can help visualise the relationship between warming level and risk. The diagram can be useful in communicating the change in risk with warming for different types of risk across sectors and regions, as well as for five categories of global aggregate risk called 'Reasons for Concern'.

A picture speaks a thousand words. The use of images to share ideas and information to convey scientific understanding is an inclusive approach for communicating complex ideas. A risk variation diagram is a simple way to present the risk levels that have been evaluated for any particular system. These diagrams take the form of bar charts where each bar represents a different category of risk. The traffic light colour system is used as a basis for doing the risks, making it universally understandable. These diagrams are known colloquially as 'burning ember' diagrams, and have been a cornerstone of IPCC assessments since the Third Assessment Report, and further developed and updated in subsequent reports. The fact that the diagrams are designed to be simple, intuitive and easily understood with the caption alone has contributed to their longstanding effectiveness. Here, in Figure FAQ16.5.1 below, we provide a simplified figure of this chapter's burning embers for five categories of global aggregate risk, called Reasons for Concern (RFCs), which collectively synthesise how global risk changes with temperature. The diagram shows the levels of concern that scientists have about the consequences of climate change (for a specified risk category and scope), and how this relates to the level of temperature rise.

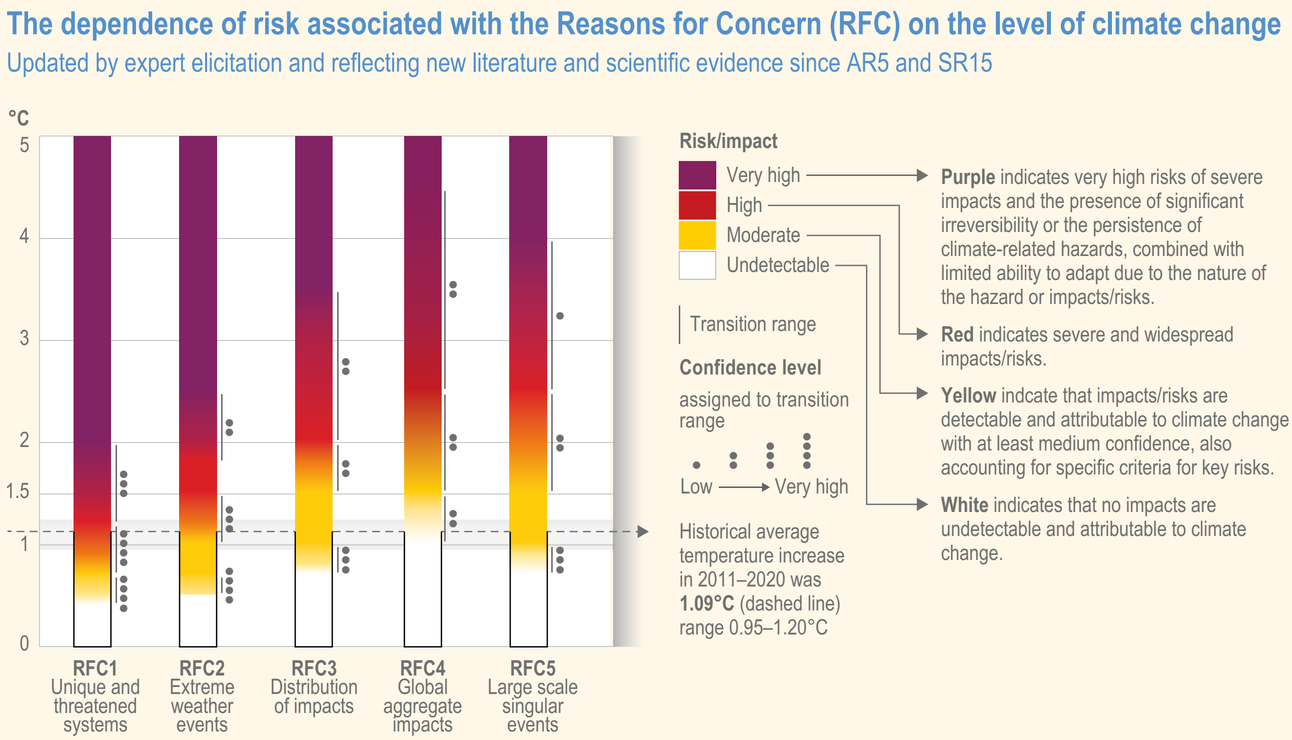

Figure FAQ16.5.1 | Simplified presentation of the five Reasons for Concern burning ember diagrams as assessed in this report (adapted from Figure 16.15). The colours indicate the level of risk accrual with global warming for a low-adaptation scenario. RFC1 Unique and threatened systems: ecological and 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 People, 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 owing 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.

Box FAQ 16.5 (continued)

In this diagram, the risk variation bars or embers are shown with temperature on the *y*-axis, and the base of the ember corresponds to a baseline temperature. Typically, this baseline temperature is that before global warming started (i.e., average temperatures for the pre-industrial period of 1850–1900). This area of the ember appears white, which indicates no to negligible impacts due to climate change. Moving up the ember bar, changing colours show the increase in risk as the Earth warms globally in terms of degrees Celsius—yellow for moderate risk, red for high risk, and purple for very high risk. Definitions of the risk levels are presented in Figure FAQ16.5.1 The risk transitions are informed by the latest literature and scientific evidence, and developed through consultation and development of consensus among experts. The bars depict an averaged assessment across the world, which has the disadvantage of hiding regional variation. For example, some locations or regions could face high risk even when the global risk level is moderate.

When the embers for different risk categories are placed next to each other, it is possible to compare risk levels at different levels of global warming. For example, at 1°C warming all embers appear yellow or white, so it is possible to say that keeping global warming below that particular temperature would help ensure risks remain moderate for all five categories of concern assessed. In contrast, at 2°C warming, risk levels have transitioned to high for all categories assessed, and even reach a very high level of risk in the case of unique and threatened systems.

Frequently Asked Questions

FAQ 16.6 | What is the role of extreme weather events in the risks we face from climate change?

Climate change has often been perceived as a slow and gradual process, but by now it is abundantly clear that many of its impacts arise through shocks, such as extreme weather events. Many places are facing more frequent and intense extremes, and also more surprises. The impact of such shocks is shaped by exposure and vulnerability, where we live, and how we are prepared for and able to cope with shocks and surprises.

The rising risk of extreme events is one of the major Reasons for Concern about climate change. It is clear that this risk has already increased today. Many recent disasters already have a fingerprint of climate change.

There are large differences in such risks from country to country, place to place, and person to person. This is of course partly due to differences in hazards such as heatwaves, floods, droughts, storms, storm surges, etc., and the way those hazards are influenced by climate change. However, an even more important aspect is people's exposure and vulnerability: do these hazards occur in places where people live and work, and how badly do they affect people's lives and livelihoods? Some groups are especially vulnerable, for instance elderly in the case of heatwaves, or people with disabilities in the case of floods. In general, poor and marginalised people tend to be much more affected than rich people, partly because they have fewer reserves and support systems that help them to prepare for, cope with and recover from a shock. On the other hand, absolute economic losses are generally higher in richer places, simply because more assets are at risk there.

Many problems caused by extreme weather do not just appear because of one weather extreme, but due to a combination of several events. For instance, dryness may increase the risk of a subsequent heatwave. But the increased risk may also cascade through human systems, for instance when several consecutive disasters erode people's savings, or when a heatwave reduces the ability of power plants to produce electricity, which subsequently affects availability of electricity to turn on air conditioning to cope with the heat. Many shocks also have impacts beyond the place where they occur, for instance when a failed harvest affects food prices elsewhere. Climate risks can also be aggravated by other shocks, such as in the case of coronavirus disease 2019 (COVID-19), which not only had a direct health impact, but also affected livelihoods around the world and left many people much more vulnerable to weather extremes.

Understanding the risks we face can help in planning for the future. This may be a combination of short-term preparation, such as early-warning systems, and longer-term strategies to reduce vulnerability, for instance through urban planning, as well as reducing greenhouse gases to avoid longer-term increases in risk. Many interventions to increase people's resilience are effective in the face of a range of shocks. For instance, social safety nets can help mitigate the impact of a drought on farmers' livelihoods, but also of the economic impacts of COVID-19.

Climate-related shocks are threats to society, but they can also offer opportunities for learning and change. Recent disasters can motivate action during a short window of opportunity when awareness of the risks is higher and policy attention is focused on solutions to adapt and reduce risk. However, those windows tend to be short, and attention is often directed at the event that was recently experienced, rather than resilience in the face of a wider range of risks.

Frequently Asked Questions

FAQ 17.1 | Which guidelines, instruments and resources are available for decision makers to recognise climate risks and decide on the best course of action?

Guidelines, instruments and resources to identify options for managing risks, and support decisions on the most suitable course of actions to take, can be collectively referred to as decision-support frameworks. These can include data services, decision-support tools, processes for making decisions and methods for monitoring and evaluating progress and success. Data services enable the identification, location and timing of risks that could manifest with negative impacts, as well as potential opportunities. Often, these are termed 'climate services' and assist with mapping hazards and how they are changing. Decision-support tools range from qualitative approaches to determining overlap of areas of concern with those hazards in the future, to more quantitative and dynamic simulation approaches that enable dynamic stress-testing of adaptation options and strategies to determine if proposed plans for adapting to the future could be successful. An important consideration is whether options for risk management or capitalisation on opportunities will limit options and flexibility for responding to unforeseen events in the future. If these options have a negative effect on other areas of concern, then they could be identified in these planning scenarios as maladaptations, and therefore avoided.

A great challenge for decision makers is how to choose effective options when the future is uncertain. Uncertainty can arise not just in the statistical error of the magnitude of risk but also in the nature and consequence of risk from uncertainty about mechanisms that link areas of concern to hazards, uncertainty in the decision processes themselves and so on. Methods are available to help develop no-regret options, commonly referred to as decision-making under conditions of deep uncertainty'.

Decision-support frameworks are most successful when they are iterative, integrative and consultative. Rather than a single decision be made, and an action taken, there are processes for making the best decision possible, then monitoring progress towards delivering a successful outcome. Given a set of suitable indicators with regular monitoring, decisions can be revised, updated or changed as the future unfolds and foundations for the original decision tested. This is important because climate responses need to be initiated well in advance of them being needed due to the time required to implement suitable responses. These forward-looking approaches allow errors to occur and corrections made before problems arise. They also enable action to be taken without having to wait for the circumstances to arise, which if this were to occur could result in only limited reactions being available and the outcomes then dependent upon recovery from events rather than proactive planning and avoidance of events. Integrated approaches to risk management are available to help manage portfolios of interacting risks, including the potential for compounding and cascading risks when climate-related events arise.

Managing uncertainty with forward-looking processes needs to be more deliberative and oriented towards building trust in a collaborative process. Building relationships through informal, bottom-up processes enables this to occur. Top-down planning processes are important for ensuring that the management of risks and opportunities do not end up with maladaptations and that the approaches are equitable and proportional to that which is needed to manage the risks.

Frequently Asked Questions

FAQ 17.2 | What financing options are available to support adaptation and climate resilience?

What do we mean by 'climate finance'?

The UNFCCC has no formally agreed upon definition of climate finance. The current IPCC definition is: '*the financial resources devoted to addressing climate change by all public and private actors from global to local scales, including international financial flows to developing countries to assist them in addressing climate change*' (see Annex II: Glossary).

What needs to be financed?

Financial resources might be needed for a range of adaptation and resilience building activities. These include research, education and capacity building; development of laws, regulations and standards; provision of climate services and other information; reducing the vulnerability of existing assets, activities and services; and ensuring future development—such as new infrastructure, settlements, health services and business activities—is climate resilient. Finance is also needed to recover and rebuild from the damage of climate hazards that cannot be completely avoided through adaptation. Adaptation actions can be undertaken by many different actors, alone or in partnership, including national and sub-national governments, public and private utilities, businesses of varying size, communities, households and individuals.

Table FAQ17.2.1 | Examples of adaptation and resilience activities that might need to be financed

Training of agricultural extension officers so that their advice to small-holder farmers can support implementation of climate adapted agriculture. Additional financial support is needed for the costs of farmers transitioning to climate-resilient agricultural practices.	A new urban development requires higher standards (and up-front costs) for buildings, roads, stormwater systems and water re-use and to be resilient to expected changes in heavy rainfall, runoff, temperature and water supply reliability.
A water utility requires capital expenditure to increase supply through a desalination plant and to reduce leakage from its reticulation system in response to a scenario of reduced surface water availability and an increase in customers.	A catastrophe risk insurance facility is established to provide post-disaster (drought, hurricane, flooding, pest outbreaks) recovery finance to national governments. The facility requires capital to be able to underwrite the insurance products it offers.

How much finance is needed?

The amount of adaptation finance depends on global, regional and local factors, including: the amount and timing of global warming, and how this translates into impacts and adaptation needs across the world; the levels of adaptation already in place; the type of risk being adapted to; and the adaptation options being chosen, including whether the adaptation required is incremental or transformational.

The most-mentioned figure for finance need is the developed countries' commitment to provide USD 100 billion per year by 2020 to support developing countries' efforts in mitigation and adaptation. Negotiations will start in 2021 on updating this amount for 2025. While sometimes thought to represent the actual cost of responding to climate change in developing countries, this is not the case. More recent estimates of the global cost of adaptation by 2030 across developed and developing countries range between about USD 80 and 300 billion per year.

What types of finance are available?

Four main types (or instruments) of finance are currently being used to support adaptation. These different types are not mutually exclusive; grants can be combined with loans to provide blended finance.

Box FAQ 17.2 (continued)

Table FAQ17.2.2 | The main instruments through which adaptation is being financed.

Grants provide finance without any repayment requirements. Most grants for adaptation have been provided by multi-lateral funds such as the Green Climate Fund or a fund managed by a single OECD country such as Germany's International Climate Initiative. Some countries have national climate or environment funds that provide grants for their own climate adaptation actions. Grants are also provided by philanthropic foundations and sometimes by companies as part of their environmental and social responsiveness mandate.	**Concessional loans** require partial repayment of the finance provided. These involve either capital repayment coupled to below-market interest rates or capital repayment only. Concessional finance is almost entirely provided through multi-lateral development banks such as the World Bank. This finance is particularly important for developing countries where market interests are high due to poor credit ratings or other risk factors, or where the return on investment is too low make a commercial loan viable.
Non-concessional loans (or debts) are commercial instruments, where capital repayment and market interest rates apply. These may be provided through development banks or private banks. Green bonds are a relatively new form of market loan, designed to meet climate and other environmental sustainability criteria in terms of how the proceeds are used. In recent years, green bonds have offered better interest than ordinary bonds owing to oversubscription by investors who are looking to move towards environmentally sustainable investment portfolios.	**Budget re-allocation** does not require raising of new finance; rather, it involves moving funds already secured away from other purposes towards adaptation. In government, this might involve re-allocation towards flood defence. In the private sector, a company might move budget from marketing, research and development, or perhaps dividends, towards increasing the climate resilience of operation, infrastructure or their value chain.

FAQ

Where are different types of finance most useful?

Grants are useful for a range of adaptation actions where it is hard to generate a financial return. These include capacity-building activities, piloting new adaptation innovations, high-risk investment settings or projects where there are considerable non-financial benefits. In contrast, loans and other debt instruments can often support larger investments, for example for scaling out of successful pilot projects or for building adaptation and resilience into general development investment. To date, a large proportion of international climate finance for adaptation in developing countries, especially in Sub-Saharan Africa and Oceania, has been grant led, sourced from OECD public funds, indicating that in many instances financing via loans is either considered too risky by the commercial investment sector or it has been hard to demonstrate sufficient return on investment.

Distribution of adaptation finance across different regions and different types of finance in 2015–2016

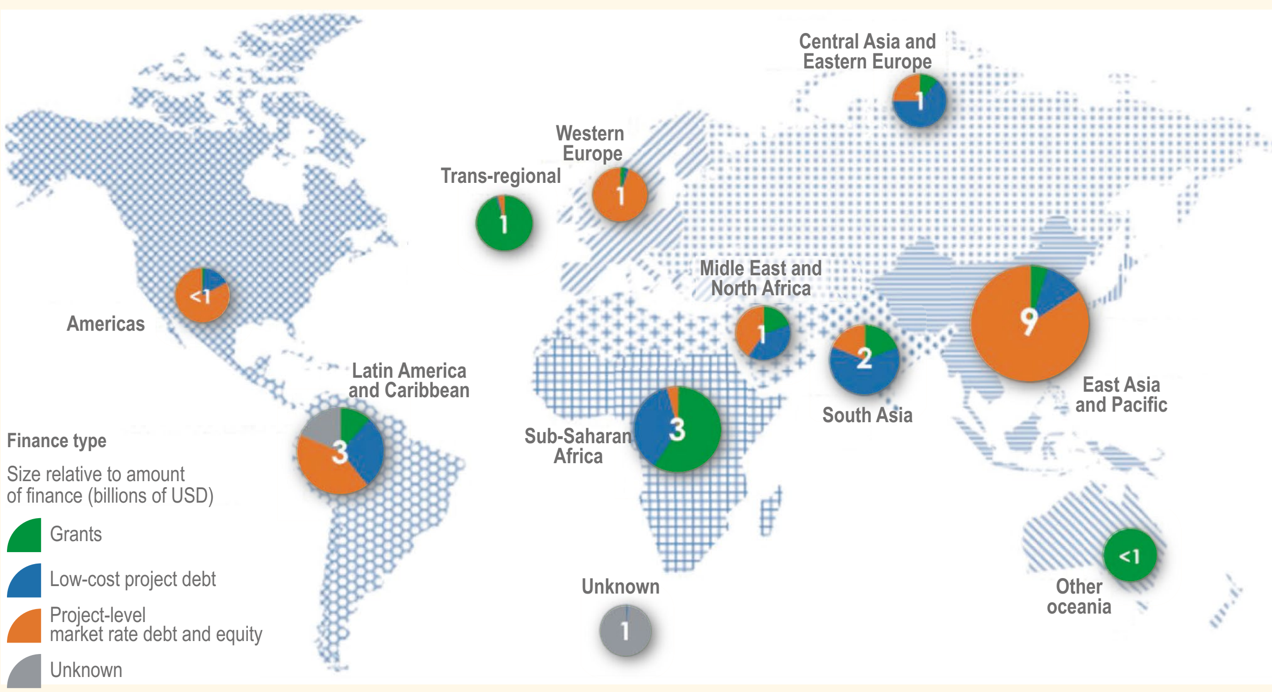

Figure FAQ17.2.1. | The distribution of adaptation finance across different regions and different types of finance in 2015–2016, as tracked by the Climate Policy Initiative. The size of each circle represents the amount of finance, with amount in billions USD superimposed.

Frequently Asked Questions

FAQ 17.3 | Why is adaptation planning along a spectrum from incremental to transformational adaptation important in a warming world?

In a warming world, incremental adaptation, that is, proven standard measures of adaptation, will not always suffice to adjust to the negative impacts from climate change leading to substantial residual risks and, in some cases, the breaching of adaptation limits; transformational adaptation, involving larger system-wide change (as compared with in-system change), will increasingly be necessary as a complement for helping individuals and communities to cope with climate change.

As an example of incremental adaptation, a farmer may decide to use drought-tolerant crops to deal with increasing occurrences of heatwaves. With further warming and increases in heatwaves and drought, however, the impacts of climate change may necessitate the consideration of system-wide change, such as moving to an entirely new agricultural system in areas where the climate is no longer suitable for current practices, or switching to livestock rearing. Where on-site adaptation becomes infeasible and pull factors exist, the farming households may decide to seek employment in other sectors, which may also lead to migration for work.

As another example, physical protection through sea walls to stop coastal flooding is a proven adaptation measure. With further projected flooding due to increasing sea level rise attributable to climate change transformational city planning, that would systemically change how flood water is managed throughout the whole city, potentially requiring deeper institutional, structural and financial support. Also, the deliberate relocation of settlements (managed retreat) is seeing attention in the face of increasingly severe coastal or riverine flooding in some regions. While transformational adaptation is increasingly being considered in theory and planning, implementation is only beginning to see attention.

Frequently Asked Questions

FAQ 17.4 | Given the existing state of adaptation, and the remaining risks that are not being managed, who bears the burden of these residual risks around the world?

A warming climate brings along increasing risks, part of which can be reduced or insured. What remains is called residual risks and needs to be retained by households, the private and public sectors. People living in conflict-affected areas benefit only marginally from adaptation investments by governments, private sector or other institutions. These people bear most of the changing climate risks themselves. Higher-income countries generally have invested heavily in structural adaptation to make sure people are not exposed to extreme events (e.g., dykes) and have developed a variety of private or public insurance systems to finance the risk of the most rare or extreme events. In other, middle- or lower-income countries, these very extreme events are less likely to be insured, and the impacts are borne by the most vulnerable people. Absent risk reduction or insurance, coping with residual risks generally means reducing consumption (e.g., food) or drawing down assets (selling machinery, houses, etc.), which all can bring along longer-term adverse developmental implications. Adaptation investments in low-income countries tend to focus more heavily on increasing capacity and reducing vulnerability; people remain exposed to the changing climate risks and bear the burden of reacting and responding.

