Climate Change 2022: Impacts, Adaptation and Vulnerability Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change

Book · August 2022

DOI: 10.1017/9781009325844.

28 authors, including:

Debra C Roberts
EThekwini Municipality; University of KwaZulu-Natal, Durban, South Africa

Katja Mintenbeck
Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung

Marlies Hildegard Craig
Africa Health Research Institute

Vincent Möller
Land Bremen

Climate Change 2022: Impacts, Adaptation and Vulnerability

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

Edited by

Hans-Otto Pörtner
Working Group II Co-Chair

Debra C. Roberts
Working Group II Co-Chair

Melinda M.B. Tignor
Head of TSU

Elvira Poloczanska
Science Advisor to the WGII Co-Chairs and TSU

Katja Mintenbeck
Director of Science

Andrés Alegría
Graphics Officer

Marlies Craig
Science Officer

Stefanie Langsdorf
Graphics Officer

Sina Löschke
Communications Manager

Vincent Möller
Science Officer

Andrew Okem
Science Officer

Bardhyl Rama
Director of Operations

With editorial assistance from Daniel Belling, Wolfgang Dieck, Sandra Götze, Tijama Kersher, Philisiwe Mangele, Bastian Maus, Anka Mühle, Komila Nabiyeva, Maike Nicolai, Almut Niebuhr, Jan Petzold, Esté Prentzler, Jussi Savolainen, Hanna Scheuffele, Stefan Weisfeld and Nora Weyer

Working Group II Technical Support Unit

Please use the following reference to cite the whole report:
IPCC, 2022: *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844.

Contents

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)

Rebecca Mary Bernadette Harris
(01 August 1969 – 24 December 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.

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

Drafting Authors: Hans-O. Pörtner (Germany), Debra C. Roberts (South Africa), Helen Adams (UK), Carolina Adler (Switzerland/Chile/Australia), Paulina Aldunce (Chile), Elham Ali (Egypt), Rawshan Ara Begum (Malaysia/Australia/Bangladesh), Richard Betts (UK), Rachel Bezner Kerr (Canada/USA), Robbert Biesbroek (The Netherlands), Joern Birkmann (Germany), Kathryn Bowen (Australia), Edwin Castellanos (Guatemala), Guéladio Cissé (Mauritania/Switzerland/France), Andrew Constable (Australia), Wolfgang Cramer (France), David Dodman (Jamaica/UK), Siri H. Eriksen (Norway), Andreas Fischlin (Switzerland), Matthias Garschagen (Germany), Bruce Glavovic (New Zealand/South Africa), Elisabeth Gilmore (USA/Canada), Marjolijn Haasnoot (The Netherlands), Sherilee Harper (Canada), Toshihiro Hasegawa (Japan), Bronwyn Hayward (New Zealand), Yukiko Hirabayashi (Japan), Mark Howden (Australia), Kanungwe Kalaba (Zambia), Wolfgang Kiessling (Germany), Rodel Lasco (Philippines), Judy Lawrence (New Zealand), Maria Fernanda Lemos (Brazil), Robert Lempert (USA), Debora Ley (Mexico/Guatemala), Tabea Lissner (Germany), Salvador Lluch-Cota (Mexico), Sina Loeschke (Germany), Simone Lucatello (Mexico), Yong Luo (China), Brendan Mackey (Australia), Shobha Maharaj (Germany/Trinidad and Tobago), Carlos Mendez (Venezuela), Katja Mintenbeck (Germany), Vincent Möller (Germany), Mariana Moncassim Vale (Brazil), Mike D Morecroft (UK), Aditi Mukherji (India), Michelle Mycoo (Trinidad and Tobago), Tero Mustonen (Finland), Johanna Nalau (Australia/Finland), Andrew Okem (SouthAfrica/Nigeria), Jean Pierre Ometto (Brazil), Camille Parmesan (France/USA/UK), Mark Pelling (UK), Patricia Pinho (Brazil), Elvira Poloczanska (UK/Australia), Marie-Fanny Racault (UK/France), Diana Reckien (The Netherlands/Germany), Joy Pereira (Malaysia), Aromar Revi (India), Steven Rose (USA), Roberto Sanchez-Rodriguez (Mexico), E. Lisa F. Schipper (Sweden/UK), Daniela Schmidt (UK/Germany), David Schoeman (Australia), Rajib Shaw (Japan), Chandni Singh (India), William Solecki (USA), Lindsay Stringer (UK), Adelle Thomas (Bahamas), Edmond Totin (Benin), Christopher Trisos (South Africa), Maarten van Aalst (The Netherlands), David Viner (UK), Morgan Wairiu (Solomon Islands), Rachel Warren (UK), Pius Yanda (Tanzania), Zelina Zaiton Ibrahim (Malaysia)

Drafting Contributing Authors: Rita Adrian (Germany), Marlies Craig (South Africa), Frode Degvold (Norway), Kristie L. Ebi (USA), Katja Frieler (Germany), Ali Jamshed (Germany/Pakistan), Joanna McMillan (German/Australia), Reinhard Mechler (Austria), Mark New (South Africa), Nicholas P. Simpson (South Africa/Zimbabwe), Nicola Stevens (South Africa)

Visual Conception and Information Design: Andrés Alegría (Germany/Honduras), Stefanie Langsdorf (Germany)

This Summary for Policymakers should be cited as:

IPCC, 2022: Summary for Policymakers [H.-O. Pörtner, D.C. Roberts, E.S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem (eds.)]. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3–33, doi:10.1017/9781009325844.001.

SPM

Table of Contents

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

---

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.

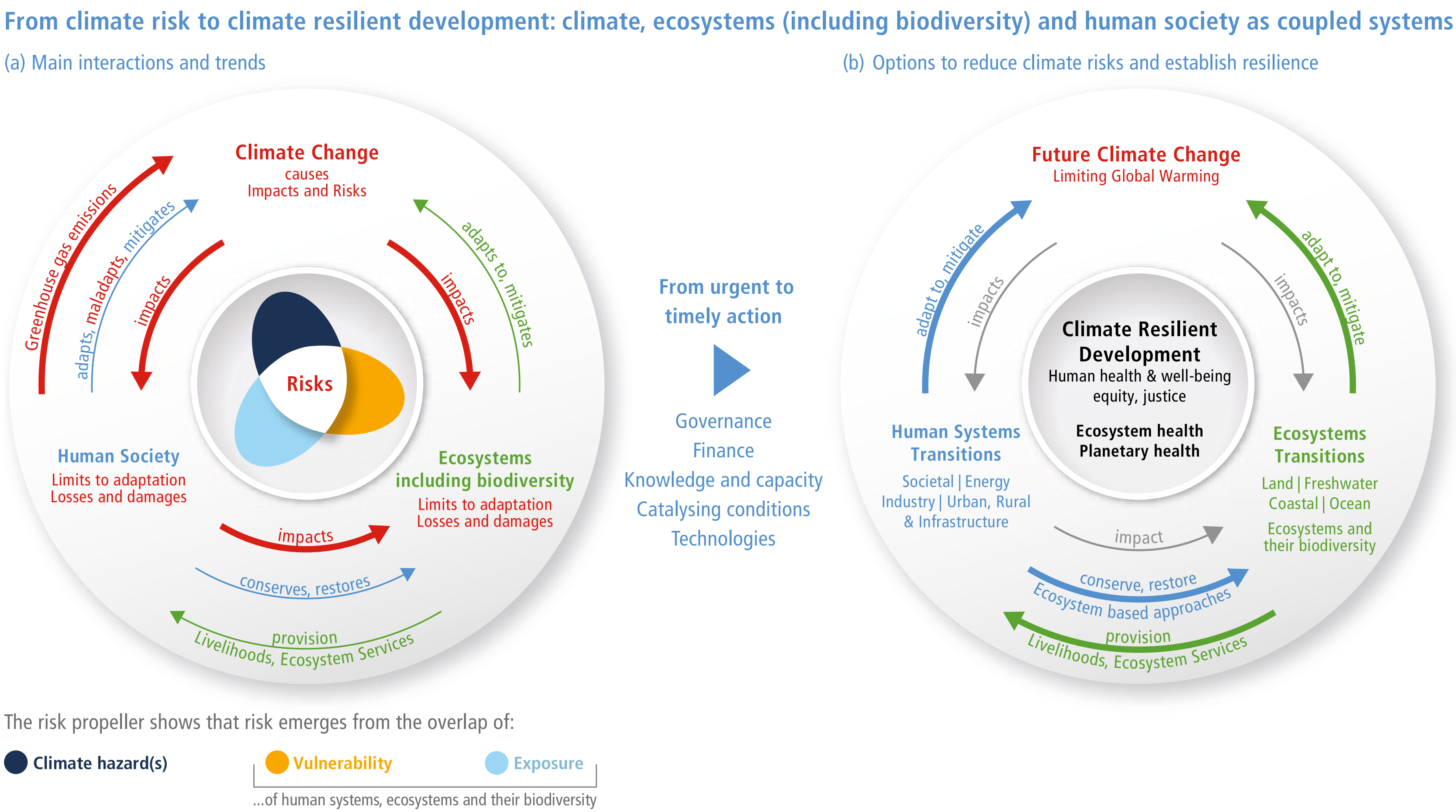


Figure SPM.1 | This report has a strong focus on the interactions among the coupled systems climate, ecosystems (including their biodiversity) and human society. These interactions are the basis of emerging risks from climate change, ecosystem degradation and biodiversity loss and, at the same time, 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}