Frequently Asked Questions

FAQ 17.5 | How do we know whether adaptation is successful?

Adaptation aims to reduce exposure and vulnerability to climate change by responding to dynamic and multi-scalar combinations of climatic risks. What might be seen as successful at one scale or at one point in time might not be at another, particularly if climate risks continue to rise. Moreover, the benefits of adaptation interventions may not reach all intended beneficiaries or everyone affected by climate impact and risk, causing different people to have different views on how successful adaptation has been.

There is, therefore, no universal way to measure adaptation success, but there is *high agreement* that success is associated with a reduction of climate risks and vulnerabilities (for humans and ecosystems) and an equitable balancing of synergies and trade-offs across diverse objectives, perspectives, expectations and values. Adaptation that is successful is also commonly expected to be inclusive of different socioeconomic groups, especially the most vulnerable, and to be based on flexible and integrative planning processes that take into account different climate scenarios.

Conceptually, the opposite of successful adaptation is maladaptation, that is, when adaptation responses produce unintended negative side effects such as exacerbating or shifting vulnerability, increasing risk for certain people or ecosystems, or increasing greenhouse gas emissions. Among the adaptation options assessed in this report (Figure FAQ17.5.1), physical infrastructure along coasts (e.g., sea walls) has the highest risk for maladaptation over time through negative side effects on ecosystem functioning and coastal livelihood opportunities. However, such adaptations may appear valuable in the short and even longer term for already densely populated urban coasts, demonstrating that an adaptation can be differently judged based on the context it is implemented in (Figure FAQ17.5.1). Many other adaptation options have a larger potential to contribute to successful adaptation (Figure FAQ17.5.1), such as nature restoration, providing social safety nets and changing diets/minimising food waste.

Assessments of adaptation need to be transparent about how they are measuring success. Monitoring and Evaluation (M&E) can be used to track progress and evaluate success and to identify if course corrections during adaptation implementation are needed to achieve the envisaged objectives. Given the diversity of adaptation actions and contexts, no one-size-fits-all approach to M&E and no common reference metrics for adaptation exist. To date, assessments of progress of adaptation have often focused on processes and outputs (i.e., actions taken, such as adaptation plans adopted) that are easier to measure than the effects of these actions in terms of long-term reduction of risks and vulnerabilities. However, knowledge about the outcomes in terms of reducing climate risk, impact and vulnerability is critically required to know if adaptation has been successful.

Tracking progress, in particular outcomes and impacts of adaptation, involves a number of challenges. First, to determine progress over time, risk and vulnerability assessments need to be repeated at least once after starting an adaptation process. This is rarely done, as it demands resources that are usually not factored into the adaptation response. Second, attributing changes in climate risks and vulnerabilities to the adaptation response is often difficult due to other influencing factors, such as socioeconomic development over time. Expected causal relationships between responses and their outcomes should already be outlined during the adaptation planning phase, for example by mapping the way from activities to outcomes, and they should be monitored during implementation. Third, as adaptation can occur in multiple forms and target multiple temporal and spatial scales, the engagement of a diversity of stakeholders is vital to understanding how responses enable adaptation and adaptation success across vulnerable groups. Although stakeholder engagement can be time intensive and costly, in particular when reaching out to populations that are usually not part of policy and planning processes, it can support evaluating co-benefits and trade-offs of adaptation responses. Consideration and analysis of co-benefits and trade-offs along with a focus on short, medium and long time horizons of adaptation goals, which is usually possible through flexible and strong institutions, facilitate successful adaptation and reduce the likelihood of maladaptation.

Box FAQ 17.5 (continued)

Contribution of adaptation options to potentially successful adaptation and to the risk of maladaptation

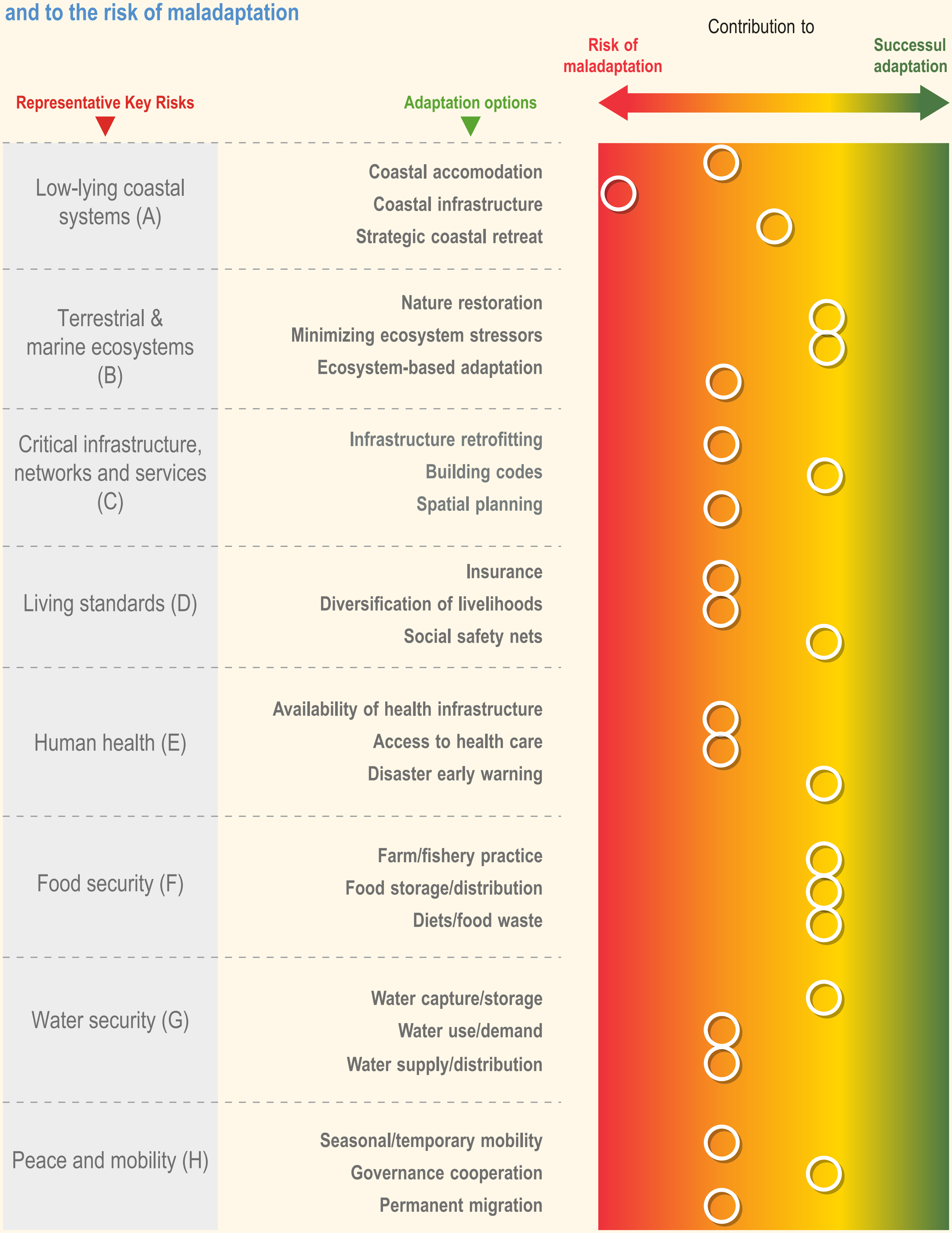

Figure FAQ17.5.1 | Contribution of adaptation options to potentially successful adaptation and to the risk of maladaptation. Note: A similar figure is part of Section 17.5.1.

Frequently Asked Questions

FAQ 18.1 | What is a climate resilient development pathway?

A pathway is defined in IPCC reports as a temporal evolution of natural and/or human systems towards a future state. Pathways can range from sets of scenarios or narratives of potential futures to solution-oriented decision-making processes to achieve desirable societal goals. Climate resilient development pathways (CRDPs) are therefore trajectories for the pursuit of climate resilient development (CRD) and navigating its complexities. They involve ongoing processes that strengthen sustainable development, eradicate poverty and reduce inequalities while promoting fair adaptation and mitigation across multiple scales. As the pursuit of CRDPs is contingent on achieving larger-scale societal transformation, CRDPs invariably raise questions of ethics, equity and feasibility of options to drastically reduce emission of greenhouse gasses (mitigation) that limit global warming (e.g., to well below 2°C) and achieve desirable and liveable futures and well-being for all.

There in no one, correct pathway for CRD, but rather multiple pathways depending on factors such as the political, cultural and economic contexts in which different actors find themselves. Some development pathways are more consistent with CRD, while others move society away from CRD. Moreover, CRDPs are not one single decision or action. Rather, CRDPs represent a continuum of coherent, consistent decisions, actions and interventions that evolve within individual communities, nations, and the world. Different actors, the private sector, and civil society, influenced by science, local and Indigenous knowledges, and the media play a role in designing and navigating CRD pathways.

While dependent on past patterns of development and their socio-ethical, political, economic, ecological and knowledge-technology outcomes at any point in time, transformation, ecological tipping points and shocks can create sudden shifts and unexpected nonlinear development pathways. Actions taken today can enable or foreclose some future potential CRDPs. The differentiated impacts of hurricanes and COVID-19 on nations and communities around the world illustrate how the character of societal development such as equity and inclusion have enabled some societies to be more resilient than others.

Frequently Asked Questions

FAQ 18.2 | What is climate resilient development and how can climate change adaptation (measures) contribute to achieving this?

Climate resilient development (CRD) is a process of implementing greenhouse gas mitigation and adaptation options to support sustainable development for all in ways that support human and planetary health and well-being, equity and justice. CRD combines adaptation and mitigation with underlying development choices and everyday actions, carried out by multiple actors within political, economic, ecological, socio-ethical and knowledge-technology arenas. The character of processes within these development arenas are intrinsic to how social choices are made and they determine whether development moves society along pathways toward CRD or away. For example, inclusion, agency and social justice are qualities within the political arena that underpin actions that enable CRD.

CRD addresses the relationship between greenhouse gas emissions, levels of warming and related climate risks. However, CRD involves more than just achieving temperature targets. It considers the possible transitions that enable those targets to be achieved as well as the evaluation of different adaptation strategies and how the implementation of these strategies interact with broader sustainable development efforts and objectives. This interdependence between patterns of development, climate risk and the demand for mitigation and adaptation action is fundamental to the concept of CRD. Therefore, climate change and sustainable development cannot be assessed or planned in isolation of one another.

Hence, CRD represents development that deliberately adopts mitigation and adaptation measures to secure a safe climate on earth, meet basic needs for each human being, eliminate poverty and enable equitable, just and sustainable development. It halts practices causing dangerous levels of global warming. CRD may involve deep societal transformation to ensure well-being for all. CRD is now emerging as one of the guiding principles for climate policy, both at the international level, reflected in the Paris Agreement (UNFCCC, 2015), and within specific countries.

FAQ 18.2 (continued)

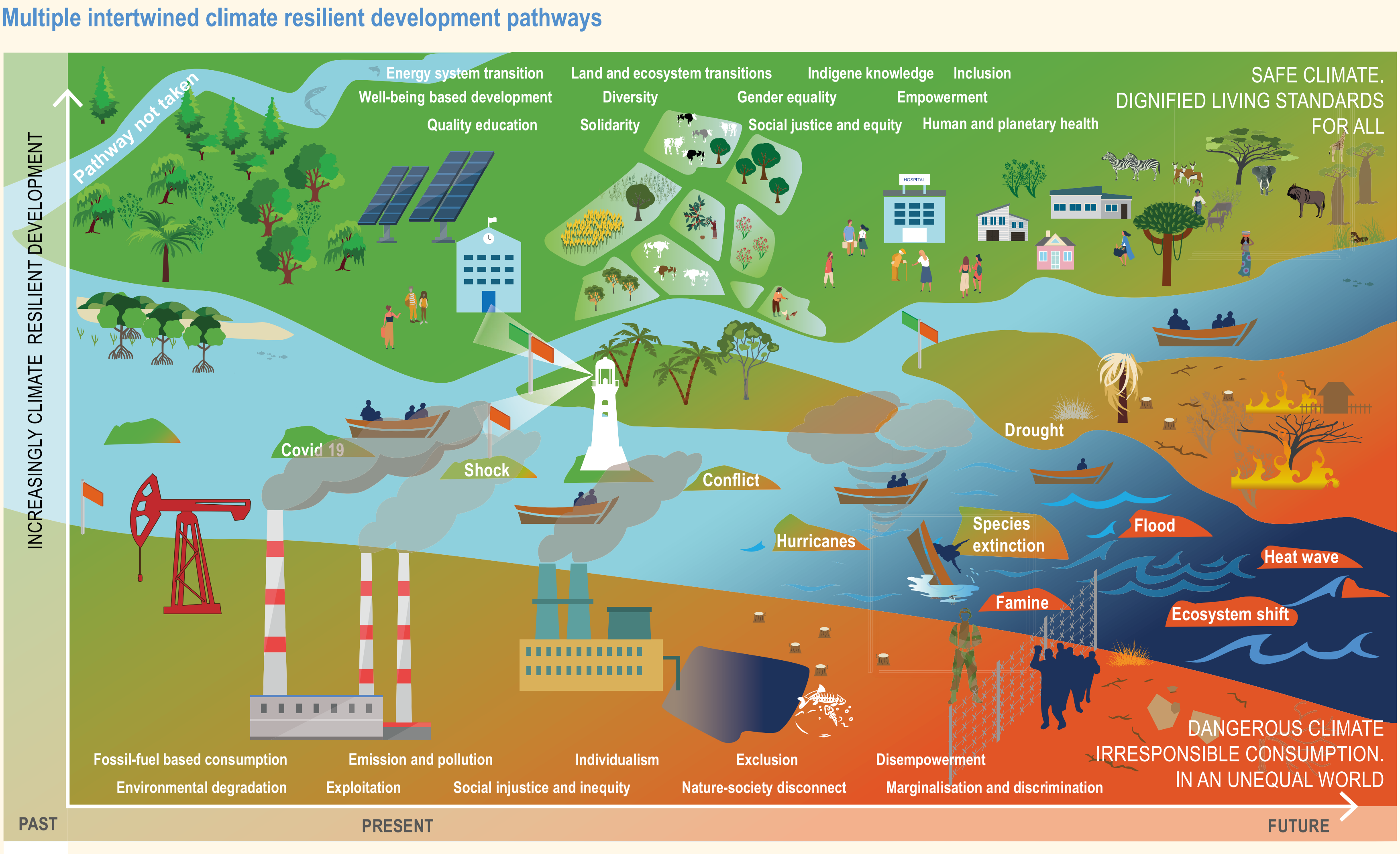

Figure FAQ18.2.1 | Multiple intertwined climate resilient development pathways. Climate change adaptation is one of several climatic and non-climatic measures carried out through decision making by multiple actors that may drive a pathway in a CRD or non-CRD direction. Adaptation, mitigation and sustainable development actions can push a society in a CRD direction, but only if these measures are just and equitable. There are multiple simultaneous pathways in the past, present and future. Societies (illustrated as boats) move on different pathways, towards CRD and non-CRD, with some pathways more dominant than others. The direction of pathways is emergent, taking place through contestations and social choices, through social transformation as well as through surprises and shocks (illustrated as rocks). Path dependency means it is possible but often turbulent to shift from a non-CRD to a CRD pathway. Such a shift becomes more difficult as risks/shocks increase (more rocks) and non-CRD processes and outcomes progress, limiting future options. Low CRD processes and outcomes at the bottom are characterised by inequity, exclusion, polarisation, environmental and social exploitation, entrenchment of Business-As-Usual, with increasing risks/shocks. High CRD processes and outcomes (at the top of the figure) are characterised by equity, solidarity, justice, human well-being, planetary health, stewardship/care and system transitions.

Frequently Asked Questions

FAQ 18.3 | How can different actors across society and levels of government be empowered to pursue climate resilient development?

CRD entails trade-offs between different policy objectives. Governments as well as political and economic elites may play a key role in defining the direction of development at a national and sub-national scale; but in practice, these pathways can be influenced and even resisted by local people, non-governmental organisations (NGOs) and civil society.

Given such tensions, contestation and debate are inherent to the definition and pursuit of climate resilient development (CRD). An active civil society and citizenship create the enabling conditions for deliberation, protest, dissent and pressure, which are fundamental for an inclusive participatory process. These enable a multiplicity of actors to engage across multiple arenas including governmental, economic and financial, political, knowledge, science & technology, and community. Decisions and actions may be influenced by uneven interactions among actors, including socio-political relations of domination, marginalisation, contestation, compliance and resistance, with diverse and often unpredictable outcomes.

In this way, recent social movements and climate protests reflect new modalities of action in response to social, economic, and political inaction. The new climate movement, led mostly by youth, seeks science-based policy and, more importantly, rejects a reformist stance toward climate action in favour of radical climate action. This is mostly pursued through collective disruptive action and non-violent resistance to promote awareness, a regenerative culture and ethics of care. These movements have resulted in notable political successes, such as declarations of climate emergency at the national and local level, as well as in universities. Also, their methods have proven effective to end fossil fuel sponsorship.

The success and importance of recent climate movements also suggest a need to rethink the role of science in society. On one hand, the new climate movements demanding political action were prompted by the findings of scientific reports, mainly the IPCC (2018a) and IPBES (2019) reports. On the other hand, these movements have increased public awareness and stimulated public engagement with climate change at unprecedented levels beyond what the scientific community can do alone.

Frequently Asked Questions

FAQ 18.4 | What role do transitions and transformations in energy, urban and infrastructure, industrial, land and ocean ecosystems, and in society, play in climate resilient development?

The IPCC SR1.5 report identified transitions in four key systems, including energy, land and ocean ecosystems, urban and infrastructure, and industry, as being fundamental to the pursuit of climate resilient development (CRD). In addition, this report identifies societal transitions, in terms of values and worldviews that shape aspirations, lifestyles and consumption patterns, as another key component of CRD. Acknowledging societal transitions has implications for how one assesses options and values different outcomes from the perspectives of ethics, equity, justice and inclusion. 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 and more equitable options. However, the way they are pursued may not necessarily be perceived as ethical or desirable to all actors. Moreover, system transitions are necessary precursors for more fundamental climate and sustainable-development transformations. Yet, these transitions can themselves be outcomes of transformative actions.

Frequently Asked Questions

FAQ 18.5 | What are success criteria in climate resilient development and how can actors satisfy those criteria?

Climate resilient development (CRD) is not a predefined goal to be achieved at a certain point or stage in the future. It is a constant process of evaluating, valuing, acting and adjusting various options for mitigation, adaptation and sustainable development, shaped by societal values as well as contestations of those values. Any achievement or success is always a work in progress driven by with continuous, directed, intentional actions. These actions will vary according to the priorities and needs of each population or system; therefore, specific criteria for, and indicators of, CRD will vary according to each specific context. This respect for context ensures the pursuit of CRD prioritizes people, planet, prosperity, peace and partnership, per the broad goals of the Agenda 2030 on sustainable development.

If CRD is defined as a process of implementing greenhouse gas mitigation and adaptation options to support sustainable development for all, this implies various potential criteria for success. These include the adoption of mitigation and adaptation measures to secure a safe climate, meet basic needs, eliminate poverty and enable equitable, just and sustainable development for all. Therefore, the 17 United Nations' Sustainable Development Goals provide a good (although limited) measure of progress toward CRD. The Sustainable Development Goals aim at ending poverty and hunger globally and protect life on land and underwater until the year 2030. Although there are proven synergies between the Sustainable Development Goals and mitigation, there remain synergies between the SDGs and adaptation that need to be explored further.

Glossary

Glossary

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Note: This glossary defines some specific terms as the Lead Authors intend them to be interpreted in the context of this report. *Italicised words* in definitions indicate that the term is defined in the Glossary. Subterms appear in italics beneath main terms.

(Internal) Displacement (of humans)
The involuntary movement, individually or collectively, of persons from their country or community, notably for reasons of armed conflict, civil unrest, or natural or human-made disasters (adapted from IOM, 2011).

2030 Agenda for Sustainable Development
A UN resolution in September 2015 adopting a plan of action for people, planet and prosperity in a new global development framework anchored in 17 *Sustainable Development Goals* (UN, 2015).

Abrupt change
A change in the system that is substantially faster than the typical rate of the changes in its history. See also *Abrupt climate change* and *Tipping point*.

Abrupt climate change
A large-scale *abrupt change* in the *climate system* that takes place over a few decades or less, persists (or is anticipated to persist) for at least a few decades and causes substantial *impacts* in *human* and/or *natural systems*. See also *Tipping point* and *Abrupt change*.

Access to food
See *Access* under *Food security*.

Acclimatisation
A change in functional or morphological traits occurring once or repeatedly (e.g., seasonally) during the lifetime of an individual organism in its natural environment. Through *acclimatisation*, the individual maintains performance across a range of environmental conditions. For a clear differentiation between findings in laboratory and field studies, the term 'acclimation' is used in ecophysiology for the respective phenomena when observed in well-defined experimental settings. The term '(adaptive) *plasticity*' characterises the generally limited scope of changes in phenotype that an individual can reach through the process of *acclimatisation*.

Accumulation (of glaciers, ice sheets or snow cover)
All processes that add to the mass of a *glacier*, an *ice sheet*, or snow cover. The main process of *accumulation* is snowfall. *Accumulation* also includes deposition of hoar, freezing rain, other types of solid precipitation, gain of wind-blown snow, avalanching and basal accumulation (often beneath floating ice).

Acute food insecurity
Acute food insecurity is a situation which can occur at any time with a severity that threatens lives, livelihoods or both, regardless of the causes, context or duration, as a result of shocks risking determinants of food security and nutrition, and used to assess the need for humanitarian action (IPC Global Partners, 2019).

Adaptation
In *human systems*, the process of adjustment to actual or expected *climate* and its effects, in order to moderate harm or exploit beneficial opportunities. In *natural systems*, the process of adjustment to actual *climate* and its effects; human intervention may facilitate adjustment to expected *climate* and its effects. See also *Adaptation options*, *Adaptive capacity* and *Maladaptive actions (Maladaptation)*.

Adaptation deficit
The gap between the current state of a system and a state that minimises adverse *impacts* from existing *climate* conditions and variability.

Adaptation gap
The difference between actually implemented *adaptation* and a societally set goal, determined largely by preferences related to tolerated climate change impacts and reflecting resource limitations and competing priorities (UNEP, 2014; UNEP, 2018).

Adaptation limits
The point at which an actor's objectives (or system needs) cannot be secured from intolerable risks through adaptive actions.

- Hard adaptation limit – No adaptive actions are possible to avoid intolerable risks.
- Soft adaptation limit – Options may exist but are currently not available to avoid intolerable risks through adaptive action.

Adaptation needs
The circumstances requiring action to ensure the safety of populations and the security of assets in response to *climate impacts*.

Adaptation options
The array of strategies and measures that are available and appropriate for addressing *adaptation*. They include a wide range of actions that can be categorised as structural, institutional, ecological or behavioural.

Autonomous adaptation
Adaptation in response to experienced *climate* and its effects, without planning explicitly or consciously focused on addressing *climate* change. Also referred to as spontaneous *adaptation*.

Community-based adaptation
Local, community-driven *adaptation*. *Community-based adaptation* focuses attention on empowering and promoting the adaptive capacity of communities. It is an approach that takes context, culture, knowledge, agency and preferences of communities as strengths.

Ecosystem-based adaptation (EBA)
The use of *ecosystem* management activities to increase the *resilience* and reduce the *vulnerability* of people and *ecosystems* to *climate change* (Campbell et al., 2009). See also *Nature-based solution (NBS)*.

Evolutionary adaptation
The process whereby a species or population becomes better able to live in a changing environment through the selection of heritable traits. Biologists usually distinguish *evolutionary adaptation* from *acclimatisation*, with the latter occurring within an organism's lifetime.

Incremental adaptation
Adaptation that maintains the essence and integrity of a system or process at a given scale (Park et al., 2012). In some cases, *incremental adaptation* can accrue to result in *transformational adaptation* (Tàbara et al., 2018; Termeer et al., 2017). Incremental *adaptations* to change in *climate* are understood as extensions of actions and behaviours that already reduce the losses or enhance the benefits of natural variations in *extreme weather/climate events*.

Transformational adaptation
Adaptation that changes the fundamental attributes of a *social-ecological system* in anticipation of *climate* change and its *impacts*.

Adaptation Fund
A Fund established under the Kyoto Protocol in 2001 and officially launched in 2007. The Fund finances *adaptation* projects and programmes in *developing countries* that are Parties to the Kyoto Protocol. Financing comes mainly from sales of Certified Emissions Reductions (CERs) and a share of proceeds amounting to 2% of the value of CERs issued each year for Clean Development Mechanism (CDM) projects. The Adaptation Fund can also receive funds from governments, the private sector and individuals.

Adaptation limits
See *Adaptation*.

Adaptation needs
See *Adaptation*.

Adaptation options
See *Adaptation*.

Adaptation pathways
See *Pathways*.

Adaptive capacity
The ability of systems, *institutions*, humans and other organisms to adjust to potential damage, to take advantage of opportunities or to respond to consequences (MA, 2005).

Adaptive governance
See *Governance*.

Adaptive management
A process of iteratively planning, implementing and modifying strategies for managing resources in the face of *uncertainty* and change. Adaptive management involves adjusting approaches in response to observations of their effect on, and changes in, the system brought on by resulting feedback effects and other variables.

Adverse side-effect
A negative effect that a *policy* or measure aimed at one objective has on another objective, thereby potentially reducing the net benefit to society or the environment. See also *Trade-off* and *Co-benefit*.

Aerosol
A suspension of airborne solid or liquid particles, with typical particle size in the range of a few nanometres to several tens of micrometres and *atmospheric lifetimes* of up to several days in the *troposphere* and up to years in the *stratosphere*. The term aerosol, which includes both the particles and the suspending gas, is often used in this report in its plural form to mean 'aerosol particles'. Aerosols may be of either natural or *anthropogenic* origin in the troposphere; stratospheric aerosols mostly stem from volcanic eruptions. Aerosols can cause an *effective radiative forcing* directly through scattering and absorbing radiation (*aerosol–radiation interaction*), and indirectly by acting as *cloud condensation nuclei* or ice nucleating particles that affect the properties of clouds (*aerosol–cloud interaction*), and upon deposition on snow- or ice-covered surfaces. Atmospheric aerosols may be either emitted as primary particulate matter or formed within the atmosphere from gaseous *precursors* (secondary production). Aerosols may be composed of sea salt, organic carbon, *black carbon (BC)*, mineral species (mainly desert dust), sulphate, nitrate and ammonium or their mixtures. See also *Particulate matter (PM)* and *Short-lived climate forcers (SLCFs)*.

Afforestation
Conversion to *forest* of *land* that historically has not contained *forests*. See also *Deforestation*.
[Note: For a discussion of the term *forest* and related terms such as *afforestation*, *reforestation* and *deforestation*, see the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and their 2019 Refinement, and information provided by the United Nations Framework Convention on Climate Change (IPCC 2006, 2019; UNFCCC 2021a, 2021b)]

Agreement
In this report, the degree of *agreement* within the scientific body of knowledge on a particular finding is assessed based on multiple lines of *evidence* (e.g., mechanistic understanding, theory, data, *models*, expert judgement) and expressed qualitatively (Mastrandrea et al., 2010). See also *Confidence*, *Evidence*, *Likelihood* and *Uncertainty*.

Agricultural and ecological drought
See *Drought*.

Agroecology
The science and practice of applying ecological concepts, principles and knowledge (i.e., the interactions of, and explanations for, the diversity, abundance and activities of organisms) to the study, design and management of sustainable agroecosystems. It includes the roles of human beings as a central organism in *agroecology* by way of social and economic processes in farming systems. *Agroecology* examines the roles and interactions among all relevant biophysical, technical and socioeconomic components of farming systems and their surrounding landscapes (IPBES, 2019).

Agroforestry
Collective name for *land*-*use* systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same *land*-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence. In agroforestry systems, there are both ecological and economical interactions between the different components. Agroforestry can also be defined as a dynamic, ecologically based, natural resource management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for *land* users at all levels (FAO, 2015a).

Air pollution
Degradation of air quality with negative effects on human *health* or the natural or built environment due to the introduction, by natural processes or human activity, into the *atmosphere* of substances (gases, *aerosols*) which have a direct (primary pollutants) or indirect (secondary pollutants) harmful effect.

Albedo
The proportion of sunlight (solar radiation) reflected by a surface or object, often expressed as a percentage. Clouds, snow and ice usually have high *albedo*; soil surfaces cover the *albedo* range from high to low; vegetation in the dry season and/or in *arid zones* can have high *albedo*, whereas photosynthetically active vegetation and the *ocean* have low *albedo*. The Earth's planetary *albedo* changes mainly through changes in cloudiness, snow, ice, leaf area and *land cover*.

Anomaly
The deviation of a variable from its value averaged over a *reference period*.

Anthropocene
A proposed new geological epoch resulting from significant human-driven changes to the structure and functioning of the Earth system, including the *climate system*. Originally proposed in the Earth System science community in 2000, the proposed new epoch is undergoing a formalisation process within the geological community based on the stratigraphic *evidence* that human activities have changed the Earth System to the extent of forming geological deposits with a signature that is distinct from those of the Holocene, and which will remain in the geological record. Both the stratigraphic and Earth system approaches to defining the *Anthropocene* consider the mid-20th century to be the most appropriate starting date (Steffen et al., 2016), although others have been proposed and continue to be discussed. The *Anthropocene* concept has already been informally adopted by diverse disciplines and the public to denote the substantive influence of humans on the Earth system.

Anthropogenic
Resulting from or produced by human activities.

Anthropogenic emissions
See *Emissions*.

Anthropogenic subsidence
Downward motion of the *land* surface induced by *anthropogenic drivers* (e.g., loading, extraction of hydrocarbons and/or groundwater, *drainage* and mining activities) causing sediment compaction or subsidence/deformation of the sedimentary sequence, or oxidation of organic material, thereby leading to relative *sea level rise*.

Arid zone
Areas where vegetation growth is severely constrained due to limited water availability. For the most part, the native vegetation of *arid zones* is sparse. There is high rainfall variability, with annual averages below 300 mm. Crop farming in *arid zones* requires irrigation.

Aridity
The state of a long-term climatic feature characterised by low average precipitation or available water in a *region*. *Aridity* generally arises from widespread persistent *atmospheric* subsidence or anticyclonic conditions, and from more localised subsidence in the lee side of mountains (adapted from Ogallo and Gbeckor-Kove, 1989). See also *Drought*.

Atmosphere
The gaseous envelope surrounding the Earth, divided into five layers: the troposphere, which contains half of the Earth's *atmosphere*, the stratosphere, the mesosphere, the thermosphere and the exosphere, which is the outer limit of the *atmosphere*. The dry *atmosphere* consists almost entirely of nitrogen (78.1% volume mixing ratio) and oxygen (20.9% volume mixing ratio), together with a number of trace gases such as argon (0.93% volume mixing ratio), helium and radiatively active *greenhouse gases (GHGs)* such as *carbon dioxide* (CO_2) (0.04% volume mixing ratio) methane (CH4), nitrous oxide (N2O) and *ozone* (O_3). In addition, the *atmosphere* contains the GHG water vapour (H_2O), whose concentrations are highly variable (0–5% volume mixing ratio) as the sources (evapotranspiration) and sinks (precipitation) of water vapour show large spatio-temporal variations, and atmospheric temperature exerts a strong constraint on the amount of water vapour an air parcel can hold.. The *atmosphere* also contains clouds and *aerosols*. See also *Hydrological cycle*.

Attribution
Attribution is defined as the process of evaluating the relative contributions of multiple causal factors to a change or event with an assessment of *confidence*.

Autonomous adaptation
See *Adaptation*.

Avalanche
A mass of snow, ice, earth or rocks, or a mixture of these, falling down a mountainside.

Baseline scenario
see *Reference scenario*.

Behavioural change
In this report, *behavioural change* refers to alteration of human decisions and actions in ways that mitigate *climate* change and/or reduce negative consequences of *climate change impacts*.

Benthic
Occurring at the bottom of a body of water; related to *benthos* (NOAA, 2018). See also *Benthos*.

Benthos
The community of organisms living on the bottom or in sediments of a body of water (such as an *ocean*, a river or a lake). The ecological zone at the bottom of a body of water, including the sediment surface and some subsurface layers, is known as the *benthic* zone.

Beta diversity
The change in species composition between different areas (spatial turnover) or times (temporal turnover) due to habitat and environmental heterogeneity

Biodiversity
Biodiversity or biological diversity means the variability among living organisms from all sources including, among other things, terrestrial, marine and other aquatic *ecosystems*, and the ecological complexes of which they are part; this includes diversity within species, between species and of *ecosystems* (UN, 1992). See also *Ecosystem* and *Ecosystem services*.

Biodiversity hotspots
Biodiversity hotspots are geographic areas exceptionally rich in species, ecologically distinct, and often contain geographically rare *endemic species*. They are thus priorities for nature conservation action.

Bioenergy
Energy derived from any form of *biomass* or its metabolic by-products. See also *Biofuel* and *Biomass*.

Biofuel
A fuel, generally in liquid form, produced from *biomass*. *Biofuels* include bioethanol from sugarcane, sugar beet or maize and biodiesel from canola or soybeans. See also *Bioenergy*.

Biomass
Organic material excluding the material that is fossilised or embedded in geological formations. *Biomass* may refer to the mass of organic matter in a specific area (ISO, 2014). See also *Bioenergy* and *Biofuel*.

Biomes
Global-scale zones, generally defined by the type of plant life that they support in response to average rainfall and temperature patterns. For example, *tundra*, *coral reefs* or savannas (IPBES, 2019).

Biosphere (terrestrial and marine)
The part of the Earth system comprising all *ecosystems* and living organisms, in the *atmosphere*, on *land* (*terrestrial biosphere*) or in the *oceans* (*marine biosphere*), including derived dead organic matter, such as litter, *soil organic matter* and oceanic detritus.

Blue carbon
Biologically driven carbon *fluxes* and storage in marine systems that are amenable to management. Coastal *blue carbon* focuses on rooted vegetation in the coastal zone, such as tidal marshes, mangroves and seagrasses. These *ecosystems* have high carbon burial rates on a per unit area basis and accumulate carbon in their soils and sediments. They provide many non-climatic benefits and can contribute to *ecosystem-based adaptation*. If degraded or lost, coastal *blue carbon ecosystems* are likely to release most of their carbon back to the *atmosphere*. There is current debate regarding the application of the *blue carbon* concept to other coastal and non-coastal processes and *ecosystems*, including the open *ocean*. See also *Ecosystem services* and *Sequestration*.

Blue infrastructure
See *Infrastructure*.

Burden
The total mass of a gaseous substance of concern in the *atmosphere*.

Business-As-Usual (BAU)
The term *Business-As-Usual* scenario has been used to describe a scenario that assumes no additional *policies* beyond those currently in place and that patterns of socio-economic development are consistent with recent trends. The term is now used less frequently than in the past. See also *Reference scenario*.

Calcification
The process of biologically precipitating calcium carbonate minerals to create organism shells, skeletons, otoliths or other body structures. The chemical equation describing *calcification* is $Ca^{2+}(aq) + 2HCO^{3-}(aq) \rightarrow CaCO_3(s) + CO_2 + H_2O$. Aragonite and calcite are two common crystalline forms of biologically precipitated calcium carbonate minerals that have different solubilities.

Capacity building
The practice of enhancing the strengths and attributes of, and resources available to, an individual, community, society or organisation to respond to change.

Carbon dioxide (CO_2)
A naturally occurring gas, CO_2 is also a by-product of burning *fossil fuels* (such as oil, gas and coal), of burning *biomass*, of *land-use changes (LUC)* and of industrial processes (e.g., cement production). It is the principal *anthropogenic greenhouse gas (GHG)* that affects the Earth's radiative balance. It is the reference gas against which other GHGs are measured and therefore has a *global warming* potential (GWP) of 1.

Carbon dioxide (CO_2) fertilisation
The increase of plant *photosynthesis* and *water-use efficiency* in response to increased atmospheric *carbon dioxide (CO_2)* concentration. Whether this increased *photosynthesis* translates into increased plant growth and carbon storage on *land* depends on the interacting effects of temperature, moisture and nutrient availability.

Carbon dioxide removal (CDR)
Anthropogenic activities removing *carbon dioxide (CO_2)* from the *atmosphere* and durably storing it in geological, terrestrial or *ocean reservoirs*, or in products. It includes existing and potential *anthropogenic* enhancement of biological or geochemical CO_2 *sinks* and direct air *carbon dioxide* capture and storage (DACCS) but excludes natural CO_2 *uptake* not directly caused by human activities. See also *Afforestation*.

Carbon footprint
Measure of the exclusive total amount of *emissions* of *carbon dioxide (CO_2)* that is directly and indirectly caused by an activity or accumulated over the life stages of a product (Wiedmann and Minx, 2008).

Carbon stock
The quantity of carbon in a carbon pool.

Cascading impacts
Cascading impacts from *extreme weather/climate events* occur when an extreme *hazard* generates a sequence of secondary events in natural and *human systems* that result in physical, natural, social or economic disruption, whereby the resulting *impact* is significantly larger than the initial *impact*. *Cascading impacts* are complex and multi-dimensional, and are associated more with the magnitude of *vulnerability* than with that of the *hazard* (modified from Pescaroli & Alexander, 2015).

Catchment
An area that collects and drains precipitation.

Cities
Cities are open systems, continually exchanging resources, products and services, waste, people, ideas and finances with the hinterlands and broader world. *Cities* are complex, self-organising, adaptive and constantly evolving. *Cities* also encompass multiple actors with varying responsibilities, capabilities and priorities, as well as processes that transcend the institutional sector-based approach to *city* administration. *Cities* are embedded in broader ecological, economic, technical, institutional, legal and *governance* structures that enable or constrain their systemic function, which cannot be separated from wider power relations. *Urban* processes of a physical, social and economic nature are causally interlinked, with interactions and feedbacks that result in both intended and unintended *impacts* on *emissions*. See also *City region*, *Peri-urban areas* and *Urban*.

City region
The areal extent of an individual *city*'s material associations and economic or political influence. The *city region* concept accepts that rural *livelihoods* and *land* uses can be incorporated within the functional activities of a *city*. This will include dormitory *settlements*, *sources* for critical inputs of water, some food, and waste disposal. See also *Region*, *Cities*, *Urban* and *Urban systems*.

Climate
In a narrow sense, *climate* is usually defined as the average weather -or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities- over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization (WMO). The relevant quantities are most often surface variables such as temperature, precipitation and wind. *Climate* in a wider sense is the state, including a statistical description, of the *climate system*.

Climate change
A change in the state of the *climate* that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. *Climate change* may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent *anthropogenic* changes in the composition of the *atmosphere* or in *land use*. Note that the United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines *climate change* as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a distinction between *climate change* attributable to human activities altering the atmospheric composition and *climate variability* attributable to natural causes. See also *Climate variability*, *Detection*, *Attribution* and *Ocean acidification (OA)*.

Climate extreme (extreme weather or climate event)
The occurrence of a value of a weather or *climate* variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable.
By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classified as an *extreme climate event*, especially if it yields an average or total that is itself extreme (e.g., high temperature, *drought* or heavy rainfall over a season). For simplicity, both *extreme weather events* and *extreme climate events* are referred to collectively as *climate extremes*.

Climate feedback
An interaction in which a perturbation in one *climate* quantity causes a change in a second and the change in the second quantity ultimately leads to an additional change in the first. A negative feedback is one in which the initial perturbation is weakened by the changes it causes; a positive feedback is one in which the initial perturbation is enhanced. The initial perturbation can either be externally forced or arise as part of internal variability.

Climate finance
There is no agreed definition of *climate finance*. The term *climate finance* is applied to the financial resources devoted to addressing *climate change* by all public and private actors from global to local scales, including international financial flows to *developing countries* to assist them in addressing *climate change*. *Climate finance* aims to reduce net *greenhouse gas emissions* and/or to enhance *adaptation* and increase *resilience* to the *impacts* of current and projected *climate change*. Finance can come from private and public sources, channelled by various intermediaries, and is delivered by a range of instruments, including grants, concessional and non-concessional debt, and internal budget reallocations.

Climate governance
See *Governance*.

Climate information
Information about the past, current or future state of the *climate system* that is relevant for *mitigation*, *adaptation* and *risk management*. It may be tailored or "co-produced" for specific contexts, taking into account users' needs and values.

Climate justice
See *Justice*.

Climate literacy
Climate literacy encompasses being aware of climate change, its anthropogenic causes and implications.

Climate model
A qualitative or quantitative representation of the *climate system* based on the physical, chemical and biological properties of its components, their interactions and feedback processes and accounting for some of its known properties. The *climate system* can be represented by *models* of varying complexity; that is, for any one component or combination of components, a spectrum or hierarchy of *models* can be identified, differing in such aspects as the number of spatial dimensions, the extent to which physical, chemical or biological processes are explicitly represented, or the level at which empirical parametrisations are involved. There is an evolution towards more complex *models* with interactive chemistry and biology. *Climate models* are applied as a research tool to study and simulate the *climate* and for operational purposes, including monthly, seasonal and interannual *climate predictions*. See also *Earth system model (ESM)*.