---

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}

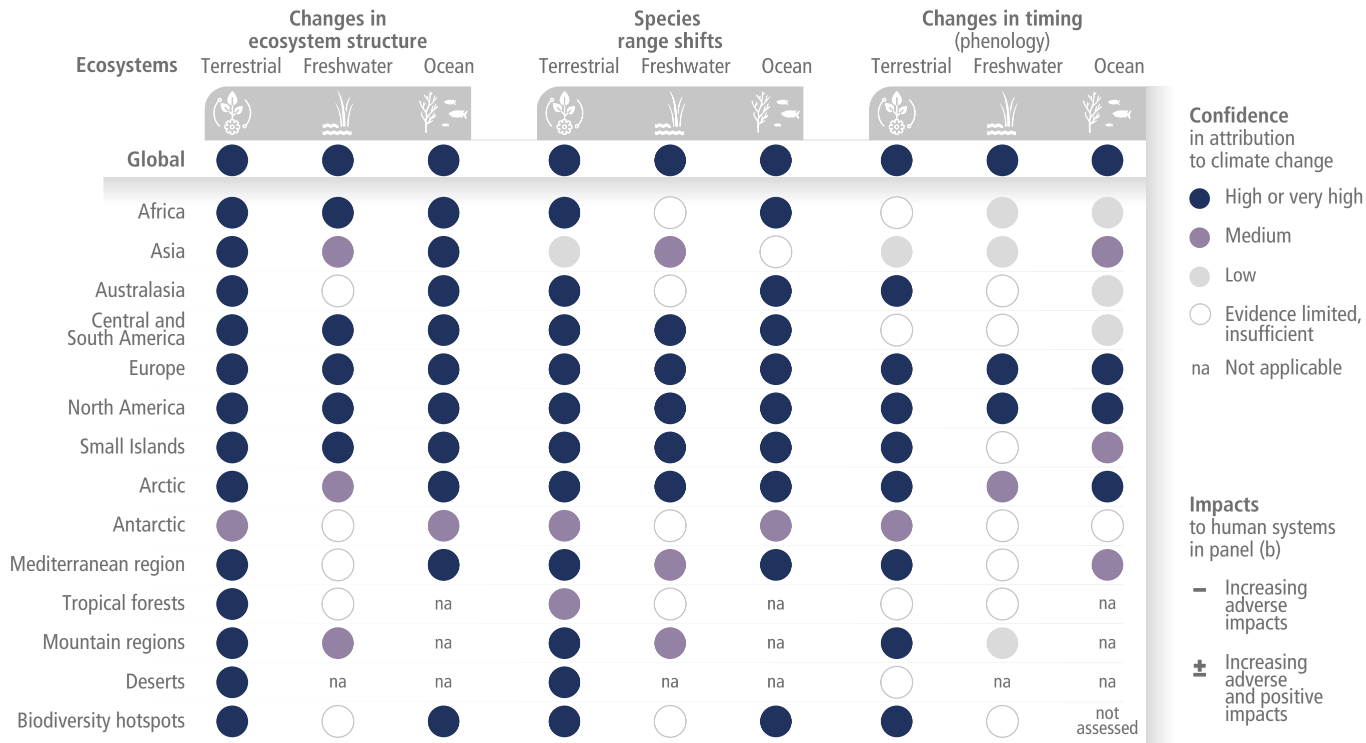
29 Impacts of climate change are caused by slow onset and extreme events. Slow onset events are described among the climatic-impact drivers of the WGI AR6 and refer to the risks and impacts associated with e.g., increasing temperature means, desertification, decreasing precipitation, loss of biodiversity, 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

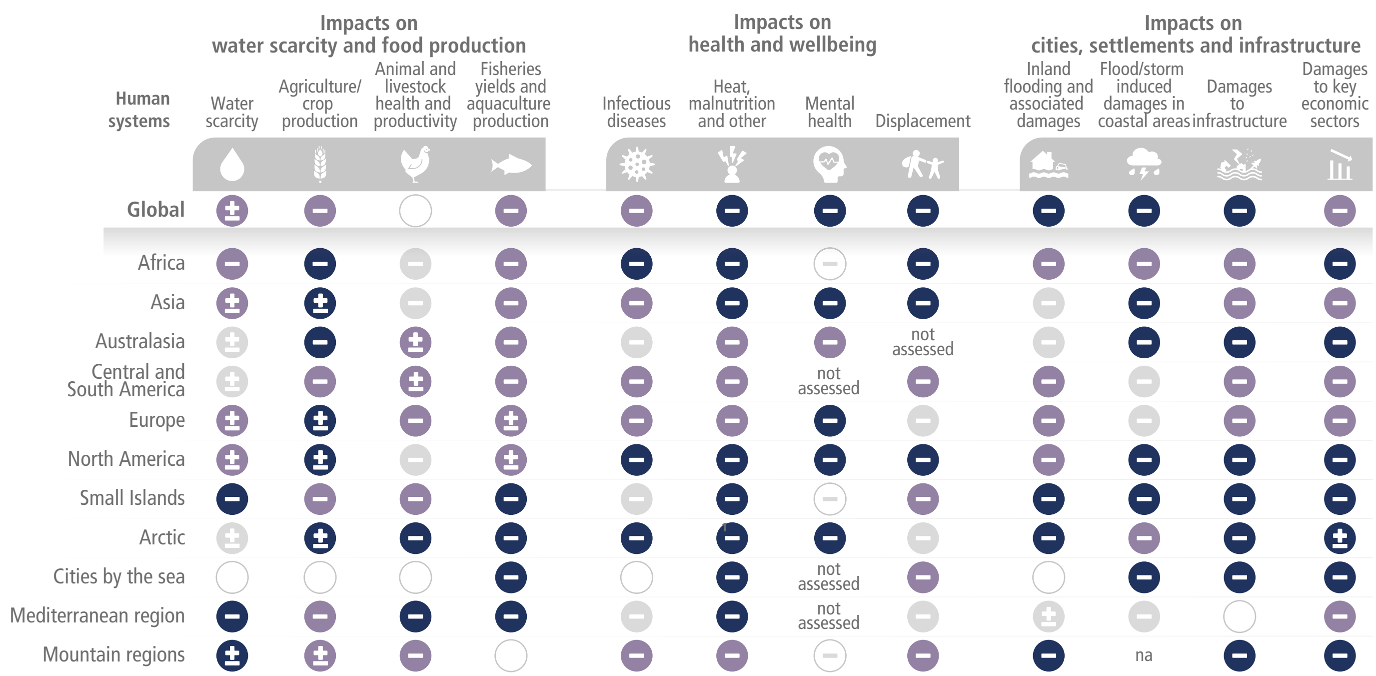


Figure SPM.2 | Observed global and regional impacts on ecosystems and human systems attributed to climate change. Confidence levels reflect uncertainty in attribution of the observed impact to climate change. Global assessments focus on large studies, multi-species, meta-analyses and large reviews. For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

SPM

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}

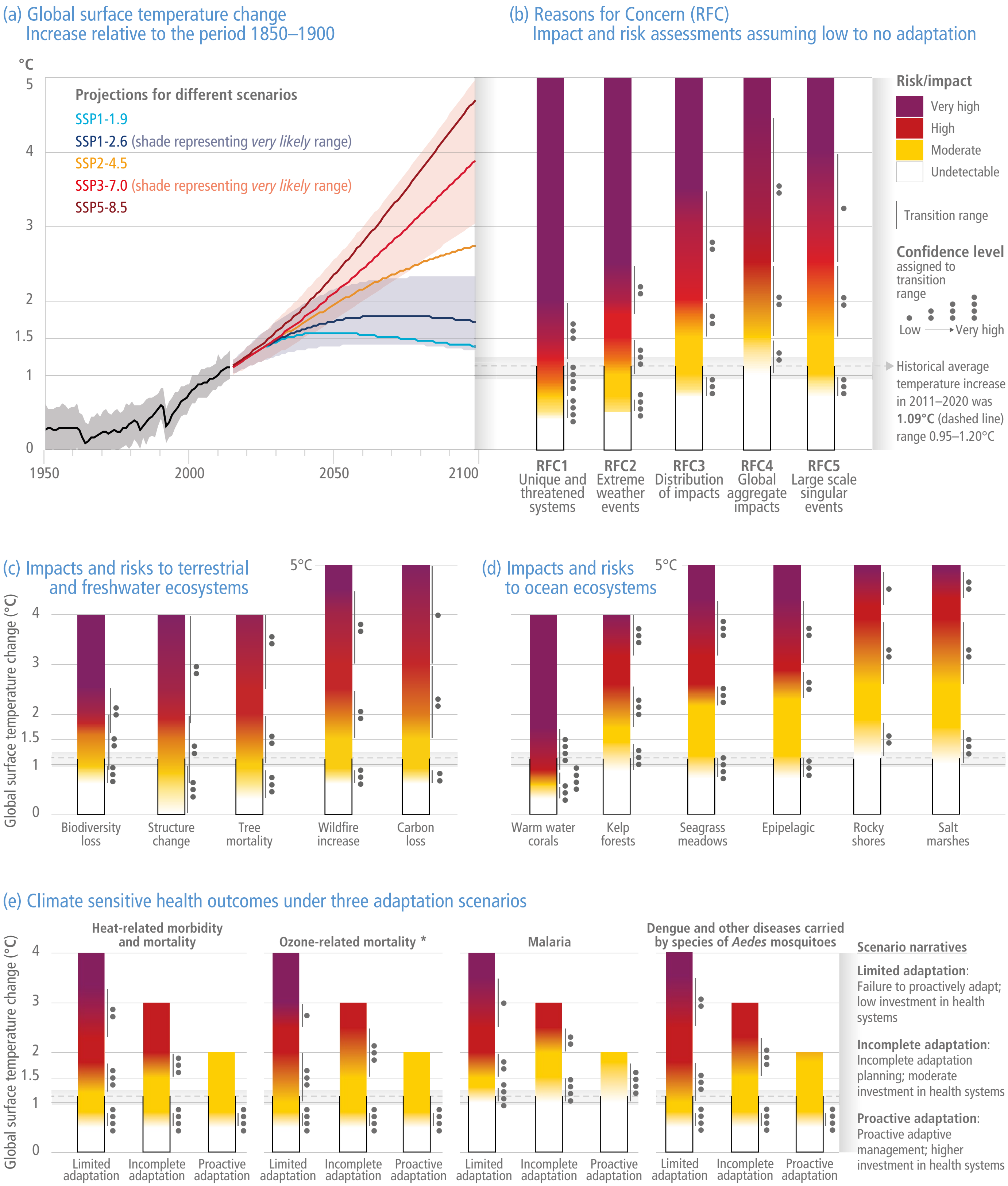
B.4.6 Projected estimates of global aggregate net economic damages generally increase non-linearly with global warming levels (*high confidence*).[35] The wide range of global estimates, and the lack of comparability between methodologies, does not allow for identification of a robust range of estimates (*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 }

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

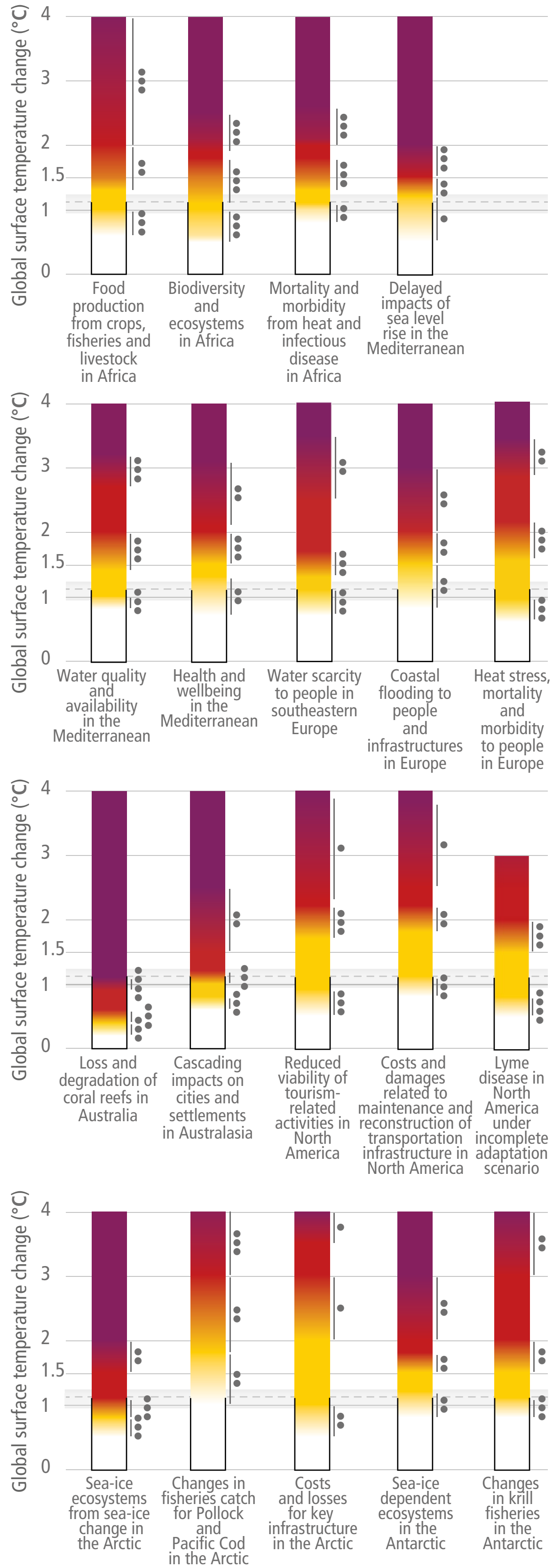


Figure SPM.3 | Synthetic diagrams of global and sectoral assessments and examples of regional key risks. Diagrams show the change in the levels of impacts and risks assessed for global warming of 0–5°C global surface temperature change relative to pre-industrial period (1850–1900) over the range.

(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}

---

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 ± 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}

---

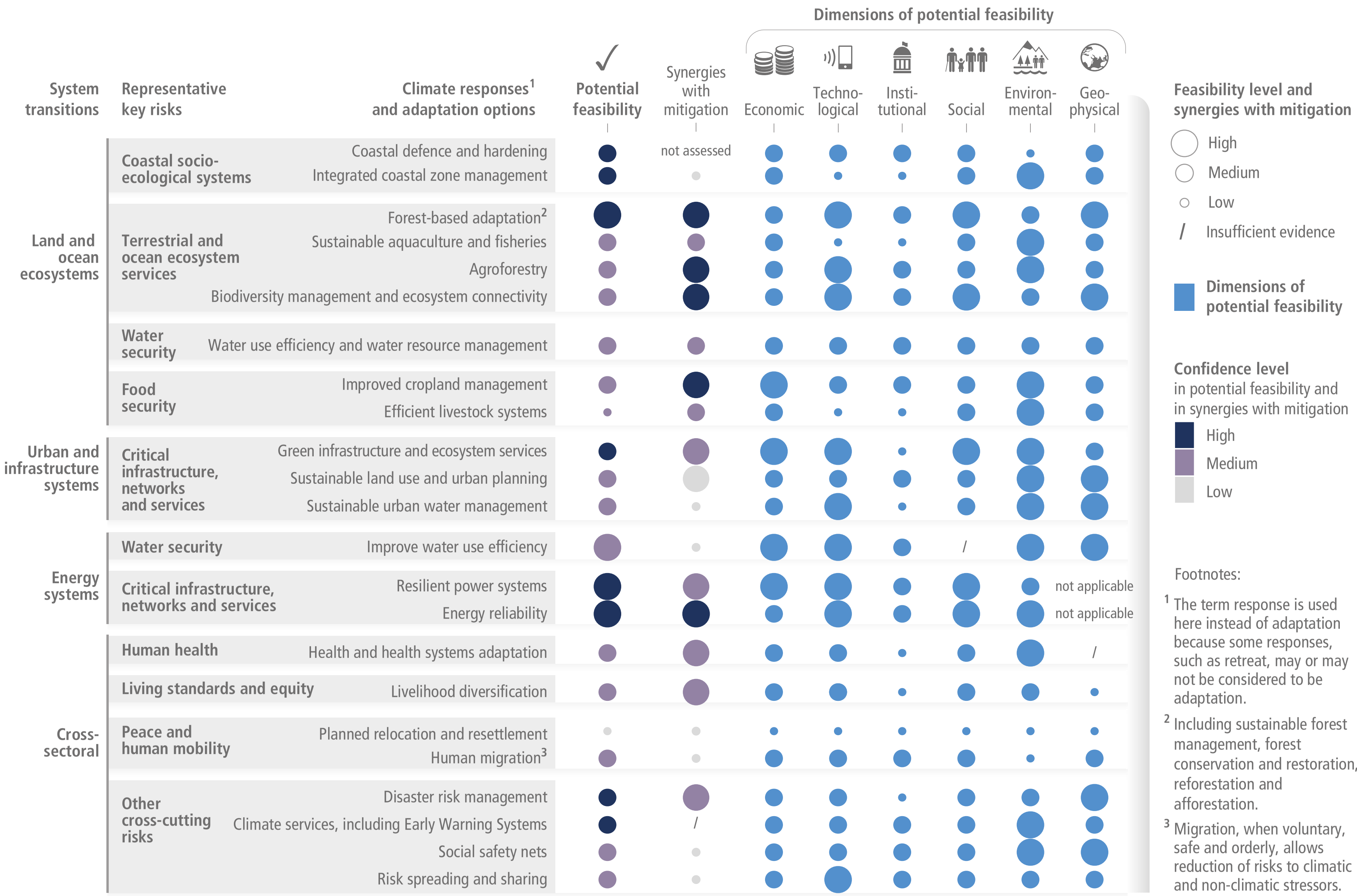
41 In this report, feasibility refers to the potential for a mitigation or adaptation option to be implemented. Factors influencing feasibility are context-dependent, temporally dynamic, and may vary between different groups and actors. Feasibility depends on geophysical, environmental-ecological, technological, 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.

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

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



Footnotes:

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

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

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

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}

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

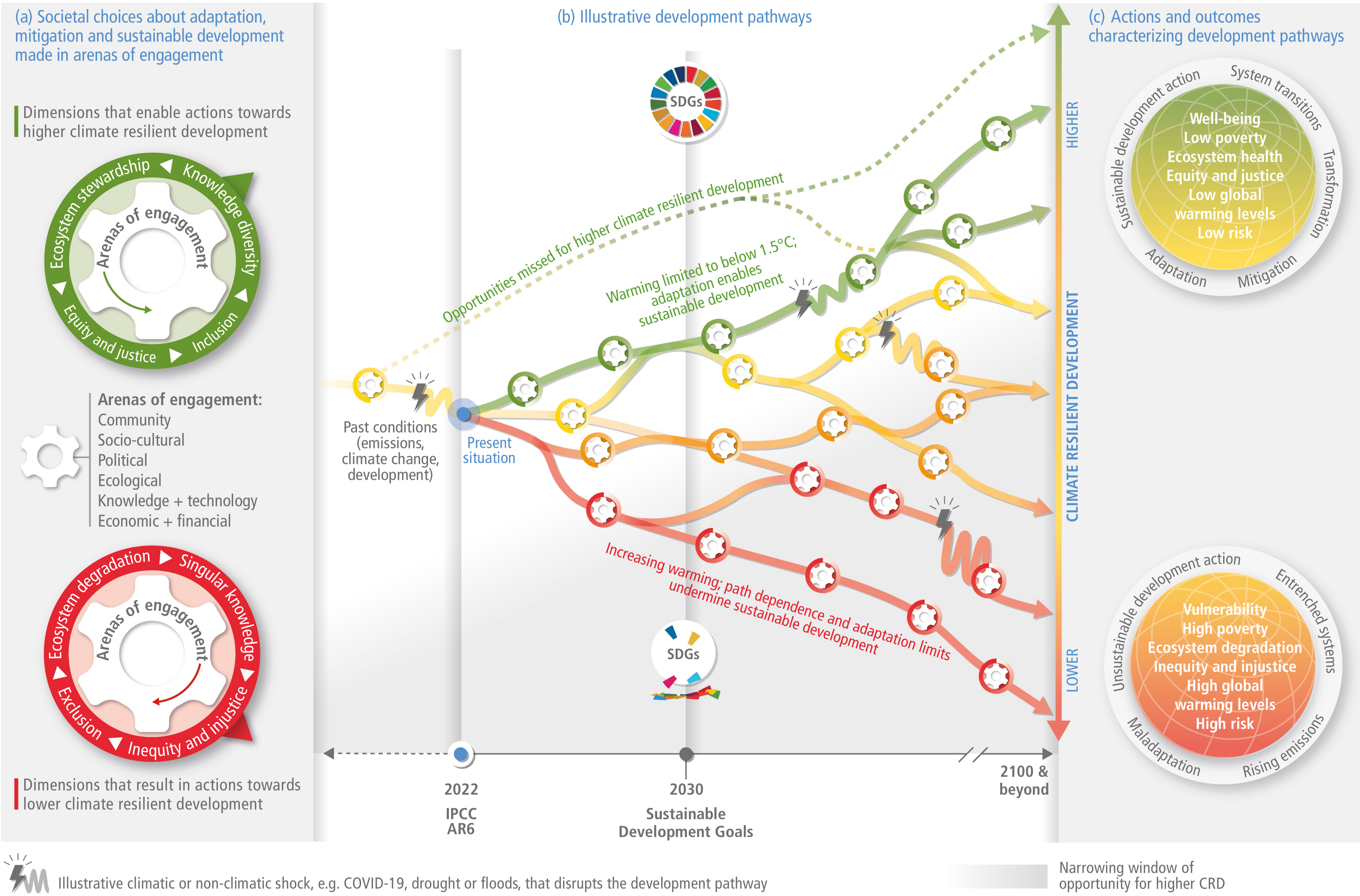


Figure SPM.5 | Climate resilient development (CRD) is the process of implementing greenhouse gas mitigation and adaptation measures to support sustainable development. This figure builds on Figure SPM.9 in AR5 WGII (depicting climate resilient pathways) by describing how CRD pathways are the result of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