Climate prediction
A *climate prediction* or *climate* forecast is the result of an attempt to produce (starting from a particular state of the *climate system*) an estimate of the actual evolution of the *climate* in the future, for example, at seasonal, interannual or decadal *time scales*. Because the future evolution of the *climate system* may be highly sensitive to initial conditions, such predictions are usually probabilistic in nature.

Climate projection
Simulated response of the *climate system* to a scenario of future *emissions* or concentrations of *greenhouse gases (GHGs)* and *aerosols* and changes in *land use*, generally derived using *climate models*. *Climate projections* depend on an emission/concentration/*radiative forcing scenario*, which is in turn based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realised.

Climate refugium
A *climate refugium* is a geographic area that has had a stable *climate* on evolutionary time scales, or that is projected to have a stable *climate* into the future. See also *Refugium*.

Climate services
Climate services involve the provision of *climate information* in such a way as to assist decision-making. The service includes appropriate engagement from users and providers, is based on scientifically credible information and expertise, has an effective access mechanism and responds to user needs (Hewitt et al. 2012).

Climate simulation ensemble
A group of parallel model simulations characterising historical *climate* conditions, *climate predictions* or *climate projections*. Variation of the results across the ensemble members may give an estimate of modelling-based *uncertainty*. Ensembles made with the same model but different initial conditions characterise the *uncertainty* associated with internal *climate variability*, whereas multi-model ensembles including simulations by several *models* also include the effect of model differences. Perturbed parameter ensembles, in which model parameters are varied in a systematic manner, aim to assess the *uncertainty* resulting from internal model specifications within a single model. Remaining sources of *uncertainty* unaddressed with model ensembles are related to systematic model errors or biases, which may be assessed from systematic comparisons of model simulations with observations wherever available.

Climate system
The global system consisting of five major components: the *atmosphere*, the hydrosphere, the *cryosphere*, the lithosphere and the *biosphere* and the interactions between them. The *climate system* changes in time under the influence of its own internal dynamics and because of external forcings such as volcanic eruptions, solar variations, orbital forcing, and *anthropogenic* forcings such as the changing composition of the *atmosphere* and *land-use change*.

Climate variability
Deviations of some *climate* variables from a given mean state (including the occurrence of extremes, etc.) at all *spatial and temporal scales* beyond that of individual weather events. Variability may be intrinsic, due to fluctuations of processes internal to the *climate system* (internal variability), or extrinsic, due to variations in natural or *anthropogenic* external forcing (forced variability).

Climate velocity
The speed at which isolines of a specified *climate* variable travel across landscapes or seascapes due to changing *climate*. For example, *climate velocity* for temperature is the speed at which isotherms move due to changing *climate* (km yr^{-1}) and is calculated as the temporal change in temperature (°C yr^{-1}) divided by the current spatial gradient in temperature (°C km^{-1}). It can be calculated using additional *climate* variables such as precipitation or can be based on the climatic niche of organisms.

Climate-resilient development
In the WGII report, *climate-resilient development* refers to the process of implementing *greenhouse gas* mitigation and *adaptation* measures to support sustainable development for all.

Climate-resilient development pathways (CRDPs)
See *Pathways*.

Climate-resilient pathways
See *Pathways*.

Climate-smart agriculture (CSA)
An approach to agriculture that aims to transform and reorient agricultural systems to effectively support development and ensure *food security* in a changing *climate* by sustainably increasing agricultural productivity and *incomes*, adapting and building *resilience* to *climate change*, and reducing and/or removing *greenhouse gas emissions*, where possible (FAO, 2018).

Climatic driver (Climate driver)
A changing aspect of the *climate system* that influences a component of a *human* or *natural* system.

Climatic impact-drivers (CIDs)
Climatic impact-drivers (CIDs) are physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems. Depending on system tolerance, CIDs and their changes can be detrimental, beneficial, neutral, or a mixture of each across interacting system elements and regions.

CMIP3, CMIP5 and CMIP6
See *Coupled Model Intercomparison Project* (CMIP).

Co-benefit
A positive effect that a *policy* or measure aimed at one objective has on another objective, thereby increasing the total benefit to society or the environment. *Co-benefits* are also referred to as ancillary benefits. See also *Trade-off* and *Adverse side-effect*.

Coast
The *land* near to the sea. The term 'coastal' can refer to that *land* (e.g., as in 'coastal communities'), or to that part of the marine environment that is strongly influenced by *land*-based processes. Thus, coastal seas are generally shallow and near-shore. The landward and seaward limits of the coastal zone are not consistently defined, neither scientifically nor legally. Thus, coastal waters can either be considered as equivalent to territorial waters (extending 12 nautical miles/22.2 km from mean low water), or to the full exclusive economic zone, or to *shelf seas*, with less than 200 m water depth.

Coastal erosion
Coastal erosion, sometimes referred to as shoreline retreat, occurs when a net loss of sediment or bedrock from the shoreline results in landward movement of the high-tide mark.

Communicable disease
Illness due to a specific infectious agent or its toxic products that arises through transmission of that agent or its products from an infected person, animal or reservoir to a susceptible host, either directly or indirectly through an intermediate plant or animal host, vector or the inanimate environment. *Communicable disease* pathogens include bacteria, viruses, fungi, parasites and prions.

Community-based adaptation
See *Adaptation*.

Compound risks
See *Risk*.

Compound weather/climate events
The terms 'compound events', 'compound extremes' and 'compound extreme events' are used interchangeably in the literature and this report and refer to the combination of multiple *drivers* and/or *hazards* that contributes to societal and/or environmental *risk* (Zscheischler et al., 2018).

Concentrations scenario
See *Scenarios*.

Confidence
The robustness of a finding based on the type, amount, quality and consistency of *evidence* (e.g., mechanistic understanding, theory, data, *models*, expert judgment) and on the degree of *agreement* across multiple lines of *evidence*. In this report, *confidence* is expressed qualitatively (Mastrandrea et al., 2010).

Conservation agriculture
A farming system that promotes minimum soil disturbance (e.g., by using no-till practices), maintenance of a permanent soil cover and diversification of plant species. It aims to prevent *land degradation* and regenerate degraded *lands* by enhancing *biodiversity* and natural biological processes above and below the ground surface that contribute to increased water and nutrient use efficiency and improved and sustained crop production (FAO, 2016).

Coping
The use of available skills, resources and opportunities to address, manage and overcome adverse conditions, with the aim of achieving basic functioning of people, *institutions*, organisations and systems in the short to medium term (UNISDR, 2009; IPCC, 2012a).

Coping capacity
The ability of people, *institutions*, organisations and systems, using available skills, values, beliefs, resources and opportunities, to address, manage and overcome adverse conditions in the short to medium term (UNISDR, 2009; IPCC, 2012a). See also *Resilience*.

Coral bleaching
Loss of coral pigmentation through the loss of intracellular symbiotic algae (known as zooxanthellae) and/or loss of their pigments.

Coral reef
An underwater *ecosystem* characterised by structure-building stony corals. Warm-water *coral reefs* occur in shallow seas, mostly in the tropics, with the corals (animals) containing algae (plants) that depend on light and relatively stable temperature conditions. Cold-water *coral reefs* occur throughout the world, mostly at water depths of 50–500 m. In both kinds of reef, living corals frequently grow on older, dead material, predominantly made of calcium carbonate ($CaCO_3$). Both warm- and cold-water *coral reefs* support high *biodiversity* of fish and other groups, and are considered to be especially vulnerable to *climate change*.

Cost–benefit analysis
Monetary assessment of all negative and positive *impacts* associated with a given action. *Cost–benefit analysis* enables comparison of different interventions, investments or strategies and reveals how a given investment or *policy* effort pays off for a particular person, company or country. *Cost–benefit analyses* representing society's point of view are important for *climate change* decision-making, but there are difficulties in aggregating costs and benefits across different actors and across timescales. See also *Discounting*.

Coupled Model Intercomparison Project (CMIP)
A *climate modelling* activity from the World Climate Research Programme (WCRP) which coordinates and archives *climate model* simulations based on shared model inputs by modelling groups from around the world. The CMIP3 multi-model data set includes *projections* using Special Report on Emissions Scenarios (SRES) scenarios. The CMIP5 data set includes *projections* using the *Representative Concentration Pathways (RCP)*. The CMIP6 phase involves a suite of common model experiments as well as an ensemble of CMIP-endorsed Model Intercomparison Projects (MIPs).

Cryosphere
The components of the Earth system at and below the *land* and *ocean* surface that are frozen, including snow cover, *glaciers*, *ice sheets*, ice shelves, icebergs, *sea ice*, lake ice, river ice, *permafrost* and seasonally frozen ground.

Cultural impacts
Impacts on material and ecological aspects of culture and the lived experience of culture, including dimensions such as identity, community cohesion and belonging, sense of place, worldview, values, perceptions and tradition. *Cultural impacts* are closely related to ecological *impacts*, especially for iconic and representational dimensions of species and landscapes. Culture and cultural practices frame the importance and value of the *impacts* of change, shape the *feasibility* and acceptability of *adaptation options*, and provide the skills and practices that enable *adaptation*.

Decarbonisation
Human actions to reduce *carbon dioxide emissions* from human activities.

Deep uncertainty
See *Uncertainty*.

Deforestation
Conversion of *forest* to non-forest. See also *Afforestation* and *Reforestation*.
[Note: For a discussion of the term *forest* and related terms such as *afforestation*, *reforestation* and *deforestation*, see the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and their 2019 Refinement, and information provided by the United Nations Framework Convention on Climate Change (IPCC 2006, 2019; UNFCCC 2021a, 2021b)]

Desertification
Land degradation in arid, semi-arid, and dry sub-humid areas resulting from many factors, including climatic variations and human activities (UNCCD, 1994).

Detection
Detection of change is defined as the process of demonstrating that *climate* or a system affected by *climate* has changed in some defined statistical sense, without providing a reason for that change. An identified change is detected in observations if its *likelihood* of occurrence by chance due to internal variability alone is determined to be small, for example, <10%.

Detection and attribution
See *Attribution* and *Detection*.

Developed/developing countries (Industrialised/developed/developing countries)
There is a diversity of approaches for categorising countries on the basis of their level of development, and for defining terms such as ‘industrialised’, ‘developed’ or ‘developing’. Several categorisations are used in this Special Report. (1) In the United Nations (UN) system, there is no established convention for the designation of *developed* and *developing countries* or areas. (2) The UN Statistics Division specifies developed and developing regions based on common practice. In addition, specific countries are designated as Least Developed Countries, landlocked *developing countries*, *Small Island Developing States (SIDS)* and transition economies. Many countries appear in more than one of these categories. (3) The World Bank uses *income* as the main criterion for classifying countries as low, lower middle, upper middle and high *income*. (4) The UN Development Programme (UNDP) aggregates indicators for life expectancy, educational attainment and *income* into a single composite Human Development Index (HDI) to classify countries as low, medium, high or very high human development.

Development pathways
See *Pathways*.

Diatoms
Microscopic (2–200 µm) unicellular photosynthetic algae that live in surface waters of lakes, rivers and *oceans* and form shells of opal. In the global *ocean*, marine *diatom* species distribution is primarily driven by nutrient availability. On regional scales, their species distribution in *ocean* sediment cores can be related to past sea surface temperatures.

Diet
The kinds of food that follow a particular pattern that a person or community eats (FAO, 2014).

Disaster
A ‘serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of *exposure*, *vulnerability* and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts’ (UNGA, 2016). See also *Exposure*, *Hazard*, *Risk* and *Vulnerability*.

Disaster management
Social processes for designing, implementing and evaluating strategies, *policies* and measures that promote and improve *disaster* preparedness, response and recovery practices at different organisational and societal levels.

Disaster risk
The *likelihood* over a specified time period of severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery.

Disaster risk management (DRM)
Processes for designing, implementing and evaluating strategies, *policies* and measures to improve the understanding of current and future *disaster risk*, foster *disaster risk reduction* and transfer, and promote continuous improvement in *disaster* preparedness, prevention and protection, response and recovery practices, with the explicit purpose of increasing *human security*, *well-being*, quality of life and *sustainable development (SD)*.

Disaster risk reduction (DRR)
Denotes both a *policy* goal or objective, and the strategic and instrumental measures employed for anticipating future *disaster risk*; reducing existing *exposure*, *hazard* or *vulnerability*; and improving *resilience*.

Discount rate
See *Discounting*.

Discounting
A mathematical operation that aims to make monetary (or other) amounts received or expended at different times (years) comparable across time. If the discount rate is positive, future values are given less weight than those today. The choice of discount rate(s) is debated as it is a judgement based on hidden and/or explicit values.

Downscaling
A method that derives local- to regional-scale information from larger-scale *models* or data analyses. Two main methods exist: dynamical *downscaling* and empirical/statistical *downscaling*. The dynamical method uses the output of regional *climate models*, global *models* with variable spatial *resolution* or high-*resolution* global *models*. The empirical/statistical methods are based on observations and develop statistical relationships that link the large-scale atmospheric variables with local/regional *climate* variables. In all cases, the quality of the driving model remains an important limitation on the quality of the downscaled information. The two methods can be combined, for example, applying empirical/statistical *downscaling* to the output of a regional *climate model*, consisting of a dynamical *downscaling* of a global *climate model*.

Drainage
Artificial lowering of the soil water table (IPCC, 2013).

Driver
Any natural or human-induced factor that directly or indirectly causes a change in a system (adapted from MA, 2005). See also *Climatic driver*.

Drought
An exceptional period of water shortage for existing *ecosystems* and the human population (due to low rainfall, high temperature and/or wind).

Megadrought
A very lengthy and pervasive *drought*, lasting much longer than normal, usually a decade or more.

Hydrological drought
A period with large *runoff* and water deficits in rivers, lakes and reservoirs.

Agricultural and ecological drought
Agricultural and ecological drought (depending on the affected *biome*): a period with abnormal *soil moisture* deficit, which results from combined shortage of precipitation and excess *evapotranspiration*, and during the growing season impinges on crop production or *ecosystem* function in general.

Meteorological drought
A period with an abnormal precipitation deficit.

Early warning systems (EWS)
The set of technical and institutional capacities to forecast, predict and communicate timely and meaningful warning information to enable individuals, communities, managed *ecosystems* and organisations threatened by a *hazard* to prepare to act promptly and appropriately to reduce the possibility of harm or loss. Dependent upon context, EWS may draw upon scientific and/or *indigenous knowledge*, and other knowledge types. EWS are also considered for ecological applications, for example, conservation, where the organisation itself is not threatened by *hazard* but the ecosystem under conservation is (e.g., *coral bleaching* alerts), in agriculture (e.g., warnings of heavy rainfall, *drought*, ground frost and hailstorms) and in fisheries (e.g., warnings of storms, *storm surges* and *tsunamis*) (UNISDR 2009; IPCC, 2012a).

Earth system model (ESM)
A coupled *Atmosphere*–*Ocean* General Circulation Model (AOGCM) in which a representation of the *carbon cycle* is included, allowing for interactive calculation of atmospheric *carbon dioxide (CO_2)* or compatible *emissions*. Additional components (e.g., atmospheric chemistry, *ice sheets*, dynamic vegetation, nitrogen cycle, but also *urban* or crop *models*) may be included.

Eastern boundary upwelling system (EBUS)
Eastern boundary upwelling systems (EBUS) are located at the eastern (landward) edges of major *ocean* basins in both hemispheres, where equatorward winds drive upwelling currents that bring cool, nutrient-rich (and often oxygen-poor) waters from the deep *ocean* to the surface near the *coast*.

Ecosystem
A functional unit consisting of living organisms, their non-living environment and the interactions within and between them. The components included in a given *ecosystem* and its spatial boundaries depend on the purpose for which the *ecosystem* is defined: in some cases, they are relatively sharp, while in others they are diffuse. *Ecosystem* boundaries can change over time. *Ecosystems* are nested within other *ecosystems*, and their scale can range from very small to the entire *biosphere*. In the current era, most *ecosystems* either contain people as key organisms or are influenced by the effects of human activities in their environment. See also *Ecosystem services* and *Ecosystem health*.

Ecosystem health
Ecosystem health is a metaphor used to describe the condition of an *ecosystem*, by analogy with human *health*. Note that there is no universally accepted benchmark for a healthy *ecosystem*. Rather, the apparent *health* status of an *ecosystem* is judged on the *ecosystem*'s

resilience to change, with details depending upon which metrics are employed in judging it and which societal aspirations are driving the assessment (following IPBES 2019).

Ecosystem services
Ecological processes or functions having monetary or non-monetary value to individuals or society at large. These are frequently classified as (1) supporting services such as productivity or *biodiversity* maintenance, (2) provisioning services such as food or fibre, (3) regulating services such as *climate regulation* or carbon *sequestration* and (4) cultural services such as tourism or spiritual and aesthetic appreciation. See also *Ecosystem* and *Ecosystem health*.

Ecosystem-based adaptation (EBA)
See *Adaptation*.

El Niño-Southern Oscillation (ENSO)
The term 'El Niño' was initially used to describe a warm-water current that periodically flows along the *coast* of Ecuador and Peru, disrupting the local fishery. It has since become identified with warming of the tropical Pacific Ocean east of the dateline. This oceanic event is associated with a fluctuation of a global-scale tropical and subtropical surface pressure pattern called the Southern Oscillation. This coupled *atmosphere*–*ocean* phenomenon, with preferred time scales of 2 to about 7 years, is known as the *El Niño-Southern Oscillation (ENSO)*. The warm and cold phases of the ENSO are called El Niño and La Niña, respectively. ENSO is often measured by the surface pressure *anomaly* difference between Tahiti and Darwin and/or the sea surface temperatures in the central and eastern equatorial Pacific. This phenomenon has a great impact on the wind, sea surface temperature and precipitation patterns in the tropical Pacific. It has climatic effects throughout the Pacific region and in many other parts of the world through global *teleconnections*. See WGI AR6 Annex AIV.2.3 (IPCC 2021a).

Emergence (of the climate signal)
Emergence of a *climate change* signal or trend refers to when a change in *climate* (the 'signal') becomes larger than the amplitude of natural or internal variations (defining the 'noise'), This concept is often expressed as a signal-to-noise ratio, and *emergence* occurs at a defined threshold of this ratio (e.g., S/N > 1 or 2). *Emergence* can refer to changes relative to a historical or modern baseline (usually at least 20 years long) and can also be expressed in terms of time (time of *emergence*) or in terms of a *global warming* level. *Emergence* is also used to refer to a time when we can expect to see a response of reducing *greenhouse gas (GHG) emissions* (*emergence* with respect to *mitigation*). *Emergence* can be estimated using observations and/or model simulations.

Emission pathways
See *Pathways*.

Emission scenario
See *Scenario*.

Emissions

Anthropogenic emissions
Emissions of *greenhouse gases (GHGs)*, *precursors* of GHGs and *aerosols* caused by human activities. These activities include the burning of *fossil fuels*, *deforestation*, *land use* and *land-use changes* (LULUC), livestock production, fertilisation, waste management and industrial processes.

Fossil-fuel emissions
Emissions of *greenhouse gases* (in particular, *carbon dioxide*), other trace gases and *aerosols* resulting from the combustion of fuels from fossil carbon deposits such as oil, gas and coal.

Non-CO_2 emissions and radiative forcing
Non-CO_2 emissions included in this report are all *anthropogenic emissions* other than CO_2 that result in *radiative forcing*. These include short-lived *climate* forcers, such as *methane (CH_4)*, some fluorinated gases, *ozone (O_3) precursors*, *aerosols* or *aerosol precursors*, such as black carbon and sulphur dioxide, respectively, as well as long-lived *greenhouse gases*, such as nitrous oxide (N_2O) or other fluorinated gases. The *radiative forcing* associated with non-CO_2 *emissions* and changes in surface *albedo* is referred to as non-CO_2 *radiative forcing*.

Enabling conditions (for adaptation and mitigation options)
Conditions that enhance the *feasibility* of *adaptation* and *mitigation options*. *Enabling conditions* include finance, technological innovation, strengthening *policy* instruments, *institutional capacity*, multi-level *governance* and changes in human behaviour and lifestyles.

Endemic species
Plants and animals that are only found in one geographic region.

Energy access
Access to clean, reliable and affordable energy services for cooking and heating, lighting, communications and productive uses (with special reference to *Sustainable Development Goal* 7) (AGECC, 2010).

Energy efficiency
The ratio of output or useful energy or energy services or other useful physical outputs obtained from a system, conversion process, transmission or storage activity to the input of energy (measured as kWh kWh^{-1}, tonnes kWh^{-1} or any other physical measure of useful output like tonne-km transported). *Energy efficiency* is often described by energy intensity.