Authors: Hans Pörtner (Germany), Debra C. Roberts (South Africa), Helen Adams (UK), Ibidun Adelekan (Nigeria), Carolina Adler (Switzerland/Chile/Australia), Rita Adrian (Germany), Paulina Aldunce (Chile), Elham Ali (Egypt), Rawshan Ara Begum (Malaysia/Australia/Bangladesh), Birgit Bednar-Friedl (Austria), Rachel Bezner Kerr (Canada/USA), Robbert Biesbroek (The Netherlands), Joern Birkmann (Germany), Kathryn Bowen (Australia), Martina Angela Caretta (Sweden), Jofre Carnicer (Spain), Edwin Castellanos (Guatemala), Tae Sung Cheong (Republic of Korea), Winston Chow (Singapore), Guéladio Cissé (Mauritania/Switzerland/France), Susan Clayton (USA), Andrew Constable (Australia), Sarah R. Cooley (USA), Mark John Costello (New Zealand/Norway/Ireland), Marlies Craig (South Africa), Wolfgang Cramer (France), Richard Dawson (UK), David Dodman (Jamaica/UK), Jackson Efitre (Uganda), Matthias Garschagen (Germany), Elisabeth Gilmore (USA/Canada), Bruce Glavovic (New Zealand/South Africa), David Gutzler (USA), Marjolijn Haasnoot (The Netherlands), Sherilee Harper (Canada), Toshihiro Hasegawa (Japan), Bronwyn Hayward (New Zealand), Jeffrey Hicke (USA), Yukiko Hirabayashi (Japan), Cunrui Huang (China), Kanungwe Kalaba (Zambia), Wolfgang Kiessling (Germany), Akio Kitoh (Japan), Rodel Lasco (Philippines), Judy Lawrence (New Zealand), Maria Fernanda Lemos (Brazil), Robert Lempert (USA), Christopher Lennard (South Africa), Debora Ley (Guatemala/Mexico), Tabea Lissner (Germany), Qiyong Liu (China), Emma Liwenga (Tanzania), Salvador Lluch-Cota (Mexico), Sina Loeschke (Germany), Simone Lucatello (Mexico), Yong Luo (China), Brendan Mackey (Australia), Katja Mintenbeck (Germany), Alisher Mirzabaev (Uzbekistan), Vincent Moeller (Germany), Mariana Moncassim Vale (Brazil), Mike Morecroft (UK), Linda Mortsch (Canada), Aditi Mukherji (India), Tero Mustonen (Finland), Michelle Mycoo (Trinidad and Tobago), Johanna Nalau (Australia/Finland), Mark New (South Africa), Andrew Okem (South Africa/Nigeria), Jean Pierre Ometto (Brazil), Brian O'Neill (USA), Rajiv Pandey (India), Camille Parmesan (France/UK/USA), Mark Pelling (UK), Patricia Fernanda Pinho (Brazil), John Pinnegar (UK), Elvira S. Poloczanska (UK/Australia/Germany), Anjal Prakash (India), Benjamin Preston (USA), Marie-Fanny Racault (UK/France), Diana Reckien (The Netherlands/Germany), Aromar Revi (India), Steven K. Rose (USA), E. Lisa F. Schipper (Sweden/UK), Daniela Schmidt (UK/Germany), David Schoeman (Australia), Rajib Shaw (Japan), Nicholas P. Simpson (Zimbabwe/South Africa), Chandni Singh (India), William Solecki (USA), Lindsay Stringer (UK), Edmond Totin (Benin), Christopher Trisos (South Africa), Yongyut Trisurat (Thailand), Maarten van Aalst (The Netherlands), David Viner (UK), Morgan Wairiu (Solomon Islands), Rachel Warren (UK), Philippus Wester (Nepal/The Netherlands), David Wrathall (USA), Zelina Zaiton Ibrahim (Malaysia)

Contributing Authors: Andrés Alegría (Germany/Honduras), Delavane Diaz (USA), Kristie L. Ebi (USA), Siri H. Eriksen (Norway), Katja Frieler (Germany), Ali Jamshed (Germany/Pakistan), Shobha Maharaj (Germany/Trinidad and Tobago), Robert McLeman (USA), Joanna McMillan (Germany/Australia), Adelle Thomas (Bahamas)

Review Editors: Andreas Fischlin (Switzerland), Mark Howden (Australia), Carlos Mendez (Venezuela), Joy Pereira (Malaysia), Roberto Sanchez-Rodriguez (Mexico), Sergey Semenov (Russian Federation), Pius Yanda (Tanzania), Taha Zatari (Saudi Arabia)

Visual Conception and Information Design: Andrés Alegría (Germany/Honduras), Stefanie Langsdorf (Germany)

This Technical Summary should be cited as:

Pörtner, H.-O., D.C. Roberts, H. Adams, I. Adelekan, C. Adler, R. Adrian, P. Aldunce, E. Ali, R. Ara Begum, B. Bednar-Friedl, R. Bezner Kerr, R. Biesbroek, J. Birkmann, K. Bowen, M.A. Caretta, J. Carnicer, E. Castellanos, T.S. Cheong, W. Chow, G. Cissé, S. Clayton, A. Constable, S.R. Cooley, M.J. Costello, M. Craig, W. Cramer, R. Dawson, D. Dodman, J. Efitre, M. Garschagen, E.A. Gilmore, B.C. Glavovic, D. Gutzler, M. Haasnoot, S. Harper, T. Hasegawa, B. Hayward, J.A. Hicke, Y. Hirabayashi, C. Huang, K. Kalaba, W. Kiessling, A. Kitoh, R. Lasco, J. Lawrence, M.F. Lemos, R. Lempert, C. Lennard, D. Ley, T. Lissner, Q. Liu, E. Liwenga, S. Lluch-Cota, S. Löschke, S. Lucatello, Y. Luo, B. Mackey, K. Mintenbeck, A. Mirzabaev, V. Möller, M. Moncassim Vale, M.D. Morecroft, L. Mortsch, A. Mukherji, T. Mustonen, M. Mycoo, J. Nalau, M. New, A. Okem, J.P. Ometto, B. O'Neill, R. Pandey, C. Parmesan, M. Pelling, P.F. Pinho, J. Pinnegar, E.S. Poloczanska, A. Prakash, B. Preston, M.-F. Racault, D. Reckien, A. Revi, S.K. Rose, E.L.F. Schipper, D.N. Schmidt, D. Schoeman, R. Shaw, N.P. Simpson, C. Singh, W. Solecki, L. Stringer, E. Totin, C.H. Trisos, Y. Trisurat, M. van Aalst, D. Viner, M. Wairiu, R. Warren, P. Wester, D. Wrathall, and Z. Zaiton Ibrahim, 2022: Technical Summary. [H.-O. Pörtner, D.C. Roberts, E.S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem (eds.)]. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 37–118, doi:10.1017/9781009325844.002.

Table of Contents

TS

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.

Evaluation and communication of degree of certainty in AR5 and AR6 findings

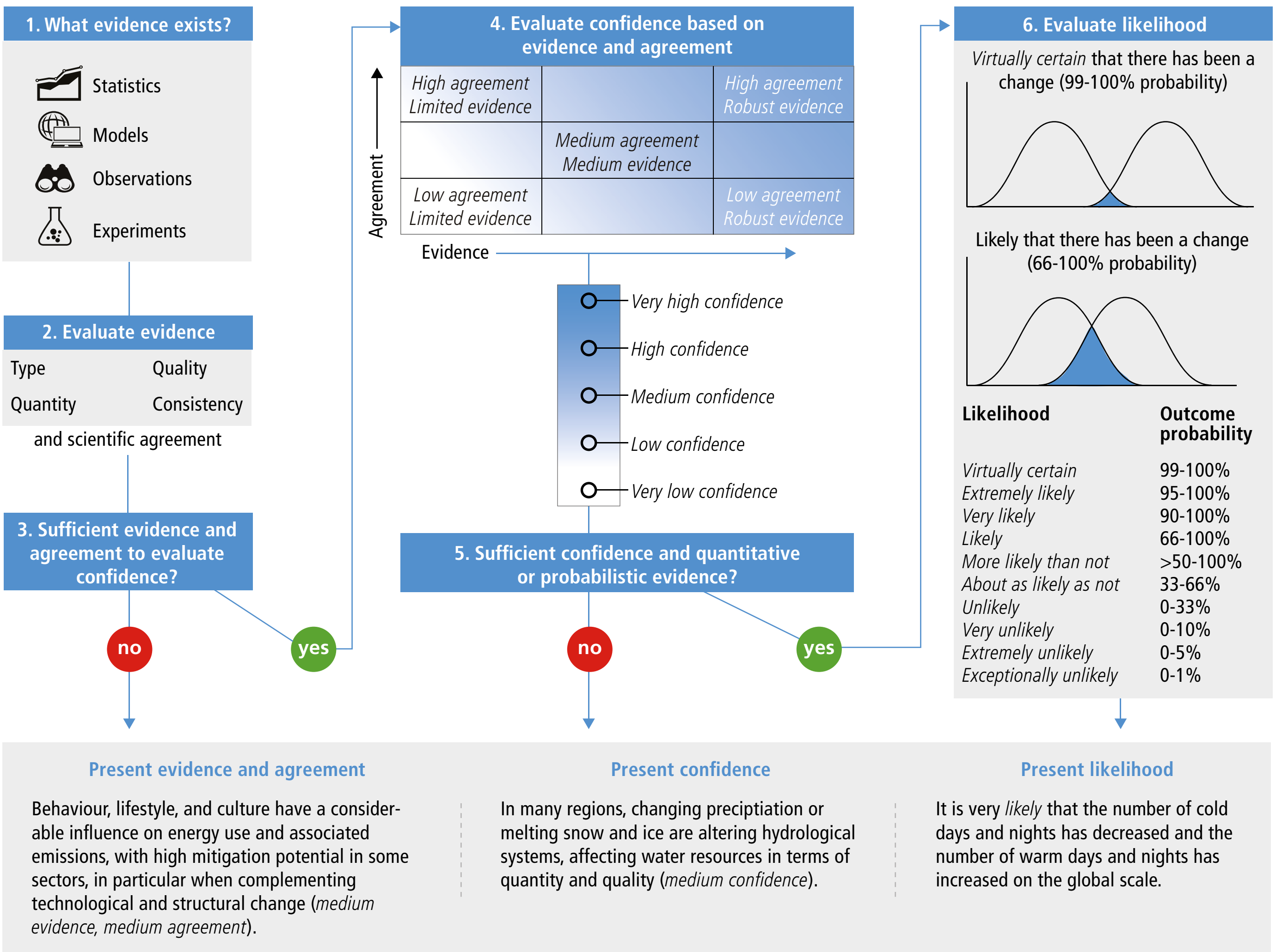


Figure TS.1 | The IPCC AR5 and AR6 framework for applying expert judgement in the evaluation and characterisation of assessment findings. This illustration depicts the process assessment authors apply in evaluating and communicating the current state of knowledge. {Figure 1.6}

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.

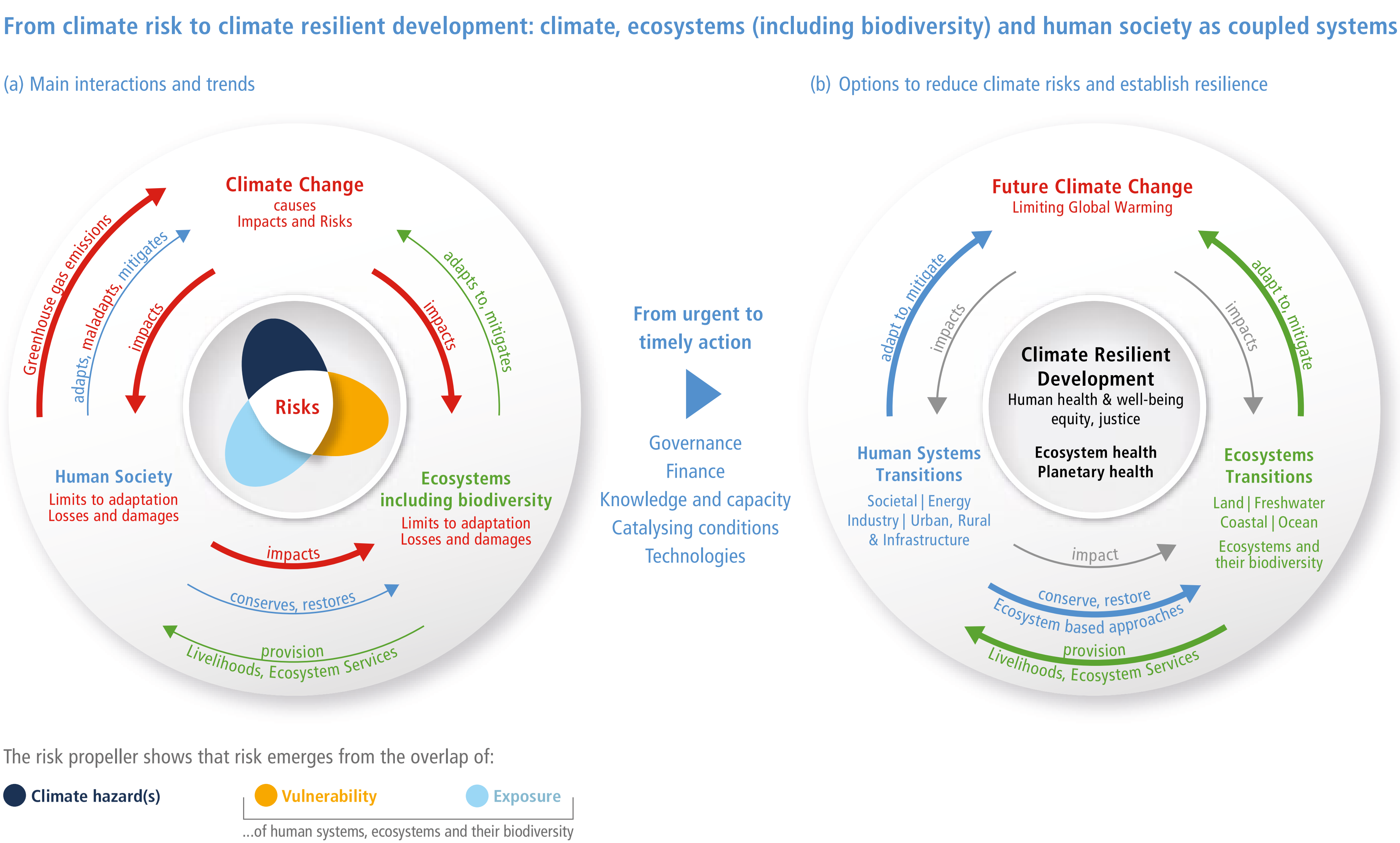


Figure TS.2 | This report has a strong focus on the interactions among the coupled systems climate, ecosystems (including their biodiversity) and human society. These interactions are the basis of emerging risks from climate change, ecosystem degradation and biodiversity loss and, at the same time, offer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

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

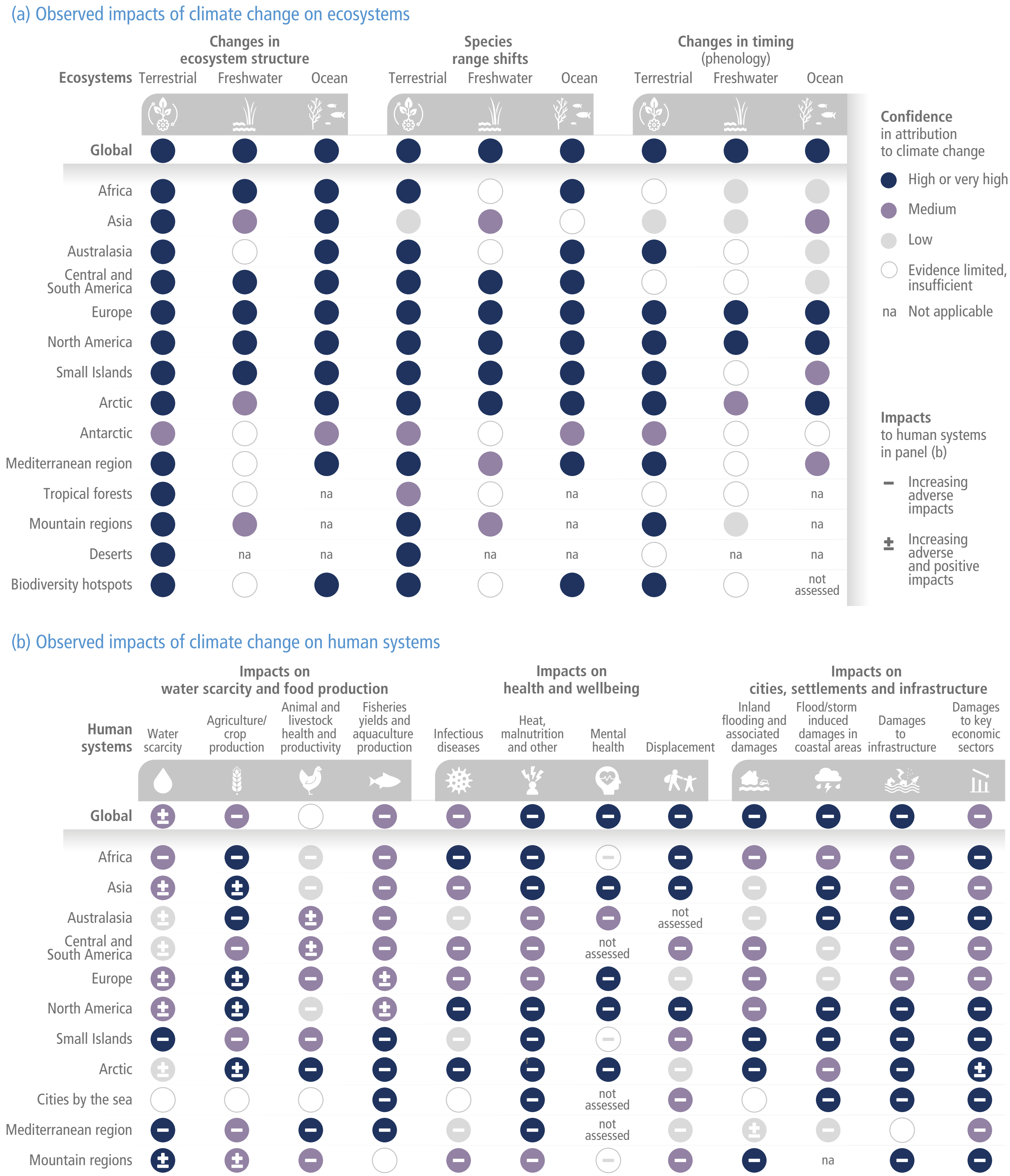


Figure TS.3 | Observed global and regional impacts on ecosystems and human systems attributed to climate change. Confidence levels reflect uncertainty in attribution of the observed impact to climate change. Global assessments focus on large studies, multi-species, meta-analyses and large reviews. For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