Energy security
The goal of a given country, or the global community as a whole, to maintain an adequate, stable and predictable energy supply. Measures encompass safeguarding the sufficiency of energy resources to meet national energy demand at competitive and stable prices and the *resilience* of the energy supply; enabling the development and deployment of technologies; building sufficient *infrastructure* to generate, store and transmit energy supplies and ensuring enforceable contracts of delivery.

Energy system
The *energy system* comprises all components related to the production, conversion, delivery and use of energy.

Equality
A principle that ascribes equal worth to all human beings, including equal opportunities, rights and obligations, irrespective of origins. See also *Equity* and *Fairness*.

Inequality
Uneven opportunities and social positions, and processes of discrimination within a group or society, based on gender, class, ethnicity, age and (dis)ability, often produced by uneven development. *Income inequality* refers to gaps between the highest and lowest *income* earners within a country and between countries.

Equity
The principle of being fair and impartial, and a basis for understanding how the *impacts* and responses to *climate change*, including costs and benefits, are distributed in and by society in more or less equal ways. Often aligned with ideas of *equality*, *fairness* and *justice* and applied with respect to *equity* in the responsibility for, and distribution of, *climate impacts* and *policies* across society, generations and gender, and in the sense of who participates and controls the processes of decision-making.

Ethics
Ethics involves questions of *justice* and value. Justice is concerned with right and wrong, *equity* and *fairness*, and, in general, with the rights to which people and living beings are entitled. Value is a matter of worth, benefit or good.

Eutrophication
Over-enrichment of water by nutrients such as nitrogen and phosphorus. It is one of the leading causes of water quality impairment. The two most acute symptoms of *eutrophication* are hypoxia (or oxygen depletion) and harmful algal blooms.

Evaporation
The physical process by which a liquid (e.g., water) becomes a gas (e.g., water vapour).

Evapotranspiration
The combined processes through which water is transferred to the *atmosphere* from open water and ice surfaces, bare soil and vegetation that make up the Earth's surface.

Evidence
Data and information used in the scientific process to establish findings. In this report, the degree of *evidence* reflects the amount, quality and consistency of scientific/technical information on which the Lead Authors are basing their findings. See also *Agreement*, *Confidence*, *Likelihood* and *Uncertainty*.

Evolutionary adaptation
See *Adaptation*.

Exposure
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.

Externality/external cost/external benefit
Externalities arise from a human activity, when agents responsible for the activity do not take full account of the activity's *impact* on others' production and consumption possibilities, and no compensation exists for such *impacts*. When the *impact* is negative, they are *external costs*. When positive they are referred to as *external benefits*. See also *Co-benefits*.

Extinction
A population, species or more inclusive taxonomic group has gone extinct when all its individuals have died. A species may go extinct locally (population *extinction*), regionally (e.g., *extinction* of all populations in a country, continent or *ocean*) or globally (IPBES, 2019). See also *Extirpation*.

Extirpation
The disappearance of a species from an area, sometimes also referred to as local *extinction*. Its use implies that the species still occurs elsewhere. See also *Extinction*.

Extreme sea level (ESL)
The occurrence of an exceptionally low or high local sea surface height, arising from (a combination of) short-term phenomena (e.g., *storm surges*, tides and waves). Relative *sea level changes* affect *extreme sea levels* directly by shifting the mean water levels and indirectly by modulating the propagation of tides, waves and/or surges due to increased water depth. In addition, *extreme sea levels* can be influenced by changes in the frequency, tracks or strength of weather systems and storms, or due to *anthropogenically* induced changes such as the modification of coastlines or dredging. In turn, changes in any or all of the contributions to *extreme sea levels* may lead to long-term relative *sea level changes*. Alternate expressions for ESL may be used depending on the processes resolved.
Extreme still water level (ESWL) refers to the combined contribution of relative *sea level change*, tides and *storm surges*. Wind-waves also contribute to coastal sea level via three processes: infragravity waves (lower-frequency gravity waves generated by wind waves), wave setup (time-mean sea level elevation due to wave energy dissipation) and swash (vertical displacement up the shore-face induced by individual waves). Extreme total water level (ETWL) is the ESWL plus wave setup. When considering coastal *impacts*, swash is also important, and extreme coastal water level (ECWL) is used. See also *Sea level change (sea level rise/sea level fall)*

Extreme weather event
An event that is rare at a particular place and time of year. Definitions of 'rare' vary, but an *extreme weather event* would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. See also *Heatwave* and *Climate extreme*.

Extreme/heavy precipitation event
An *extreme/heavy precipitation event* is an event that is of very high magnitude with a very rare occurrence at a particular place. Types of extreme precipitation may vary depending on its duration, hourly, daily or multi-days (e.g., 5 days), though all of them qualitatively represent high magnitude. The intensity of such events may be defined with block maxima approach such as annual maxima or with peak over threshold approach, such as rainfall above 95th or 99th percentile at a particular space.

Fairness
Impartial and just treatment without favouritism or discrimination in which each person is considered of equal worth with equal opportunity. See also *Equality* and *Equity*.

Feasibility
In this report, *feasibility* refers to the potential for a *mitigation* or *adaptation option* to be implemented. Factors influencing *feasibility* are context dependent, temporally dynamic and may vary between different groups and actors. *Feasibility* depends on geophysical, environmental-ecological, technological, economic, socio-cultural and institutional factors that enable or constrain the implementation of an option. The *feasibility* of options may change when different options are combined, and increase when *enabling conditions* are strengthened. See also *Enabling conditions (for adaptation and mitigation options)*.

Fire weather
Weather conditions conducive to triggering and sustaining wildfires, usually based on a set of indicators and combinations of indicators including temperature, *soil moisture*, humidity and wind. *Fire weather* does not include the presence or absence of fuel load.

Flood
The overflowing of the normal confines of a stream or other water body, or the *accumulation* of water over areas that are not normally submerged. *Floods* can be caused by unusually heavy rain, for example during storms and cyclones. *Floods* include river (fluvial) *floods*, flash *floods*, *urban floods*, rain (pluvial) *floods*, sewer *floods*, coastal *floods*, and *glacial lake outburst floods (GLOF)*.

Flux
A movement (flow) of matter (e.g., water vapour, particles), heat or energy from one place to another, or from one medium (e.g., *land* surface) to another (e.g., *atmosphere*).

Food security
A situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. The four pillars of *food security* are availability, access, utilisation and stability. The nutritional dimension is integral to the concept of *food security* (FAO, 2018/ 2009).

Availability
Physical availability of food. *Food availability* addresses the supply side of food security and is determined by the levels of food production, stocks and net trade.

Access
Economic and/or physical access to food. Economic access is determined by disposable *income*, food prices and the provision of and access to social support. Physical access is determined by the availability and quality of *land* and other *infrastructure*, property rights or the functioning of markets.

Utilisation
The way in which the body uses the various nutrients in food. Individuals achieve sufficient energy and nutrient intake through good care and feeding practices, food preparation, *diet* diversity and intrahousehold distribution of food. Combined with biological utilisation of the food consumed, energy and nutrient intake determine the nutrition status of individuals.

Stability
The stability of the other three dimensions over time. Even if individuals' food intake is adequate today, they are still considered food-insecure if periodically they have inadequate access to food, risking deterioration of their nutrition status. Adverse weather conditions, political instability or economic factors (unemployment, rising food prices) may have an impact on individuals' *food security* status.

Food system
All the elements (environment, people, inputs, processes, infrastructures, *institutions*, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food, and the output of these activities, including socio-economic and environmental outcomes (HLPE, 2017). [Note: While there is a global *food system* (encompassing the totality of global production and consumption), each location's *food system* is unique, being defined by that place's mix of food produced locally, nationally, regionally or globally.]

Food-borne diseases
Illnesses transmitted through the consumption of unsafe or contaminated food. That contamination can come from a variety of *sources*, including contaminated water (adapted from UNEP, 2018).

Forest
A vegetation type dominated by trees. Many definitions of the term *forest* are in use throughout the world, reflecting wide differences in bio-geophysical conditions, social structure and economics. See also *Afforestation*, *Deforestation* and *Reforestation*
[Note: For a discussion of the term forest in the context of national GHG inventories, see the 2006 IPCC Guidelines for National GHG Inventories and their 2019 Refinement, and information provided by the United Nations Framework Convention on Climate Change (IPCC 2006, 2019; UNFCCC, 2021a, 2021b).]

Forest degradation
A reduction in the capacity of a *forest* to produce *ecosystem services* such as carbon storage and wood products as a result of *anthropogenic* and environmental changes.

Forest dieback
See *Forest degradation*.

Forest line
The upper limit of the closed upper montane forest or forest at high latitudes. It is less elevated or less poleward than the tree line.

Forest management
See *Sustainable forest management*.

Fossil fuels
Carbon-based fuels from fossil hydrocarbon deposits, including coal, oil and natural gas.

Glacial lake outburst flood (GLOF)/Glacier lake outburst
A sudden release of water from a *glacier* lake, including any of the following types: a *glacier*-dammed lake, a pro-glacial moraine-dammed lake or water that was stored within, under or on the *glacier*.

Glacier
A perennial mass of ice, and possibly firn and snow, originating on the *land* surface by *accumulation* and compaction of snow and showing *evidence* of past or present flow. A *glacier* typically gains mass by *accumulation* of snow and loses mass by ablation. *Land* ice masses of continental size (>50,000 km^2) are referred to as *ice sheets* (Cogley et al., 2011).

Global change
A generic term to describe global-scale changes in systems, including the *climate system*, *ecosystems* and *social-ecological systems*.

Global mean sea level change
Global mean sea level (GMSL) *change* is the increase or decrease in the volume of the *ocean* divided by the *ocean* surface area. It is the sum of changes in *ocean* density through temperature changes (global mean thermosteric *sea level change*) and changes in the *ocean* mass as a result of changes in the *cryosphere* or land water storage (barystatic *sea level change*).

Global mean surface air temperature (GSAT)
The global average of near-surface air temperatures over *land*, *oceans* and *sea ice*. Changes in GSAT are often used as a measure of global temperature change in *climate models*. See also *Global mean surface temperature (GMST)*.

Global mean surface temperature (GMST)
The estimated global average of near-surface air temperatures over *land* and *sea ice*, and sea surface temperature (SST) over ice-free *ocean regions*, with changes normally expressed as departures from a value over a specified *reference period*. See also *Global mean surface air temperature (GSAT)*.

Global monsoon
The *global monsoon* (GM) is a global-scale solstitial mode that dominates the annual variation of tropical and sub-tropical precipitation and circulation. The GM domain is defined as the area where the annual range of precipitation (local summer minus winter mean precipitation rate) is greater than 2.5 mm/day, following on from the definition as in Kitoh et al. (2013). Further details on how the GM is defined, used and related to regional *monsoons* throughout the report are provided by WGI AR6 Annex V (IPCC 2021b).

Global warming
Global warming refers to the increase in global surface temperature relative to a baseline *reference period*, averaging over a period sufficient to remove interannual variations (e.g., 20 or 30 years). A common choice for the baseline is 1850–1900 (the earliest period of reliable observations with sufficient geographic coverage), with more modern baselines used depending upon the application. See also *Climate change* and *Climate variability*.

Governance
The structures, processes and actions through which private and public actors interact to address societal goals. This includes formal and informal *institutions* and the associated norms, rules, laws and procedures for deciding, managing, implementing and monitoring *policies* and measures at any geographic or political scale, from global to local.

Adaptive governance
Adjusting to changing conditions, such as *climate change*, through *governance* interactions that seek to maintain a desired state in a *social-ecological system*.

Climate governance
The structures, processes and actions through which private and public actors seek to mitigate and adapt to *climate change*.

Multi-level governance
The dispersion of *governance* across multiple levels of jurisdiction and decision-making, including, global, regional, national and local as well as trans-regional and trans-national levels.

Polycentric governance
Polycentric governance involves multiple centres of decision-making with overlapping jurisdictions. While the centres have some degree of autonomy, they also take each other into account, coordinating their actions and seeking to resolve conflicts (Carlisle and Gruby, 2017; Jordan et al., 2018; McGinnis and Ostrom, 2012).

Governance capacity
The ability of *governance institutions*, leaders and non-state and civil society to plan, coordinate, fund, implement, evaluate and adjust *policies* and measures over the short, medium and long term, adjusting for *uncertainty*, rapid change and wide-ranging *impacts* and multiple actors and demands.

Green Climate Fund (GCF)
The *Green Climate Fund* was established by the 16th Session of the Conference of the Parties (COP) in 2010 as an operating entity of the financial mechanism of the United Nations Framework Convention on Climate Change (UNFCCC), in accordance with Article 11 of the Convention, to support projects, programmes and *policies* and other activities in *developing country* Parties. The Fund is governed by a board and will receive guidance from the COP.

Green infrastructure
See *Infrastructure*.

Greenhouse gases (GHG)
Gaseous constituents of the *atmosphere*, both natural and *anthropogenic*, that absorb and emit radiation at specific wavelengths within the spectrum of radiation emitted by the Earth's *ocean* and *land* surface, by the *atmosphere* itself and by clouds. This property causes the greenhouse effect. Water vapour (H_2O), *carbon dioxide (CO_2)*, nitrous oxide (N_2O), *methane (CH_4)* and *ozone (O_3)* are the primary GHGs in the Earth's *atmosphere*. Human-made GHGs include sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs), chlorofluorocarbons (CFCs) and perfluorocarbons (PFCs); several of these are also O_3-depleting (and are regulated under the Montreal Protocol).

Grey infrastructure
See *Infrastructure*.

Gross domestic product (GDP)
The sum of gross value added, at purchasers' prices, by all resident and non-resident producers in the economy, plus any taxes and minus any subsidies not included in the value of the products in a country or a geographic region for a given period, normally one year. GDP is calculated without deducting for depreciation of fabricated assets or depletion and degradation of natural resources.

Groundwater recharge
The process by which external water is added to the zone of saturation of an aquifer, either directly into a geologic formation that traps the water or indirectly by way of another formation.

Habitability (human)
The ability of a place to support human life by providing protection from *hazards* which challenge human survival, and by assuring adequate space, food and freshwater.

Hazard
The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury or other *health impacts*, as well as damage and loss to property, *infrastructure*, *livelihoods*, service provision, *ecosystems* and environmental resources. See also *Impacts* and *Risk*.

Health
Health is a state of complete physical, mental and social *well-being* and not merely the absence of disease or infirmity (WHO).

Heat index
A measure of how hot the air feels to the human body. The index is mainly based on surface air temperature and *relative humidity* and thus reflects the combined effect of high temperature and humidity on human physiology and provides a relative indication of potential *health risks*. See also *Heatwave*.

Heat stress
A range of conditions in, for example, terrestrial or aquatic organisms when the body absorbs excess heat during overexposure to high air or water temperatures or thermal radiation. In aquatic water-breathing animals, hypoxia and acidification can exacerbate *vulnerability* to heat. *Heat stress* in mammals (including humans) and birds, both in air, is exacerbated by a detrimental combination of ambient heat, high humidity and low wind speed, causing the regulation of body temperature to fail.

Heatwave
A period of abnormally hot weather, often defined with reference to a relative temperature threshold, lasting from two days to months. *Heatwaves* and warm spells have various and, in some cases, overlapping definitions. See also *Heat index*, *Heat stress* and *Marine heatwave*.

Heavy precipitation event
See *Extreme/heavy precipitation event*.

Human mobility
The permanent or semi-permanent move by a person for at least 1 year and involving crossing an administrative, but not necessarily a national, border.

Human rights
Rights that are inherent to all human beings, universal, inalienable and indivisible, typically expressed and guaranteed by law. They include the right to life, economic, social and cultural rights, and the right to development and self-determination (UNOHCHR, 2018).

Human security
A condition that is met when the vital core of human lives is protected, and when people have the freedom and capacity to live with dignity. In the context of *climate change*, the vital core of human lives includes the universal and culturally specific, material and non-material elements necessary for people to act on behalf of their interests and to live with dignity.

Human system
Any system in which human organisations and *institutions* play a major role. Often, but not always, the term is synonymous with society or social system. Systems such as agricultural systems, *urban systems*, political systems, technological systems and economic systems are all *human systems* in the sense applied in this report.

Hydrological cycle
The cycle in which water evaporates from the *ocean* and the *land* surface, is carried over the Earth in atmospheric circulation as water vapour, condenses to form clouds, precipitates over the *ocean* and *land* as rain or snow, which on *land* can be intercepted by trees and vegetation, potentially accumulating as snow or ice, provides *runoff* on the *land* surface, infiltrates into soils, recharges groundwater, discharges into streams and, ultimately, flows into the *oceans* as rivers, polar *glaciers* and *ice sheets*, from which it will eventually evaporate again. The various systems involved in the *hydrological cycle* are usually referred to as hydrological systems.

Hydrological drought
See *Drought*.

Hydropower
Power harnessed from the flow of water.

Hyperthermal events
Geologically abrupt *global warming* events of the past associated with disturbances of the carbon cycle and *impacts* on the *biosphere*.

Hypoxic
Conditions of low dissolved oxygen in shallow-water *ocean* and freshwater environments. There is no universal threshold for hypoxia. A value around 60 µmol kg^{-1} has commonly been used for some estuarine systems, although this does not necessarily directly translate into biological *impacts*. Anoxic conditions occur where there is no oxygen present at all. See also *Eutrophication*.

Hypoxic events
Events that lead to deficiencies of oxygen in water bodies.

Ice sheet
An ice body originating on *land* that covers an area of continental size, generally defined as covering >50,000 km^2, and that has formed over thousands of years through *accumulation* and compaction of snow. An *ice sheet* flows outward from a high central ice plateau with a small average surface slope. The margins usually slope more steeply, and most ice is discharged through fast-flowing ice streams or outlet *glaciers*, often into the sea or into ice shelves floating on the sea. There are only two *ice sheets* in the modern world, one on Greenland and one on Antarctica. The latter is divided into the East Antarctic Ice Sheet (EAIS), the West Antarctic Ice Sheet (WAIS) and the Antarctic Peninsula Ice Sheet. During glacial periods, there were other *ice sheets*.

Impacts
The consequences of realised *risks* on *natural* and *human systems*, where *risks* result from the interactions of *climate*-related *hazards* (including *extreme weather/climate events*), *exposure*, and *vulnerability*. *Impacts* generally refer to effects on lives, *livelihoods*, *health* and *well-being*, *ecosystems* and species, economic, social and cultural assets, services (including *ecosystem services*) and *infrastructure*. *Impacts* may be referred to as consequences or outcomes, and can be adverse or beneficial. See also *Adaptation*, *Exposure*, *Loss and Damage, and losses and damages*, *Vulnerability* and *Risk*.

Income
The maximum amount that a household, or other unit, can consume without reducing its real net worth. Total *income* is the broadest measure of *income* and refers to regular receipts such as wages and salaries, *income* from self-employment, interest and dividends from invested funds, pensions or other benefits from social *insurance*, and other current transfers receivable. OECD (2003).

Incremental adaptation
See *Adaptation*.

Indigenous knowledge (IK)
The understandings, skills and philosophies developed by societies with long histories of interaction with their natural surroundings. For many indigenous peoples, IK informs decision-making about fundamental aspects of life, from day-to-day activities to longer-term actions. This knowledge is integral to cultural complexes, which also encompass language, systems of classification, resource use practices, social interactions, values, ritual and spirituality. These distinctive ways of knowing are important facets of the world's cultural diversity (UNESCO, 2018). See also *Local knowledge*.

Indigenous Peoples
Indigenous Peoples and Nations are those that, having a historical continuity with pre-invasion and pre-colonial societies that developed on their territories, consider themselves distinct from other sectors of the societies now prevailing on those territories, or parts of them. They form at present principally non-dominant sectors of society and are often determined to preserve, develop and transmit to future generations their ancestral territories, and their ethnic identity, as the basis of their continued existence as Peoples, in accordance with their own cultural patterns, social *institutions* and common law system. Cobo (1987)

Indirect land-use change (iLUC)
See *Land-use change*.

Inequality
See *Equality*.

Informal settlement
A term given to *settlements* or residential areas that, by at least one criterion, fall outside official rules and *regulations*. Most *informal settlements* have poor housing (with widespread use of temporary materials) and are developed on *land* that is occupied illegally with high levels of overcrowding. In most such *settlements*, provision for safe water, sanitation, *drainage*, paved roads and basic services is inadequate or lacking. The term 'slum' is often used for *informal settlements*, although it is misleading as many *informal settlements* develop into good-quality residential areas, especially where governments support such development.

Infrastructure
The designed and built set of physical systems and corresponding institutional arrangements that mediate between people, their communities and the broader environment to provide services that support economic growth, *health*, quality of life and safety (Chester, 2019; Dawson et al., 2018) There are four categories of *infrastructure*:

Blue infrastructure
Blue infrastructure includes bodies of water, watercourses, ponds, lakes and storm *drainage*, that provide ecological and hydrological functions including *evaporation*, transpiration, *drainage*, infiltration and temporarily storage of *runoff* and discharge.

Green infrastructure
The strategically planned interconnected set of natural and constructed ecological systems, green spaces and other landscape features that can provide functions and services including air and water purification, temperature management, floodwater management and coastal defence often with *co-benefits* for human and ecological *well-being*. *Green infrastructure* includes planted and

remnant native vegetation, soils, wetlands, parks and green open spaces, as well as building and street-level design interventions that incorporate vegetation (after Culwick and Bobbins, 2016).

Grey infrastructure
Engineered physical components and networks of pipes, wires, roads and tracks that underpin energy, transport, communications (including digital), built form, water and sanitation, and solid-waste management systems.

Social infrastructure
The social, cultural and financial activities and *institutions* as well as associated property, buildings and artefacts and *policy* domains such as *social protection*, *health* and education that support *well-being* and public life (Frolova et al., 2016; Latham and Layton, 2019).

Institutional capacity
Building and strengthening individual organisations and providing technical and management training to support integrated planning and decision-making processes between organisations and people, as well as empowerment, social capital and an enabling environment, including culture, values and power relations (Willems and Baumert, 2003).

Institutions
Rules, norms and conventions that guide, constrain or enable human behaviours and practices. *Institutions* can be formally established, for instance through laws and *regulations*, or informally established, for instance by traditions or customs. *Institutions* may spur, hinder, strengthen, weaken or distort the emergence, adoption and implementation of *climate* action and *climate governance*.
[Note: *Institutions* can also refer to a large organisation]

Insurance/reinsurance
A family of financial instruments for sharing and transferring *risk* among a pool of at-*risk* households, businesses and/or governments.

Integrated assessment
A method of analysis that combines results and *models* from the physical, biological, economic and social sciences and the interactions among these components in a consistent framework to evaluate the status and consequences of environmental change and the *policy* responses to it.

Integrated assessment model (IAM)
Models that integrate knowledge from two or more domains into a single framework. They are one of the main tools for undertaking *integrated assessments*. One class of IAM used in respect of *climate change mitigation* may include representations of: multiple sectors of the economy, such as energy, *land* use and *land use change*; interactions between sectors; the economy as a whole; associated *greenhouse gas (GHG) emissions* and *sinks*; and reduced representations of the *climate system*. This class of model is used to assess linkages between economic, social and technological development and the evolution of the *climate system*. Another class of IAM additionally includes representations of the costs associated with *climate change impacts*, but includes less detailed representations of economic systems. These can be used to assess *impacts* and *mitigation* in a cost–benefit framework and have been used to estimate the social cost of carbon.

Invasive species
A species that is not native to a specific location or nearby, lacking natural controls, and that has a tendency to rapidly increase in abundance, displacing *native species*. *Invasive species* may also damage the human economy or human *health*.

Justice
Justice is concerned with, setting out the moral or legal principles of *fairness* and *equity* in the way people are treated, often based on the *ethics* and values of society.

Climate justice
Justice that links development and *human rights* to achieve a human-centred approach to addressing *climate change*, safeguarding the rights of the most vulnerable people and sharing the burdens and benefits of *climate change* and its *impacts* equitably and fairly (MRFJC, 2018).

Procedural justice
Justice in the way outcomes are brought about, including who participates and is heard in the processes of decision-making.

Social justice
Just or fair relations within society that seek to address the distribution of wealth, access to resources, opportunity and support according to principles of *justice* and *fairness*.

Key risk
Key risks have potentially severe adverse consequences for humans and social-ecological systems resulting from the interaction of climate related *hazards* with vulnerabilities of societies and systems exposed.

Representative Key Risks (RKRs)
are representative, thematic clusters of key risks.

Land
The terrestrial portion of the *biosphere* that comprises the natural resources (soil, near-surface air, vegetation and other biota, and water), the ecological processes, topography, and human *settlements* and *infrastructure* that operate within that system (FAO, 2007; UNCCD, 1994).

Land cover
The biophysical coverage of *land* (e.g., bare soil, rocks, *forests*, buildings and roads, or lakes). *Land cover* is often categorised in broad *land-cover* classes (e.g., deciduous forest, coniferous forest, mixed forest, grassland and bare ground). Note: In some literature assessed in this report, *land cover* and *land use* are used interchangeably, but the two represent distinct classification systems. For example, the *land cover* class of woodland can be under various *land uses* such as livestock grazing, recreation, conservation or wood harvest.

Land cover change
Change from one *land cover* class to another, due to change in *land use* or change in natural conditions (Pongratz et al., 2018). See also *Land cover* and *Land-use change*.

Land degradation
A negative trend in *land* condition, caused by direct or indirect human-induced processes including *anthropogenic climate change*, expressed as a long-term reduction or loss of at least one of the following: biological productivity, ecological integrity or value to humans. [Note: This definition applies to *forest* and non-*forest land*. Changes in *land* condition resulting solely from natural processes (such as volcanic eruptions) are not considered to be *land degradation*. Reduction of biological productivity or ecological integrity or value to humans can constitute degradation, but any one of these changes need not necessarily be considered degradation.]

Land management
The sum of *land-use* practices (e.g., sowing, fertilising, weeding, harvesting, thinning and clear-cutting) that take place within broader *land-use* categories (Pongratz et al., 2018).

Land use
The total of arrangements, activities and inputs applied to a parcel of *land*. The term *land use* is also used in the sense of the social and economic purposes for which *land* is managed (e.g., grazing, timber extraction, conservation and *city* dwelling). In national *greenhouse gas (GHG)* inventories, *land use* is classified according to the IPCC *land-use* categories of *forest land*, cropland, grassland, wetlands, *settlements* and other *lands* (see the 2006 IPCC Guidelines for National GHG Inventories and their 2019 Refinement for details (IPCC, 2006, 2019)).

Land-use change
The change from one *land-use* category to another. Note that, in some scientific literature, *land-use change* encompasses changes in *land-use* categories as well as changes in *land management*. See also *Afforestation*, *Deforestation* and *Reforestation*.

Indirect land-use change (iLUC)
Land-use change outside the area of focus that occurs as a consequence of change in use or management of *land* within the area of focus, such as through market or *policy drivers*. For example, if agricultural *land* is diverted to *biofuel* production, forest clearance may occur elsewhere to replace the former agricultural production. See *Land-use change (LUC)*.

Least Developed Countries (LDCs)
A list of countries designated by the Economic and Social Council of the United Nations (ECOSOC) as meeting three criteria: (1) a low *income* criterion below a certain threshold of gross national income per capita of between USD 750 and USD 900, (2) a human resource weakness based on indicators of *health*, education and adult literacy, and (3) an economic *vulnerability* weakness based on indicators on instability of agricultural production, instability of export of goods and services, economic importance of non-traditional activities, merchandise export concentration and the handicap of economic smallness. Countries in this category are eligible for a number of programmes focused on assisting countries most in need. These privileges include certain benefits under the articles of the United Nations Framework Convention on Climate Change (UNFCCC).

Likelihood
The chance of a specific outcome occurring, where this might be estimated probabilistically. *Likelihood* is expressed in this Special Report using a standard terminology (Mastrandrea et al., 2010). See also *Agreement*, *Confidence*, *Evidence* and *Uncertainty*.

Livelihood
The resources used and the activities undertaken in order for people to live. *Livelihoods* are usually determined by the entitlements and assets to which people have access. Such assets can be categorised as human, social, natural, physical or financial.

Local extinction
See *Extirpation*.

Local knowledge (LK)
The understandings and skills developed by individuals and populations, specific to the places where they live. Local knowledge informs decision-making about fundamental aspects of life, from day-to-day activities to longer-term actions. This knowledge is a key element of the social and cultural systems which influence observations of and responses to *climate change*; it also informs *governance* decisions (UNESCO, 2018). See also *Indigenous knowledge*.

Lock-in
A situation in which the future development of a system, including *infrastructure*, technologies, investments, institutions and behavioural norms, is determined or constrained ('locked in') by historical developments. See also *Path dependence*.

Loss and Damage, and losses and damages
Research has taken Loss and Damage (capitalised letters) to refer to political debate under the United Nations Framework Convention on Climate Change (UNFCCC) following the establishment of the Warsaw Mechanism on Loss and Damage in 2013, which is to 'address loss and damage associated with impacts of climate change, including extreme events and slow onset events, in developing countries that are particularly vulnerable to the adverse effects of climate change.' Lowercase letters (losses and damages) have been taken to refer broadly to harm from (observed) *impacts* and (projected) *risks* and can be economic or non-economic (Mechler et al., 2018).

Low Elevation Coastal Zones (LECZ)
Coastal areas below 10 m of elevation above sea level that are hydrologically connected to the sea.

Low-likelihood, high-impact outcomes
Outcomes/events whose probability of occurrence is low or not well known (as in the context of *deep uncertainty*) but whose potential *impacts* on society and *ecosystems* could be high. To better inform *risk* assessment and decision-making, such low-*likelihood* outcomes are considered if they are associated with very large consequences and may

therefore constitute material *risks*, even though those consequences do not necessarily represent the most likely outcome. See also *Impacts*.

Maladaptive actions (Maladaptation)
Actions that may lead to increased *risk* of adverse climate-related outcomes, including via increased *greenhouse gas (GHG) emissions*, increased or shifted *vulnerability* to *climate change*, more inequitable outcomes, or diminished welfare, now or in the future. Most often, *maladaptation* is an unintended consequence.

Malnutrition
Deficiencies, excesses or imbalances in a person's intake of energy and/or nutrients. The term *malnutrition* addresses three broad groups of conditions: undernutrition, which includes wasting (low weight-for-height), stunting (low height-for-age) and underweight (low weight-for-age); micronutrient-related malnutrition, which includes micronutrient deficiencies (a lack of important vitamins and minerals) or micronutrient excess; and overweight, obesity and *diet*-related *non-communicable diseases* (such as heart disease, stroke, diabetes and some cancers) (WHO, 2018). Micronutrient deficiencies are sometimes termed 'hidden hunger' to emphasise that people can be malnourished in the sense of deficient without being deficient in calories. Hidden hunger can apply even where people are obese.

Marine heatwave
A period during which water temperature is abnormally warm for the time of the year relative to historical temperatures, with that extreme warmth persisting for days to months. The phenomenon can manifest in any place in the *ocean* and at scales of up to thousands of kilometres. See also *Heatwave*.

Mean sea level
The surface level of the *ocean* at a particular point averaged over an extended period of time such as a month or year. *Mean sea level* is often used as a national datum to which heights on land are referred.

Measurement
Processes of data collection over time, providing basic data sets, including associated accuracy and precision, for the range of relevant variables. Possible data sources are field *measurements*, field observations, detection through remote sensing and interviews (UN-REDD, 2009).

Megacity
An *urban* agglomeration with 10 million inhabitants or more (United Nations, Department of Economic and Social Affairs, Population Division (2019).

Megadrought
See *Drought*.

Meteorological drought
See *Drought*.

Mental health
The state of *well-being* in which an individual realises his or her own abilities, can cope with the normal stresses of life, can work productively and is able to contribute to his or her community.

Methane (CH_4)
One of the six *greenhouse gases (GHGs)* to be mitigated under the Kyoto Protocol. *Methane* is the major component of natural gas and associated with all hydrocarbon fuels. Significant *anthropogenic emissions* also occur as a result of animal husbandry and paddy rice production. *Methane* is also produced naturally where organic matter decays under anaerobic conditions, such as in wetlands. Under future *global warming*, there is *risk* of increased *methane emissions* from thawing *permafrost*, coastal wetlands and sub-sea gas hydrates.

Metric
A consistent *measurement* of a characteristic of an object or activity that is otherwise difficult to quantify. Within the context of the evaluation of *climate models*, this is a quantitative measure of agreement between a simulated and an observed quantity which can be used to assess the performance of individual *models*.

Metropolitan region
See *City region*.

Microclimate
Local *climate* at or near the Earth's surface.

Migrant
Any person who is moving or has moved across an international border or within a state away from his/her habitual place of residence, regardless of (1) the person's legal status, (2) whether the movement is voluntary or involuntary, (3) what the causes for the movement are and (4) what the length of the stay is (IOM, 2018).

Migration (of humans)
Movement of a person or a group of persons, either across an international border, or within a state. It is a population movement, encompassing any kind of movement of people, whatever its length, composition and causes; it includes migration of refugees, displaced persons, economic *migrants* and persons moving for other purposes, including family reunification (IOM, 2018).

Mitigation (of climate change)
A human intervention to reduce *emissions* or enhance the *sinks* of *greenhouse gases*.

Mitigation measures
In *climate policy*, *mitigation measures* are technologies, processes or practices that contribute to *mitigation*, for example renewable energy technologies, waste minimisation processes and public transport commuting practices.

Mitigation option
A technology or practice that reduces *greenhouse gas (GHG) emissions* or enhances *sinks*.

Mitigation scenario
A plausible description of the future that describes how the (studied) system responds to the implementation of *mitigation policies* and measures.

Model ensemble
See *Climate simulation ensemble*.

Models
Structured imitations of a system's attributes and mechanisms to mimic the appearance or functioning of systems, for example, the *climate*, the economy of a country, or a crop. Mathematical *models* assemble (many) variables and relations (often in a computer code) to simulate system functioning and performance for variations in parameters and inputs.

Monitoring and evaluation (M&E)
Mechanisms put in place to respectively monitor and evaluate efforts to reduce *greenhouse gas emissions* and/or adapt to the *impacts* of *climate change* with the aim of systematically identifying, characterising and assessing progress over time.

Monsoon
See *Global monsoon*.

Mountains
A mountain is a landform formed through plate tectonics that rises above its surrounding area, characterised by verticality and ruggedness such as gentle or steep sloping sides, sharp or rounded ridges and a high point called a peak or a summit. Mountain *regions* consist of mountains and mountain ranges as defined by ruggedness, intermontane valleys, plateaus and tablelands, and hills and hilly forelands, together forming a complex terrain.
To delineate mountain *regions*, a combination of terrain characteristics is used, such as elevation above sea level, steepness of slope and relative relief or local elevational range.
Three mountain characterisations using different combinations of the above criteria applied to digital elevation models have been developed to arrive at mountain area statistics, described and analysed in detail by Sayre et al. (2018), namely K1 (Kapos et al., 2000), K2 (Körner et al., 2011) and K3 (Karagulle et al., 2017).

Multi-level governance
See *Governance*.

Narrative
See *Storyline*. See also *Pathways*.

Native species
Indigenous species of animals or plants that naturally occur in a given region or *ecosystem*. Under *climate change*, many species colonise new areas where they may become native over time (following IPBES, 2019). See also *Invasive species*.

Natural systems
The dynamic physical, physicochemical and biological components of the Earth system that would operate independently of human activities.

Nature-based solution (NBS)
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. (IUCN, 2016). See also *Biodiversity* and *Ecosystem*.

Net primary production (NPP)
See *Primary production*.

Net zero CO_2 emissions
Condition in which *anthropogenic carbon dioxide (CO_2)* emissions are balanced by *anthropogenic* CO_2 removals over a specified period. See also *Land use*.
[Note: Carbon neutrality and *net zero CO_2 emissions* are overlapping concepts. The concepts can be applied at global or sub-global scales (e.g., regional, national and sub-national). At a global scale, the terms 'carbon neutrality' and *net zero CO_2 emissions* are equivalent. At sub-global scales, *net zero CO_2 emissions* is generally applied to *emissions* and removals under direct control or territorial responsibility of the reporting entity, while carbon neutrality generally includes *emissions* and removals within and beyond the direct control or territorial responsibility of the reporting entity. Accounting rules specified by GHG programmes or schemes can have a significant influence on the quantification of relevant CO_2 *emissions* and removals.]

New Urban Agenda
The New Urban Agenda was adopted at the United Nations Conference on Housing and Sustainable Urban Development (Habitat III) in Quito, Ecuador, on 20 October 2016. It was endorsed by the United Nations General Assembly at its 68th plenary meeting of the 71st session on 23 December 2016.

Non-climatic driver (Non-climate driver)
An agent or process outside the *climate system* that influences a *human* or *natural system*.

Non-communicable diseases
Non-communicable diseases (NCDs), also known as chronic diseases, tend to be of long duration and are the result of a combination of genetic, physiological, environmental and behavioural factors. The main types of NCDs are cardiovascular diseases (such as heart attacks and stroke), cancers, chronic respiratory diseases (such as chronic obstructive pulmonary disease and asthma) and diabetes (WHO).

Ocean
The interconnected body of saline water that covers 71% of the Earth's surface, contains 97% of the Earth's water and provides 99% of the Earth's biologically habitable space. It includes the Arctic, Atlantic, Indian, Pacific and Southern Oceans, as well as their marginal seas and coastal waters.

Ocean acidification (OA)
A reduction in the *pH* of the *ocean*, accompanied by other chemical changes (primarily in the levels of carbonate and bicarbonate ions), over an extended period, typically decades or longer, which is caused primarily by *uptake* of *carbon dioxide (CO_2)* from the *atmosphere*, but can also be caused by other chemical additions or subtractions from

the *ocean*. *Anthropogenic* OA refers to the component of pH reduction that is caused by human activity (IPCC, 2011, p. 37).

Ocean deoxygenation
The loss of oxygen in the *ocean*. It results from *ocean* warming, which reduces oxygen solubility and increases oxygen consumption and *stratification*, thereby reducing the mixing of oxygen into the *ocean* interior. Deoxygenation can also be exacerbated by the addition of excess nutrients in the coastal zone.

Ocean stratification
See *Stratification*.

Outbreak
Often used synonymously with 'epidemic', usually to indicate localised as opposed to generalised epidemics (WHO, 2020).

Overshoot pathways
See *Pathways*.

Oxygen minimum zone (OMZ)
The midwater layer (200–1000 m) in the open *ocean* in which oxygen saturation is the lowest in the *ocean*. The degree of oxygen depletion depends on the largely bacterial consumption of organic matter, and the distribution of the OMZs is influenced by large-scale *ocean* circulation. In coastal *oceans*, OMZs extend to the shelves and may also affect *benthic ecosystems*.

Ozone (O_3)
The triatomic form of oxygen, and a gaseous atmospheric constituent. In the troposphere, O_3 is created both naturally and by photochemical reactions involving gases resulting from human activities (e.g., smog). Tropospheric O_3 acts as a *greenhouse gas (GHG)*. In the stratosphere, O_3 is created by the interaction between solar ultraviolet radiation and molecular oxygen (O_2). Stratospheric O_3 plays a dominant role in the stratospheric radiative balance. Its concentration is highest in the *ozone* layer.

Pandemic
A worldwide outbreak of a disease in humans in numbers clearly in excess of normal (WHO, 2020).

Particulate matter (PM)
Atmospheric aerosol involved in air pollution issues. Of greatest concern for health are particles of aerodynamic diameter less than or equal to 10 micrometers, usually designated as PM10 and particles of diameter less than or equal to 2.5 micrometers, usually designated as PM2.5.

Pasture
Area covered with grass or other plants used or suitable for grazing of livestock; grassland.

Path dependence
The generic situation where decisions, events or outcomes at one point in time constrain *adaptation*, *mitigation* or other actions or options at a later point in time. See also *Lock-in*.

Pathways
The temporal evolution of *natural* and/or *human systems* towards a future state. *Pathway* concepts range from sets of quantitative and qualitative *scenarios* or *narratives* of potential futures to solution-oriented decision-making processes to achieve desirable societal goals. *Pathway* approaches typically focus on biophysical, techno-economic and/or socio-behavioural trajectories and involve various dynamics, goals and actors across different scales. See also *Scenario*.

Adaptation pathways
A series of *adaptation* choices involving *trade-offs* between short-term and long-term goals and values. These are processes of deliberation to identify solutions that are meaningful to people in the context of their daily lives and to avoid potential *maladaptation*.

Climate-resilient development pathways (CRDPs)
Trajectories that strengthen sustainable development and efforts to eradicate *poverty* and reduce inequalities while promoting fair and cross-scalar *adaptation* to and *resilience* in a changing *climate*. They raise the *ethics*, *equity* and *feasibility* aspects of the deep *societal transformation* needed to drastically reduce *emissions* to limit *global warming* (e.g., to well below 2°C) and achieve desirable and liveable futures and *well-being* for all.

Climate-resilient pathways
Iterative processes for managing change within complex systems in order to reduce disruptions and enhance opportunities associated with *climate change*. See also *Development pathways* and *Pathways*.

Development pathways
Development pathways evolve as the result of the countless decisions being made and actions being taken at all levels of societal structure, as well due to the emergent dynamics within and between *institutions*, cultural norms, technological systems and other *drivers* of *behavioural change*.

Emission pathways
Modelled trajectories of global *anthropogenic emissions* over the 21st century are termed *emission pathways*.