(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}

TS

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

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

TS

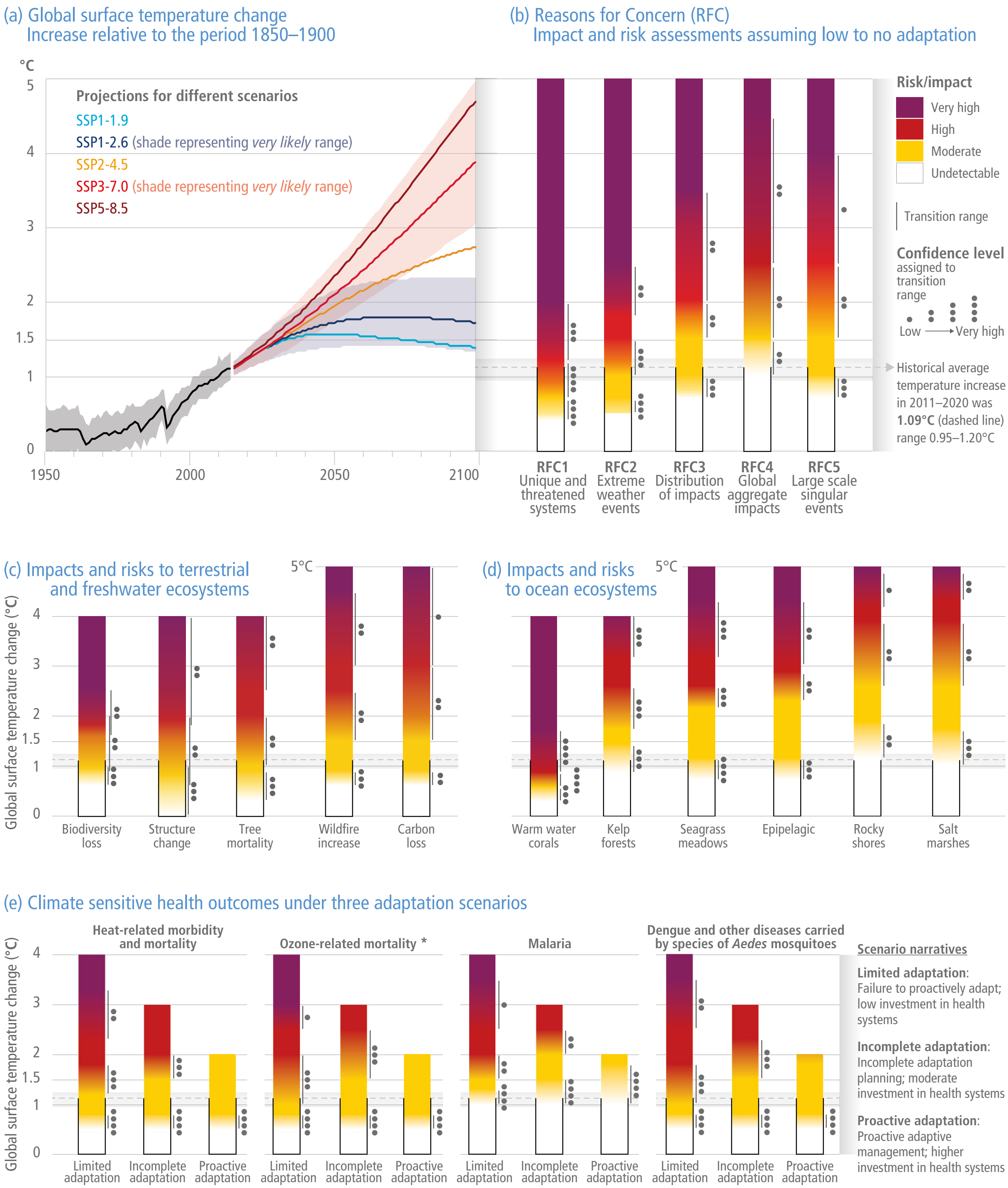
Food systems and food security

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

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

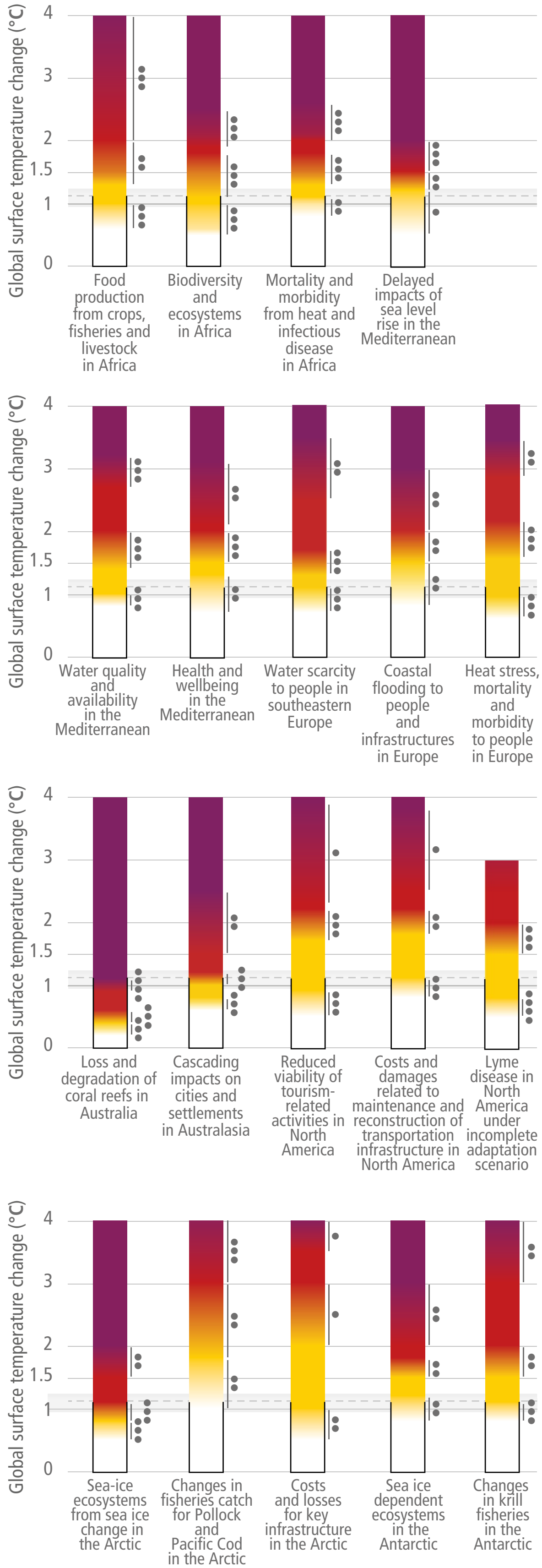


Figure TS.4 | Synthetic diagrams of global and sectoral assessments and examples of regional key risks. Diagrams show the change in the levels of impacts and risks assessed for global warming of 0–5°C global surface temperature change relative to pre-industrial period (1850–1900) over the range.

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

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

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

Reasons for concern (RFC)

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

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

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

***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 warming; reduced marine food provisioning, fishery distribution and revenue value with projected approximate 13% decline in ocean animal biomass.	Projected to transition to high risk	1.5°C–2.5°C (*medium confidence*)
	Widespread death of trees, damage to ecosystems and reduced provision of ecosystem services over temperature range 2.5°C–4.5°C; projected global annual damages associated with sea level rise of USD31,000 billion yr^{-1} in 2100 for 4°C warming scenario.	Projected to transition to very high risk (new in AR6)	2.5°C–4.5°C (*low confidence*)
RFC5 Large-scale singular events: relatively large, abrupt and sometimes irreversible changes in systems caused by global warming, such as ice sheet disintegration or thermohaline circulation slowing, sometimes called tipping points or critical thresholds.	Mass loss from both Antarctic (whether associated with marine ice sheet instability or not) and Greenland ice sheets is more than seven times higher over the period 2010–2016 than over the period 1992–1999 for Greenland and four times higher for the same time intervals for Antarctica; in Amazon forest, increases in tree mortality and a decline in carbon sink are reported	Current risk level is moderate	1.1°C (*high confidence*)
	Implications for 2000-year commitments to sea level rise from sustained mass loss from both ice sheets as projected by various ice sheet models, reaching 2.3–3.1 m at 1.5°C peak warming and 2–6 m at 2°C peak warming; risk of savannisation for Amazon alone was assessed to lie between 1.5°C and 3°C, with a median value at 2°C	Projected to transition to high risk	1.5°C–2.5°C (*medium confidence*)
	Uncertainties in projections of sea level rise at higher levels of warming, long-term equilibrium sea level rise of 5–25 m at mid-Pliocene temperatures of 2.5°C; potential for Amazon forest dieback between 4°C and 5°C; risk of ecosystem carbon loss from tipping points in tropical forest and loss of Arctic permafrost.	Projected to transition to very high risk (new in AR6)	2.5°C–4°C (*low confidence*)