Overshoot pathways
Pathways that first exceed a specified concentration, forcing or *global warming* level, and then return to or below that level again before the end of a specified period of time (e.g., before 2100). Sometimes the magnitude and *likelihood* of the overshoot are also characterised. The overshoot duration can vary from one *pathway* to the next, but in most *overshoot pathways* in the literature and referred to as *overshoot pathways* in the AR6, the overshoot occurs over a period of at least one decade and up to several decades.

Representative Concentration Pathways (RCPs)
Scenarios that include time series of *emissions* and concentrations of the full suite of *greenhouse gases (GHGs)* and *aerosols* and chemically active gases, as well as *land use*/*land cover* (Moss et al., 2008; van Vuuren et al., 2011). The word 'representative' signifies that each RCP provides only one of many possible scenarios that would lead to the specific *radiative forcing* characteristics. The term *pathway*

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emphasises the fact that not only the long-term concentration levels, but also the trajectory taken over time to reach that outcome are of interest (Moss et al., 2010; van Vuuren et al., 2011).

RCPs usually refer to the portion of the concentration *pathway* extending up to 2100, for which *integrated assessment models* produced corresponding *emission scenarios*. Extended concentration *pathways* describe extensions of the RCPs from 2100 to 2300 that were calculated using simple rules generated by stakeholder consultations, and do not represent fully consistent scenarios. Four RCPs produced from *integrated assessment models* were selected from the published literature and are used in the Fifth IPCC Assessment and are also used in this Assessment for comparison, spanning the range from approximately below 2°C warming to high (>4°C) warming best-estimates by the end of the 21st century: RCP2.6, RCP4.5 and RCP6.0, and RCP8.5.

- RCP2.6: One *pathway* where *radiative forcing* peaks at approximately 3 W m^{-2} and then declines to be limited at 2.6 W m^{-2} in 2100 (the corresponding Extended Concentration Pathway, or ECP, has constant *emissions* after 2100).
- RCP4.5 and RCP6.0: Two intermediate stabilisation *pathways* in which *radiative forcing* is limited at approximately 4.5 W m^{-2} and 6.0 W m^{-2} in 2100 (the corresponding ECPs have constant concentrations after 2150).
- RCP8.5: One high *pathway* which leads to >8.5 W m^{-2} in 2100 (the corresponding ECP has constant *emissions* after 2100 until 2150 and constant concentrations after 2250).

Shared socio-economic pathways (SSPs)

Shared socio-economic pathways (SSPs) have been developed to complement the *Representative Concentration Pathways (RCPs)*. By design, the RCP *emission* and concentration *pathways* were stripped of their association with a certain socio-economic development. Different levels of *emissions* and *climate change* along the dimension of the RCPs can hence be explored against the backdrop of different *socio-economic development pathways* (SSPs) on the other dimension in a matrix. This integrative SSP-RCP framework is now widely used in the *climate impact* and *policy* analysis literature (see, e.g., http://iconics-ssp.org), where *climate projections* obtained under the RCP scenarios are analysed against the backdrop of various SSPs.

As several *emission* updates were due, a new set of *emission scenarios* was developed in conjunction with the SSPs. Hence, the abbreviation SSP is now used for two things: On the one hand SSP1, SSP2, …, SSP5 is used to denote the five *socio-economic scenario* families. On the other hand, the abbreviations SSP1-1.9, SSP1-2.6, …, SSP5-8.5 are used to denote the newly developed *emission scenarios* that are the result of an SSP implementation within an *integrated assessment model*. Those SSP scenarios are bare of *climate policy* assumption, but in combination with so-called shared *policy* assumptions (SPAs), various approximate *radiative forcing* levels of 1.9, 2.6, …, or 8.5 W m^{-2} are reached by the end of the century, respectively.

Sustainable development pathways (SDPs)

Trajectories aimed at attaining the *Sustainable Development Goals (SDGs)* in the short term and the goals of *sustainable development* in the long term. In the context of *climate change*, such *pathways* denote trajectories that address social, environmental and economic dimensions of sustainable development, *adaptation* and *mitigation*, and *transformation*, in a generic sense or from a particular methodological perspective such as *integrated assessment models* and *scenario* simulations.

Peat

Soft, porous or compressed, sedentary deposit of which a substantial portion is partly decomposed plant material with high water content in the natural state (up to about 90%) (IPCC, 2013).

Peatlands

Peatlands are wetland *ecosystems* where soils are dominated by *peat*. In peatlands, *net primary production* exceeds organic matter decomposition as a result of waterlogged conditions, which leads to the *accumulation* of *peat*.

Pelagic

The *pelagic* zone consists of the entire water column of the open *ocean*. It is subdivided into the epipelagic zone (<200 m, the uppermost part of the *ocean* that receives enough sunlight to allow *photosynthesis*), the mesopelagic zone (200–1000 m depth) and the bathypelagic zone (>1000 m depth). The term *pelagic* can also refer to organisms that live in the *pelagic* zone.

Pelagos

Organisms large and small living in the *pelagic* zones. Includes *plankton* (small) and nekton (free swimming, large). See *Benthos*.

Percentiles

A partition value in a population distribution that a given percentage of the data values are below or equal to. The 50th percentile corresponds to the median of the population. Percentiles are often used to estimate the extremes of a distribution. For example, the 90th (10th) percentile may be used to refer to the threshold for the upper (lower) extremes.

Peri-urban areas

Dynamic transition zones that have intense interaction between rural and *urban* economies, activities, households and lifestyles. Neither fully rural or *urban* (following Seto et al., 2010).

Permafrost

Ground (soil or rock, and included ice and organic material) that remains at or below 0°C for at least two consecutive years (Harris et al., 1988). Note that *permafrost* is defined via temperature rather than ice content and, in some instances, may be ice-free.

Permafrost degradation

Decrease in the thickness and/or areal extent of *permafrost*.

Permafrost thaw

Progressive loss of ground ice in *permafrost*, usually due to input of heat. Thaw can occur over decades to centuries over the entire depth of *permafrost* ground, with *impacts* occurring while thaw progresses. During thaw, temperature fluctuations are subdued because energy is transferred by phase change between ice and water. After the transition from *permafrost* to non-*permafrost*, ground can be described as thawed.

pH
A dimensionless measure of the acidity of a solution given by its concentration of hydrogen ions (H^+). *pH* is measured on a logarithmic scale where *pH* = $-\log_{10}(H^+)$. Thus, a *pH* decrease of 1 unit corresponds to a 10-fold increase in the concentration of H^+, or acidity.

Phenology
The relationship between biological phenomena that recur periodically (e.g., development stages, migration) especially related to *climate* and seasonal changes.

Photosynthesis
The production of carbohydrates in plants, algae and some bacteria using the energy of light. *Carbon dioxide (CO_2)* is used as the carbon source.

Planetary health
a concept based on the understanding that human health and human civilisation depend on ecosystem health and the wise stewardship of ecosystems.

Plankton
Free-floating organisms living in the upper layers of aquatic systems. Their distribution and migration are primarily determined by water currents. A distinction is made between phytoplankton, which depend on *photosynthesis* for their energy supply, and zooplankton, which feed on phytoplankton, other zooplankton and bacterioplankton.

Planned relocation (of humans)
A form of *human mobility* response in the face of *sea level rise* and related *impacts*. *Planned relocation* is typically initiated, supervised and implemented from national to local level and involves small communities and individual assets but may also involve large populations. Also termed resettlement, managed retreat or managed realignment.

Plasticity (biology)
Change in organismal trait values in response to an environmental cue and which does not require change in underlying DNA sequence.

Policies (for climate change mitigation and adaptation)
Strategies that enable actions to be undertaken to accelerate *adaptation* and *mitigation*. *Policies* include those developed by national and subnational public agencies, and with the private sector. *Policies* for *adaptation* and *mitigation* often take the form of economic incentives, regulatory instruments, and decision-making and engagement processes.

Political economy
The set of interlinked relationships between people, the State, society and markets as defined by law, politics, economics, customs and power that determine the outcome of trade and transactions and the distribution of wealth in a country or economy.

Polycentric governance
See *Governance*.

Potential evapotranspiration
The potential rate of water loss without any limits imposed by the water supply.

Poverty
A complex concept with several definitions stemming from different schools of thought. It can refer to material circumstances (such as need, pattern of deprivation or limited resources), economic conditions (such as standard of living, *inequality* or economic position) and/or social relationships (such as social class, dependency, exclusion, lack of basic security or lack of entitlement). See also *Poverty trap*.

Poverty trap
Poverty trap is understood differently across disciplines. In the social sciences, the concept, primarily employed at the individual, household or community level, describes a situation in which escaping *poverty* becomes impossible due to unproductive or inflexible resources. A *poverty trap* can also be seen as a critical minimum asset threshold, below which families are unable to successfully educate their children, build up their productive assets and get out of poverty. Extreme poverty is itself a *poverty trap* since poor persons lack the means to participate meaningfully in society. In economics, the term *poverty trap* is often used at national scales, referring to a self-perpetuating condition where an economy, caught in a vicious cycle, suffers from persistent underdevelopment (Matsuyama, 2008). Many proposed models of *poverty traps* are found in the literature.

Pre-industrial (period)
The multi-century period prior to the onset of large-scale industrial activity around 1750. The *reference period* 1850–1900 is used to approximate *pre-industrial global mean surface temperature (GMST)*.

Precursors
Atmospheric compounds that are not *greenhouse gases (GHGs)* or *aerosols*, but that have an effect on GHG or *aerosol* concentrations by taking part in physical or chemical processes regulating their production or destruction rates.

Predictability
The extent to which future states of a system may be predicted based on knowledge of current and past states of the system. Because knowledge of the *climate system*'s past and current states is generally imperfect, as are the models that utilise this knowledge to produce a *climate prediction*, and because the *climate system* is inherently nonlinear and chaotic, the *predictability* of the *climate system* is inherently limited. Even with arbitrarily accurate models and observations, there may still be limits to the *predictability* of such a nonlinear system (AMS, 2000).

Primary production
The synthesis of organic compounds by plants and microbes, on *land* or in the *ocean*, primarily by *photosynthesis* using light and *carbon dioxide (CO_2)* as *sources* of energy and carbon, respectively. It can also occur through chemosynthesis, using chemical energy, for example, in deep sea vents.

Net primary production (NPP)
The difference between how much CO_2 vegetation takes in during *photosynthesis* (gross *primary production*) minus how much CO_2 the plants release during *respiration* (IPBES, 2019, Global Assessment).

Procedural justice
See *Justice*.

Projection
A potential future evolution of a quantity or set of quantities, often computed with the aid of a *model*. Unlike predictions, *projections* are conditional on assumptions concerning, for example, future socio-economic and technological developments that may or may not be realised. See also *Pathways* and *Scenario*.

Proxy
A *proxy climate* indicator is a record that is interpreted, using physical and biophysical principles, to represent some combination of *climate*-related variations back in time. *Climate*-related data derived in this way are referred to as *proxy* data. Examples of *proxies* include *pollen analysis*, *tree ring* records, speleothems, characteristics of corals and various data derived from marine sediments and ice cores. *Proxy* data can be calibrated to provide quantitative *climate information*.

Radiative forcing
The change in the net, downward minus upward, radiative *flux* (expressed in W m^{-2}) at the tropopause or top of *atmosphere* due to a change in an (external) *driver* of *climate change*, such as a change in the concentration of *carbon dioxide* (CO_2), the concentration of volcanic *aerosols* or the output of the Sun. The traditional *radiative forcing* is computed with all tropospheric properties held fixed at their unperturbed values, and after allowing for stratospheric temperatures, if perturbed, to readjust to radiative-dynamical equilibrium. *Radiative forcing* is called instantaneous if no change in stratospheric temperature is accounted for. The *radiative forcing* once rapid adjustments are accounted for is termed the effective *radiative forcing*. *Radiative forcing* is not to be confused with cloud *radiative forcing*, which describes an unrelated measure of the *impact* of clouds on the radiative *flux* at the top of the *atmosphere*.

Reasons for Concern (RFCs)
Elements of a classification framework, first developed in the IPCC Third Assessment Report, which aims to facilitate judgements about what level of *climate change* may be dangerous (in the language of Article 2 of the UNFCCC) by aggregating *risks* from various sectors, considering *hazards*, *exposures*, vulnerabilities, capacities to adapt and the resulting *impacts*.

Reference period
A time period of interest, or a period over which some relevant statistics are calculated. A *reference period* can be used as a baseline period or as a comparison to a baseline period.

Reforestation
Conversion to *forest* of land that has previously contained *forests* but that has been converted to some other use. See also *Afforestation* and *Forest*.

[Note: For a discussion of the term *forest* and related terms such as *afforestation*, *reforestation* and *deforestation*, see the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and their 2019 Refinement, and information provided by the United Nations Framework Convention on Climate Change (IPCC 2006, 2019; UNFCCC 2021a, 2021b)].

Refugium
A *refugium* is a geographic area where a population found safety from some threat to its existence, for example, *climate refugia* or glacial refugia (refuge from glaciations). See also *Climate refugium*.

Region
A *land* and/or *ocean* area characterised by specific geographical and/or climatological features. The *climate* of a *region* emerges from a multi-scale combination of its own features, remote influences from other *regions* and global *climate* conditions.

Regulation
A rule or order issued by governmental executive authorities or regulatory agencies and having the force of law. *Regulations* implement *policies* and are mostly specific for particular groups of people, legal entities or targeted activities. *Regulation* is also the act of designing and imposing rules or orders. Informational, transactional, administrative and political constraints in practice limit the regulator's capability for implementing preferred *policies*.

Relative humidity
The *relative humidity* specifies the ratio of actual water vapour pressure to that at saturation with respect to liquid water or ice at the same temperature.

Reporting
The process of formal reporting of assessment results to the UNFCCC, according to predetermined formats and according to established *standards*, especially the Intergovernmental Panel on Climate Change (IPCC) Guidelines and Good Practice Guidance (GPG) (UN REDD, 2009).

Representative Concentration Pathways (RCPs)
See *Pathways*.

Reservoir
A component or components of the *climate system* where a *greenhouse gas (GHG)* or a *precursor* of a *greenhouse gas* is stored (UNFCCC Article 1.7).

Residual risk
The *risk* related to *climate change impacts* that remains following *adaptation* and *mitigation* efforts. *Adaptation* actions can redistribute *risk* and *impacts*, with increased *risk* and *impacts* in some areas or populations, and decreased *risk* and *impacts* in others. See also *Loss and Damage, and losses and damages*.

Resilience
The capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganising in ways that maintain their essential function, identity

and structure. *Resilience* is a positive attribute when it maintains capacity for *adaptation*, learning and/or *transformation* (Arctic Council, 2016). See also *Hazard*, *Risk* and *Vulnerability*.

Resolution
In *climate models*, this term refers to the physical distance (metres or degrees) between each point on the grid used to compute the equations. Temporal *resolution* refers to the time step or time elapsed between each *model* computation of the equations.

Respiration
The process whereby living organisms convert organic matter to *carbon dioxide* (CO_2), releasing energy and consuming molecular oxygen.

Restoration
In environmental context, *restoration* involves human interventions to assist the recovery of an *ecosystem* that has been previously degraded, damaged or destroyed.

Return period
An estimate of the average time interval between occurrences of an event (e.g., flood or extreme rainfall) of (or below/above) a defined size or intensity.

Risk
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*, *risks* can arise from potential *impacts* of *climate change* as well as human responses to *climate change*. Relevant adverse consequences include those on lives, *livelihoods*, *health* and *well-being*, economic, social and cultural assets and investments, *infrastructure*, services (including *ecosystem services*), *ecosystems* and species.
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 to the *hazards*. *Hazards*, *exposure* and *vulnerability* may each be subject to *uncertainty* in terms of magnitude and *likelihood* of occurrence, and each may change over time and space due to socio-economic changes and human decision-making.
In the context of *climate change* responses, *risks* result from the potential for such responses not achieving the intended objective(s), or from potential *trade-offs* with, or negative side-effects on, other societal objectives, such as the *Sustainable Development Goals (SDGs)*. *Risks* can arise for example from *uncertainty* in the implementation, effectiveness or outcomes of *climate policy*, *climate*-related investments, technology development or adoption, and system *transitions*. See also *Hazard* and *Impacts*.

Compound risks {↑ Risk}
arise from the interaction of hazards, which may be characterised by single extreme events or multiple coincident or sequential events that interact with exposed systems or sectors.

Risk assessment
The qualitative and/or quantitative scientific estimation of *risks*. See also *Risk management* and *Risk perception*.

Risk management
Plans, actions, strategies or *policies* to reduce the *likelihood* and/or magnitude of adverse potential consequences, based on assessed or perceived *risks*.

Risk perception
The subjective judgement that people make about the characteristics and severity of a *risk*. See also *Risk assessment* and *Risk management*.

Risk transfer
The process of formally or informally shifting the financial consequences of particular *risks* from one party to another whereby a household, community, enterprise or state authority will obtain resources from the other party after a *disaster* occurs, in exchange for ongoing or compensatory social or financial benefits provided to that other party.

Runoff
The flow of water over the surface or through the subsurface, which typically originates from the part of liquid precipitation and/or snow/ice melt that does not evaporate, transpire or refreeze, and returns to water bodies.

Salt-water intrusion/encroachment
Displacement of fresh surface water or groundwater by the advance of salt water due to its greater density. This usually occurs in coastal and estuarine areas due to decreasing *land*-based influence (e.g., from reduced *runoff* or *groundwater recharge*, or from excessive water withdrawals from aquifers) or increasing marine influence (e.g., relative *sea level rise*).

Scenario
A plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technological change (TC), prices) and relationships. Note that *scenarios* are neither predictions nor forecasts, but are used to provide a view of the implications of developments and actions. See also *Pathways*.

Baseline scenario
See *Reference scenario*.

Concentration scenario
A plausible representation of the future development of atmospheric concentrations of substances that are radiatively active (e.g., *greenhouse gases (GHGs)*, *aerosols*, tropospheric *ozone*), plus human-induced *land-cover changes* that can be radiatively active via *albedo* changes, and often used as input to a *climate model* to compute *climate projections*.

Emission scenario
A plausible representation of the future development of *emissions* of substances that are radiatively active (e.g., *greenhouse gases (GHGs)* or *aerosols*) based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socio-economic development, technological change, energy and *land use*) and their key relationships. *Concentration scenarios*, derived from *emission scenarios*, are often used as input to a *climate model* to compute *climate projections*.

Reference scenario
The *scenario* used as starting or reference point for a comparison between two or more *scenarios*.
[Note 1: In many types of *climate change* research, *reference scenarios* reflect specific assumptions about patterns of socio-economic development and may represent futures that assume no *climate policies* or specified *climate policies*, for example those in place or planned at the time a study is carried out. *Reference scenarios* may also represent futures with limited or no *climate impacts* or *adaptation*, to serve as a point of comparison for futures with *impacts* and *adaptation*. These are also referred to as *baseline scenarios* in the literature.
Note 2: *Reference scenarios* can also be *climate policy* or *impact scenarios*, which in that case are taken as a point of comparison to explore the implications of other features, for example, of delay, technological options, *policy* design and strategy or to explore the effects of additional *impacts* and *adaptation* beyond those represented in the *reference scenario*.
Note 3: The term Business-As-Usual *scenario* has been used to describe a *scenario* that assumes no additional policies beyond those currently in place and that patterns of socio-economic development are consistent with recent trends. The term is now used less frequently than in the past.
Note 4: In *climate change*, *attribution* or *impact attribution* research *reference scenarios* may refer to counterfactual historical *scenarios* assuming no *anthropogenic greenhouse gas emissions* (*climate change attribution*) or no *climate change* (impact *attribution*)]

Socio-economic scenario
A *scenario* that describes a possible future in terms of population, *gross domestic product (GDP)*, and other socio-economic factors relevant to understanding the implications of *climate change*.

Sea ice
Ice found at the sea surface that has originated from the freezing of seawater. *Sea ice* may be discontinuous pieces (ice floes) moved on the *ocean* surface by wind and currents (pack ice), or a motionless sheet attached to the *coast* (land-fast ice). *Sea ice* concentration is the fraction of the *ocean* covered by ice. *Sea ice* less than 1 year old is called first-year ice. Perennial ice is *sea ice* that survives at least one summer. It may be subdivided into second-year ice and multi-year ice, where multi-year ice has survived at least two summers.

Sea level change (sea level rise/sea level fall)
Change to the height of sea level, both globally and locally (relative *sea level change*) (at seasonal, annual or longer time scales) due to (1) a change in *ocean* volume as a result of a change in the mass of water in the *ocean* (e.g., due to melt of *glaciers* and *ice sheets*), (2) changes in *ocean* volume as a result of changes in *ocean* water density (e.g., expansion under warmer conditions), (3) changes in the shape of the *ocean* basins and changes in the Earth's gravitational and rotational fields and (4) local subsidence or uplift of the *land*. *Global mean sea level change* resulting from change in the mass of the *ocean* is called barystatic. The amount of barystatic *sea level change* due to the addition or removal of a mass of water is called its sea level equivalent (SLE). *Sea level changes*, both globally and locally, resulting from changes in water density are called steric. Density changes induced by temperature changes only are called thermosteric, while density changes induced by salinity changes are called halosteric. Barystatic and steric *sea level changes* do not include the effect of changes in the shape of *ocean* basins induced by the change in the *ocean* mass and its distribution. See also *Extreme sea level (ESL)*.