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}

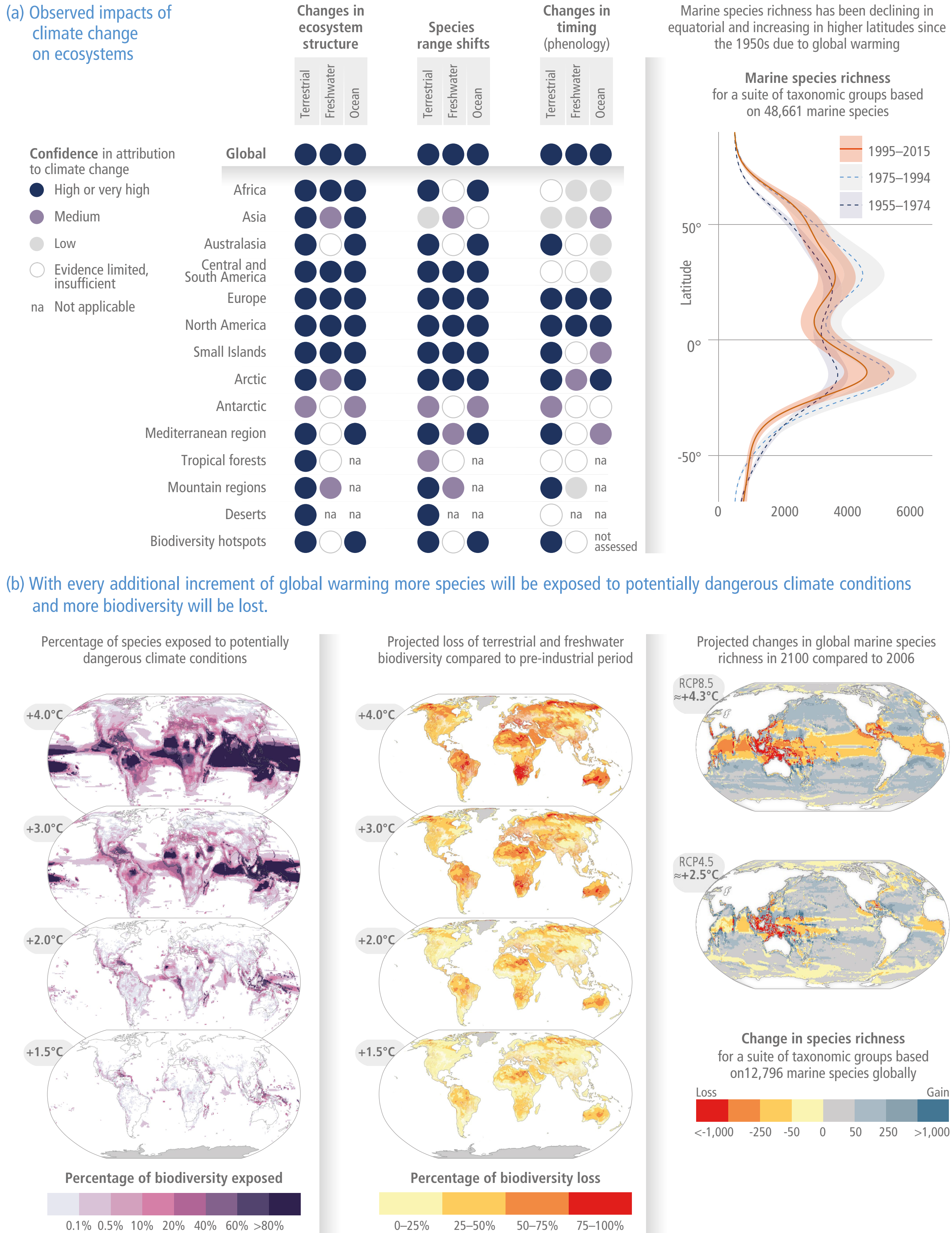
TS.D.1.1 Responses have accelerated in both developed and developing regions since AR5, with some examples of regression (*high confidence*). Growing adaptation knowledge in public and private sectors, increasing numbers of policy and legal frameworks and dedicated spending on adaptation are all clear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

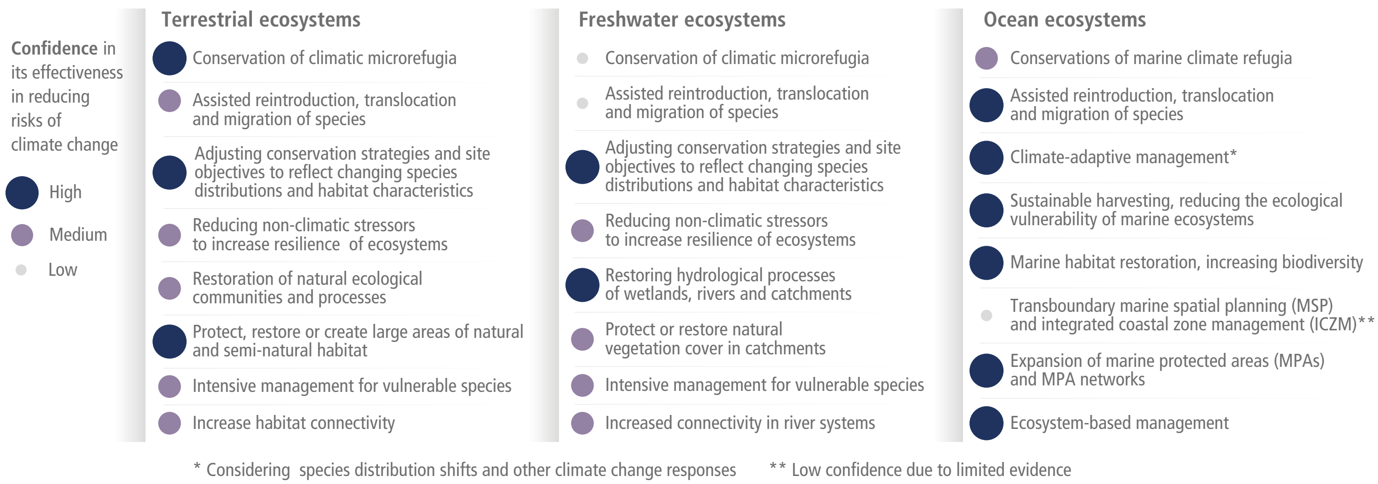
TS.D.1.3 The ambition, scope and progress on adaptation have risen among governments at the local, national and international levels, along with businesses, communities and civil society, but many funding, knowledge and practice gaps remain for effective implementation, monitoring and evaluation (*high 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.



(d) Adaptation pathways for ecosystems.

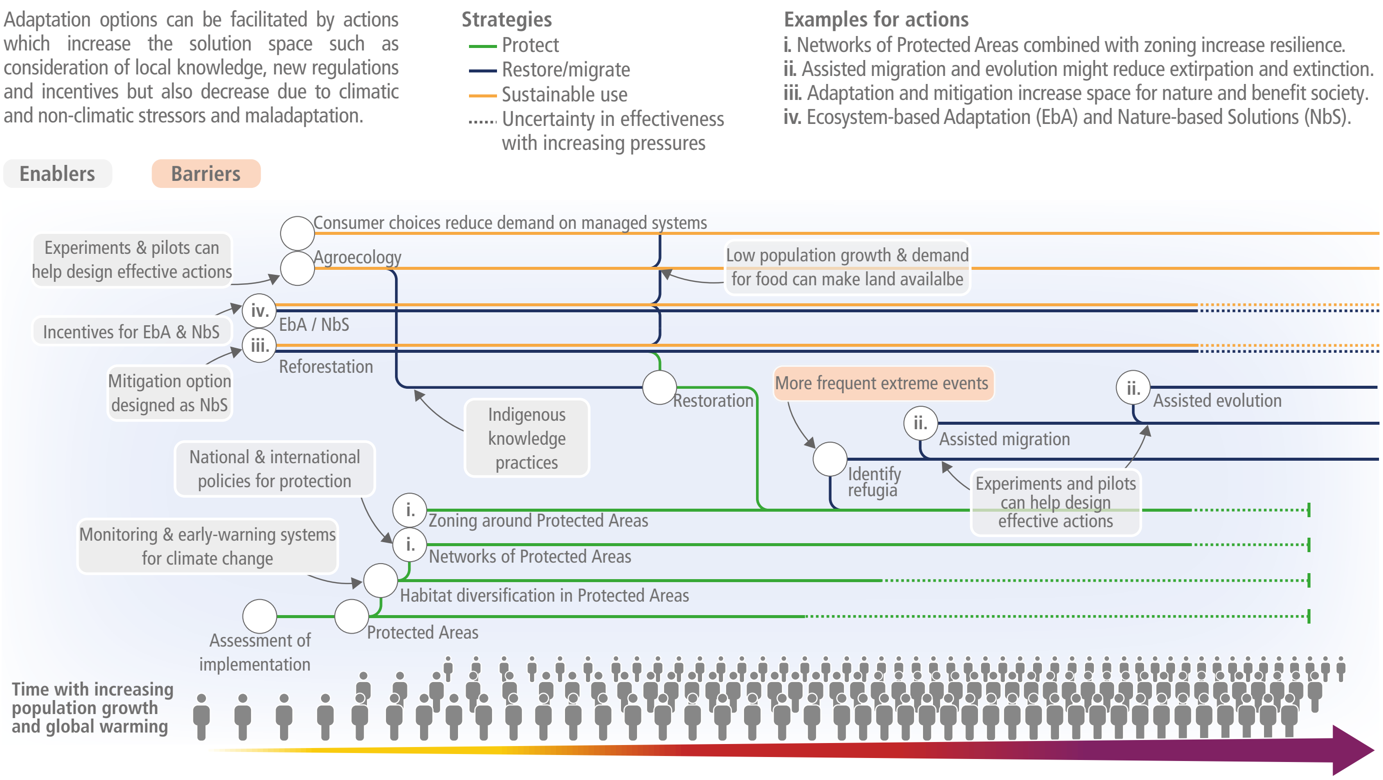
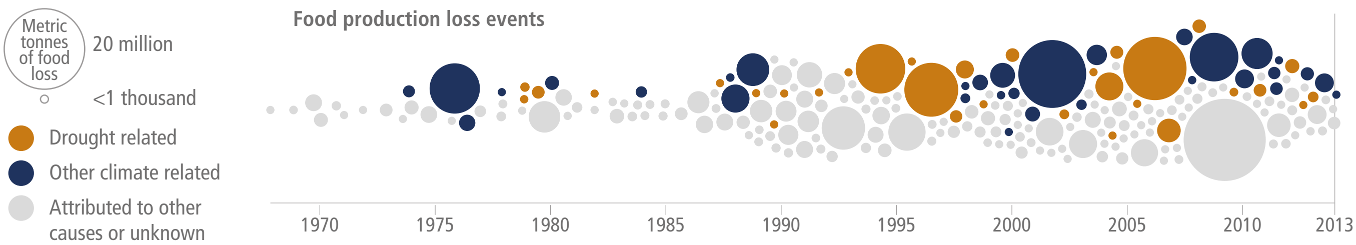


Figure TS.5 ECOSYSTEMS | (a) Left: Observed global and regional impacts on ecosystems and human systems attributed to climate change. Confidence levels reflect uncertainty in attribution of the observed impact to climate change. For more details and line of sight to chapters and cross-chapter papers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