Sea surface temperature (SST)
The subsurface bulk temperature in the top few metres of the *ocean*, measured by ships, buoys and drifters. From ships, *measurements* of water samples in buckets were mostly switched in the 1940s to samples from engine intake water. Satellite *measurements* of skin temperature (uppermost layer; a fraction of a millimetre thick) in the infrared or the top centimetre or so in the microwave are also used, but must be adjusted to be compatible with the bulk temperature.

Semi-arid zone
Areas where vegetation growth is constrained by limited water availability, often with short growing seasons and high interannual variation in *primary production*. Annual precipitation ranges from 300 to 800 mm, depending on the occurrence of summer and winter rains.

Sendai Framework for Disaster Risk Reduction
The Sendai Framework for Disaster Risk Reduction 2015–2030 outlines seven clear targets and four priorities for action to prevent new, and to reduce existing, *disaster risks*. The voluntary, non-binding agreement recognises that the State has the primary role to reduce *disaster risk* but that responsibility should be shared with other stakeholders, including local government and the private sector. Its aim is to achieve 'substantial reduction of *disaster risk* and losses in lives, *livelihoods* and *health* and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries'.

Sensitivity
The degree to which a system or species is affected, either adversely or beneficially, by *climate variability* or *change*. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to *sea level rise*).

Sequestration
The process of storing carbon in a carbon pool. See also *Sink*.

Settlements
Places of concentrated human habitation. *Settlements* can range from isolated rural villages to *urban regions* with significant global influence. They can include formally planned and informal or illegal habitation and related *infrastructure*. See also *Cities*, *Urban* and *Urbanisation*.

Shared Socio-economic Pathways (SSPs)
See *Pathways*.

Shelf seas
Relatively shallow water covering the shelf of continents or around islands. The limit of *shelf seas* is conventionally considered as 200 m water depth at the continental shelf edge, where there is usually a steep slope to the deep *ocean* floor. During glacial periods, most *shelf seas* are lost

since they become *land* as the build-up of *ice sheets* caused a decrease of global sea level.

Sink
Any process, activity or mechanism which removes a *greenhouse gas*, an *aerosol* or a *precursor* of a *greenhouse gas* from the *atmosphere* (UNFCCC Article 1.8 (UNFCCC, 1992)). See also *Sequestration*.

Small Island Developing States (SIDS)
Small Island Developing States (SIDS), as recognised by the United Nations Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States (OHRLLS), are a distinct group of *developing countries* facing specific social, economic and environmental vulnerabilities (UN-OHRLLS, 2011). They were recognised as a special case for both their environment and their development at the Rio Earth Summit in Brazil in 1992. Fifty-eight countries and territories are presently classified as SIDS by the UN OHRLLS, with 38 being UN member states and 20 being Non-UN Members or Associate Members of the Regional Commissions (UN-OHRLLS, 2018).

Snow cover extent
The areal extent of snow-covered ground.

Snow water equivalent (SWE)
The depth of liquid water that would result if a mass of snow melted completely.

Social inclusion
A process of improving the terms of participation in society, particularly for people who are disadvantaged, through enhancing opportunities, access to resources and respect for rights (UN, DESA 2016).

Social infrastructure
See *Infrastructure*.

Social justice
See *Justice*.

Social learning
A process of social interaction through which people learn new behaviours, capacities, values and attitudes.

Social protection
In the context of development aid and *climate policy*, *social protection* usually describes public and private initiatives that provide income or consumption transfers to the poor, protect the vulnerable against *livelihood risks* and enhance the social status and rights of the marginalised, with the overall objective of reducing the economic and social *vulnerability* of poor, vulnerable and marginalised groups (Devereux and Sabates-Wheeler, 2004). In other contexts, *social protection* may be used synonymously with social *policy* and can be described as all public and private initiatives that provide access to services, such as *health*, education or housing, or income and consumption transfers to people. *Social protection policies* protect the poor and vulnerable against *livelihood risks* and enhance the social status and rights of the marginalised, as well as prevent vulnerable people from falling into *poverty*.

Social-ecological system
An integrated system that includes human societies and *ecosystems*, in which humans are part of nature. The functions of such a system arise from the interactions and interdependence of the social and ecological subsystems. The system's structure is characterised by reciprocal feedbacks, emphasising that humans must be seen as a part of, not apart from, nature (Arctic Council, 2016; Berkes and Folke, 1998).

Societal (social) transformation
See *Transformation*.

Socio-economic scenario
See *Scenarios*.

Socio-technical transitions
Where technological change is associated with social systems and the two are inextricably linked.

Soil erosion
The displacement of the soil by the action of water or wind. *Soil erosion* is a major process of *land degradation*.

Soil moisture
Water stored in the soil in liquid or frozen form. Root-zone *soil moisture* is of most relevance for plant activity.

Soil organic carbon
Carbon contained in *soil organic matter*.

Soil organic matter
The organic component of soil, comprising plant and animal residue at various stages of decomposition, and soil organisms.

Solar radiation modification (SRM)
Refers to a range of radiation modification measures not related to *greenhouse gas (GHG) mitigation* that seek to limit *global warming*. Most methods involve reducing the amount of incoming solar radiation reaching the surface, but others also act on the longwave radiation budget by reducing optical thickness and cloud lifetime.

Solution space
The set of biophysical, cultural, socio-economic and political-institutional dimensions within which opportunities and constraints determine why, how, when and who acts to reduce *climate risks*. Within these dimensions, there are 'hard' (unsurpassable) limits and 'soft' (surpassable) limits. The boundaries of the *solution space* are path dependent, contested and in constant flux (Haasnoot et. al. 2020).

Source
Any process or activity which releases a *greenhouse gas*, an *aerosol* or a *precursor* of a *greenhouse gas* into the *atmosphere* (UNFCCC Article 1.9). See also *Sink* and *Sequestration*.

Southern Ocean
The *ocean region* encircling Antarctica that connects the Atlantic, Indian and Pacific Oceans together, allowing inter-*ocean* exchange. This *region* is the main *source* of much of the deep water of the world's *ocean* and

also provides the primary return *pathway* for this deep water to the surface (Marshall and Speer, 2012; Toggweiler and Samuels, 1995). The drawing up of deep waters and the subsequent transport into the *ocean* interior has major consequences for the global heat, nutrient and carbon balances, as well as the Antarctic *cryosphere* and marine *ecosystems*.

Spatial and temporal scales
Climate may vary on a large range of *spatial and temporal scales*. *Spatial scales* may range from local (less than 100,000 km^2), through regional (100,000 to 10 million km^2) to continental (10–100 million km^2). *Temporal scales* may range from seasonal to geological (up to hundreds of millions of years).

Standard
Set of rules or codes mandating or defining product performance (e.g., grades, dimensions, characteristics, test methods and rules for use). Product, technology or performance *standards* establish minimum requirements for affected products or technologies. *Standards* impose reductions in *greenhouse gas (GHG) emissions* associated with the manufacture or use of the products and/or application of the technology.

Storm surge
The temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and/or strong winds). The *storm surge* is defined as being the excess above the level expected from the tidal variation alone at that time and place. See also *Extreme sea level* and *Sea level change (sea level rise/sea level fall)*.

Storyline
A way of making sense of a situation or a series of events through the construction of a set of explanatory elements. Usually, it is built on logical or causal reasoning. In *climate* research, the term *storyline* is used both in connection to *scenarios* as related to a future trajectory of the *climate* and *human systems* and to a weather or *climate* event. In this context, *storylines* can be used to describe plural, conditional possible futures or explanations of a current situation, in contrast to single, definitive futures or explanations.

Stranded assets
Assets exposed to devaluations or conversion to 'liabilities' because of unanticipated changes in their initially expected revenues due to innovations and/or evolutions of the business context, including changes in public *regulations* at the domestic and international levels.

Stratification
Process of forming of layers of (*ocean*) water with different properties such as salinity, density and temperature that act as barriers to water mixing. The strengthening of near-surface *stratification* generally results in warmer surface waters, decreased oxygen levels in deeper water and intensification of *ocean acidification (OA)* in the upper *ocean*.

Streamflow
Water flow within a river channel, for example, expressed in m^3 s^{-1}. A synonym for river discharge.

Stressors
Events and trends, often not *climate*-related, that have an important effect on the system exposed and can increase *vulnerability* to *climate*-related *risk*.

Sustainability
Involves ensuring the persistence of *natural* and *human systems*, implying the continuous functioning of *ecosystems*, the conservation of high *biodiversity*, the recycling of natural resources and, in the human sector, successful application of *justice* and *equity*.

Sustainable development (SD)
Development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987) and balances social, economic and environmental concerns. See also *Development pathways* and *Sustainable Development Goals (SDGs)*.

Sustainable Development Goals (SDGs)
The 17 global goals for development for all countries established by the United Nations through a participatory process and elaborated in the 2030 Agenda for Sustainable Development, including ending *poverty* and hunger; ensuring *health* and *well-being*, education, gender *equality*, clean water and energy, and decent work; building and ensuring resilient and sustainable *infrastructure*, *cities* and consumption; reducing *inequalities*; protecting land and water *ecosystems*; promoting peace, *justice* and partnerships; and taking urgent action on *climate change*. See also *Development pathways* and *Sustainable development*.

Sustainable development pathways (SDPs)
See *Pathways*.

Sustainable forest management
The stewardship and use of *forests* and *forest* lands in a way, and at a rate, that maintains their *biodiversity*, productivity, regeneration capacity, vitality and potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national and global levels, and that does not cause damage to other *ecosystems* (Forest Europe, 1993).

Sustainable land management
The stewardship and use of *land* resources, including soils, water, animals and plants, to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions (adapted from WOCAT, undated).

Sympagic
Organisms and habitats related to the *sea ice*, analogous to *pelagic* (water column) or *benthic* (sea floor).

Teleconnection
Association between *climate* variables at widely separated, geographically fixed locations related to each other through physical processes and oceanic and/or atmospheric dynamical pathways. *Teleconnections* can be caused by several *climate* phenomena, such as Rossby wave-trains, mid-latitude jet and storm track displacements,

fluctuations of the Atlantic Meridional Overturning Circulation, fluctuations of the Walker circulation, etc. They can be initiated by modes of *climate variability*, thus providing the development of remote *climate anomalies* at various temporal lags.

Temperature overshoot
Exceedance of a specified *global warming* level, followed by a decline to or below that level during a specified period of time (e.g., before 2100). Sometimes the magnitude and *likelihood* of the overshoot is also characterized. The overshoot duration can vary from one *pathway* to the next but in most *overshoot pathways* in the literature and referred to as *overshoot pathways* in the AR6, the overshoot occurs over a period of at least one and up to several decades. See also *Pathways*

Tier
In the context of the IPCC Guidelines for National Greenhouse Gas Inventories, a tier represents a level of methodological complexity. Usually three tiers are provided. Tier 1 is the basic method, Tier 2 intermediate and Tier 3 most demanding in terms of complexity and data requirements. Tiers 2 and 3 are sometimes referred to as higher-tier methods and are generally considered to be more accurate (IPCC, 2019).

Tipping element
A component of the Earth system that is susceptible to a *tipping point*. See also *Abrupt climate change* and *Tipping point*.

Tipping point
A critical threshold beyond which a system reorganises, often abruptly and/or irreversibly. See also *Abrupt climate change*.

Trade-off
A competition between different objectives within a decision situation, where pursuing one objective will diminish achievement of other objective(s). A *trade-off* exists when a *policy* or measure aimed at one objective (e.g., reducing *GHG emissions*) reduces outcomes for other objective(s) (e.g., *biodiversity* conservation, *energy security*) due to adverse side effects, thereby potentially reducing the net benefit to society or the environment. See also *Adverse side-effect* and *Co-benefit*.

Transformation
A change in the fundamental attributes of *natural* and *human systems*.

Deliberate transformations
A profound shift towards *sustainability*, envisioned and intended by at least some societal actors, facilitated by changes in individual and collective values and behaviours, and a fairer balance of political, cultural and institutional power in society.

Societal (social) transformations
A change in the fundamental attributes of *human systems* advanced by societal actors

Transformational adaptation
See *Adaptation*.

Transformative change
A system-wide change that requires more than technological change through consideration of social and economic factors that, with technology, can bring about rapid change at scale.

Transition
The process of changing from one state or condition to another in a given period of time. *Transition* can occur in individuals, firms, *cities*, *regions* and nations, and can be based on incremental or *transformative change*.

Just transitions
A set of principles, processes and practices that aim to ensure that no people, workers, places, sectors, countries or *regions* are left behind in the transition from a high-carbon to a low-carbon economy. It stresses the need for targeted and proactive measures from governments, agencies and authorities to ensure that any negative social, environmental or economic *impacts* of economy-wide transitions are minimised, while benefits are maximised for those disproportionally affected. Key principles of *just transitions* include: respect and dignity for vulnerable groups; *fairness* in energy access and use, social dialogue and democratic consultation with relevant stakeholders; the creation of decent jobs; *social protection*; and rights at work. *Just transitions* could include *fairness* in energy, *land use* and *climate* planning and decision-making processes; economic diversification based on low-carbon investments; realistic training/retraining programs that lead to decent work; gender-specific *policies* that promote equitable outcomes; the fostering of international cooperation and coordinated multilateral actions; and the eradication of *poverty*. Lastly, *just transitions* may embody the redressing of past harms and perceived injustices (ILO 2015; UNFCCC 2016).

Tree line
The upper limit of tree growth in mountains or at high latitudes. It is more elevated or more poleward than the *forest line*.

Tropical cyclone
The general term for a strong, cyclonic-scale disturbance that originates over tropical *oceans*. Distinguished from weaker systems (often named tropical disturbances or depressions) by exceeding a threshold wind speed. A tropical storm is a *tropical cyclone* with one-minute average surface winds between 18 and 32 m s^{-1}. Beyond 32 m s^{-1}, a *tropical cyclone* is called a hurricane, typhoon or cyclone, depending on geographic location.

Tsunami
A wave, or train of waves, produced by a disturbance such as a submarine earthquake displacing the sea floor, a landslide, a volcanic eruption or an asteroid impact.

Tundra
A treeless *biome* characteristic of polar and alpine *regions*.

Uncertainty
A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may

have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, incomplete understanding of critical processes or uncertain *projections* of *human behaviour*. *Uncertainty* can therefore be represented by quantitative measures (e.g., a probability density function) or by qualitative statements (e.g., reflecting the judgement of a team of experts) (Moss and Schneider, 2000; IPCC, 2004; Mastrandrea et al., 2010). See also *Agreement*, *Confidence* and *Likelihood*.

Deep uncertainty

A situation of *deep uncertainty* exists when experts or stakeholders do not know or cannot agree on: (1) appropriate conceptual models that describe relationships among key driving forces in a system, (2) the probability distributions used to represent *uncertainty* about key variables and parameters and/or (3) how to weigh and value desirable alternative outcomes (Lempert et al., 2003).

United Nations Framework Convention on Climate Change (UNFCCC)

The UNFCCC was adopted in May 1992 and opened for signature at the 1992 Earth Summit in Rio de Janeiro. It entered into force in March 1994 and as of May 2018 had 197 Parties (196 States and the European Union). The Convention's ultimate objective is the 'stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'. The provisions of the Convention are pursued and implemented by two treaties: the Kyoto Protocol and the Paris Agreement.

Uptake

The transfer of substances (such as carbon) or energy (e.g., heat) from one compartment of a system to another; for example, in the Earth system from the *atmosphere* to the *ocean* or to the *land*. See also *Sequestration*, *Sink* and *Source*.

Upwelling region

A region of an *ocean* where cold, typically nutrient-rich waters well up from the deep *ocean*.

Urban

The categorisation of areas as "*urban*" by government statistical departments is generally based either on population size, population density, economic base, provision of services, or some combination of the above. *Urban systems* are networks and nodes of intensive interaction and exchange including capital, culture, and material objects. *Urban* areas exist on a continuum with rural areas and tend to exhibit higher levels of complexity, higher populations and population density, intensity of capital investment, and a preponderance of secondary (processing) and tertiary (service) sector industries. The extent and intensity of these features varies significantly within and between *urban* areas. *Urban* places and systems are open, with much movement and exchange between more rural areas as well as other *urban regions*. *Urban* areas can be globally interconnected, facilitating rapid flows between them, of capital investment, of ideas and culture, human migration, and disease. See also *City*, *City region*, *Urbanisation* and *Urban systems*.

Urban and peri-urban agriculture

The cultivation of crops and rearing of animals for food and other uses within and surrounding the boundaries of *cities*, including fisheries and forestry (EPRS, 2014).

Urban heat island (UHI)

The relative warmth of a *city* compared with surrounding rural areas, associated with heat trapping due to *land use*, the configuration and design of the built environment, including street layout and building size, the heat-absorbing properties of *urban* building materials, reduced ventilation, reduced greenery and water features, and domestic and industrial heat *emissions* generated directly from human activities.

Urbanisation

Urbanisation is a multi-dimensional process that involves at least three simultaneous changes: (1) *land-use change*: transformation of formerly rural *settlements* or natural land into *urban settlements*, (2) demographic change: a shift in the spatial distribution of a population from rural to *urban* areas and (3) *infrastructure* change: an increase in provision of *infrastructure* services including electricity, sanitation, etc. *Urbanisation* often includes changes in lifestyle, culture and behaviour, and thus alters the demographic, economic and social structure of both *urban* and rural areas (based on World Urbanization Prospects 2018; IPCC 2014; Stokes and Seto, 2019). See also *Settlements*, *Urban and Urban systems*.

Urban systems

Urban systems refer to two interconnected systems-- first, the comprehensive collections of *city* elements with multiple dimensions and characteristics: a) encompass physical, built, socio-economic-technical, political, and ecological subsystems; b) integrate social agent/constituency/processes with physical structure and processes; and c) exist within broader *spatial and temporal scales* and *governance* and institutional contexts; and second, the global system of *cities* and towns. See also *City region*, and *Urban*

Values and beliefs

Fundamental attitudes about what is important, good and right; strongly held principles or qualities intrinsically valuable or desirable, often enshrined in laws, traditions and religions. Examples include *human rights*, subsistence and equitable distribution of costs and benefits of *climate policies* (Hulme, 2009, 2018; Nakashima et al., 2012; UNFCCC, 1992; UN Universal Declaration of Human Rights, 1948).

Vector-borne disease

Illnesses caused by parasites, viruses and bacteria that are transmitted by various vectors (e.g., mosquitoes, sandflies, triatomine bugs, blackflies, ticks, tsetse flies, mites, snails and lice) (UNEP 2018).

Ventilation (ocean)

The exchange of *ocean* properties with the atmospheric surface layer such that property concentrations are brought closer to equilibrium values with the *atmosphere* (AMS, 2000), and the processes that propagate these properties into the *ocean* interior.

Vulnerability
The propensity or predisposition to be adversely affected. *Vulnerability* encompasses a variety of concepts and elements, including *sensitivity* or susceptibility to harm and lack of capacity to cope and adapt. See also *Exposure*, *Hazard* and *Risk*.

Vulnerability index
A metric characterising the *vulnerability* of a system. A *climate vulnerability index* is typically derived by combining, with or without weighting, several indicators assumed to represent *vulnerability*.

Water-borne diseases
Illnesses transmitted through contact with, or consumption of, unsafe or contaminated water (UNEP 2018).

Water security
The capacity of a population to safeguard sustainable access to adequate quantities of acceptable-quality water for sustaining *livelihoods*, human *well-being* and socio-economic development, for ensuring protection against water-borne pollution and water-related *disasters* and for preserving *ecosystems* in a climate of peace and political stability (UN-Water, 2013).

Water-use efficiency
Carbon gain by *photosynthesis* per unit of water lost by *evapotranspiration*. It can be expressed on a short-term basis as the ratio of photosynthetic carbon gain per unit transpirational water loss, or on a seasonal basis as the ratio of *net primary production* or agricultural yield to the amount of water used.

Weathering
The gradual removal of atmospheric CO_2 through dissolution of silicate and carbonate rocks. *Weathering* may involve physical processes (mechanical *weathering*) or chemical activity (chemical *weathering*).

Well-being
A state of existence that fulfils various human needs, including material living conditions and quality of life, as well as the ability to pursue one's goals, to thrive and to feel satisfied with one's life. *Ecosystem well-being* refers to the ability of *ecosystems* to maintain their diversity and quality.

Wetland
Land that is covered or saturated by water for all or part of the year (e.g., peatland).

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