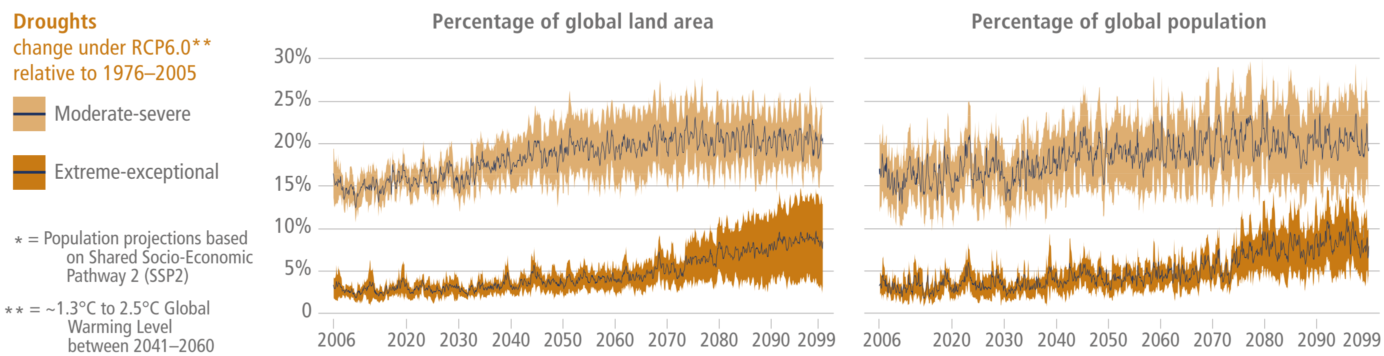
Climate change is affecting food security through pervasive water impacts

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

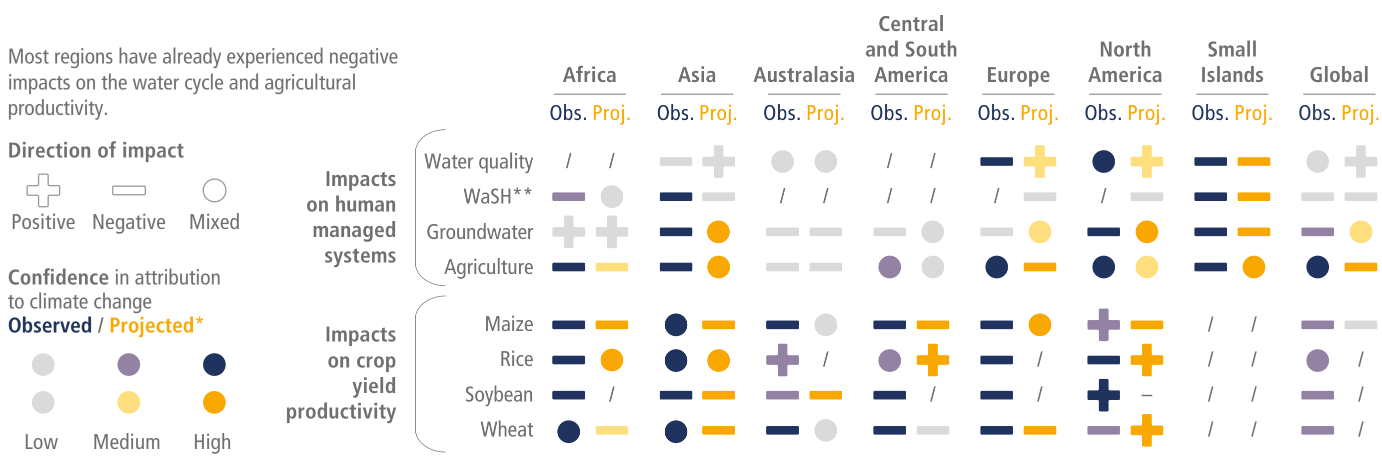
(a) The frequency of climated-related food production losses in crops, livestocks, fisheries and aquacultures has been increasing over the last decades.



(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.

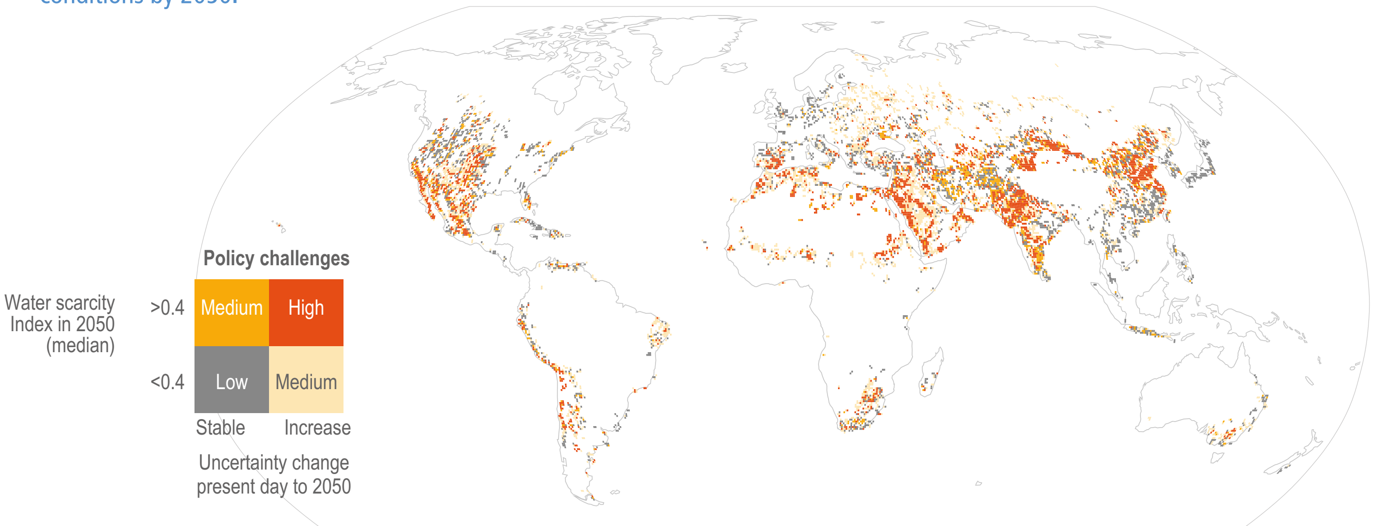


*Mid-century at RCP4.5 (~2°C Global Warming Level)

** = 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.

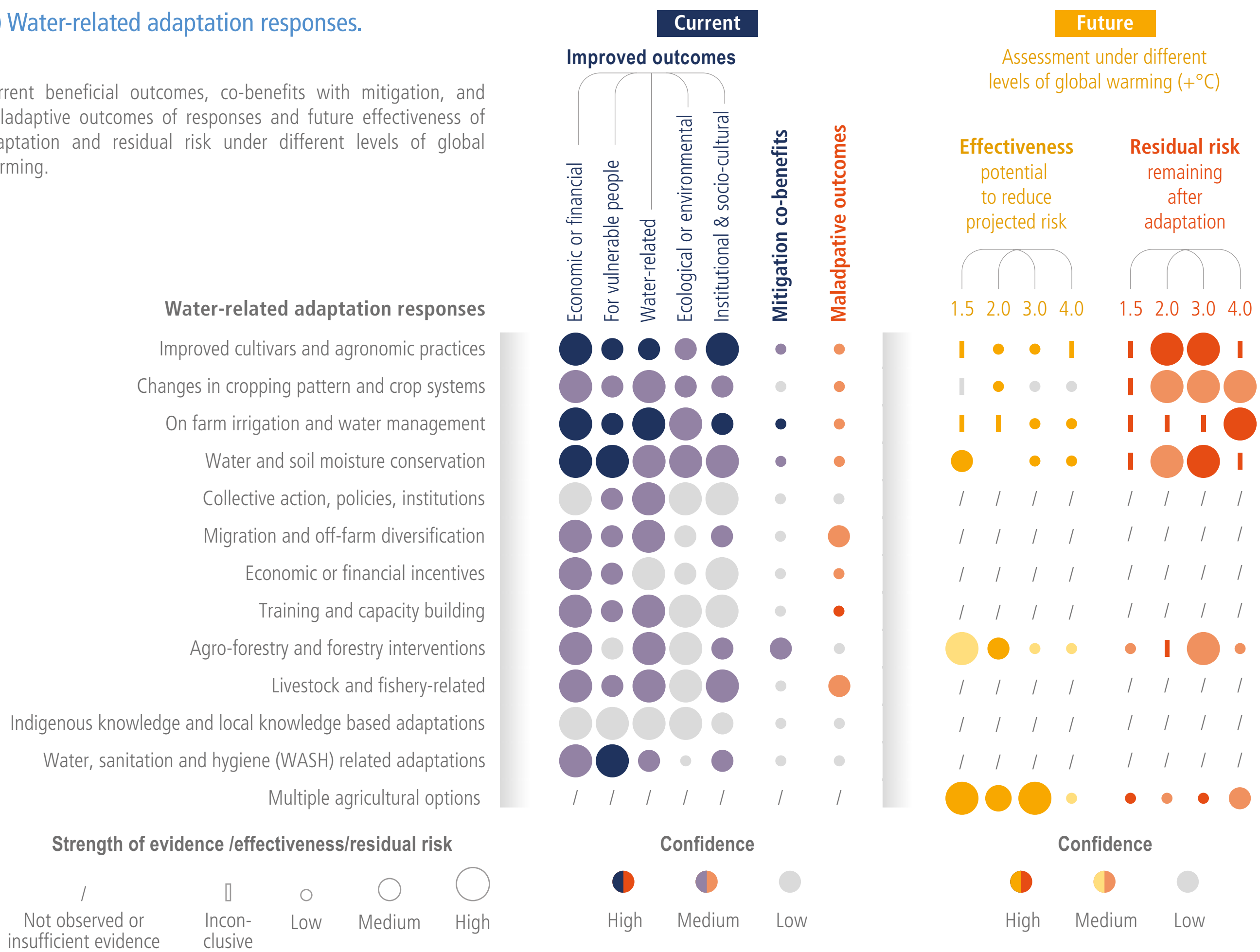
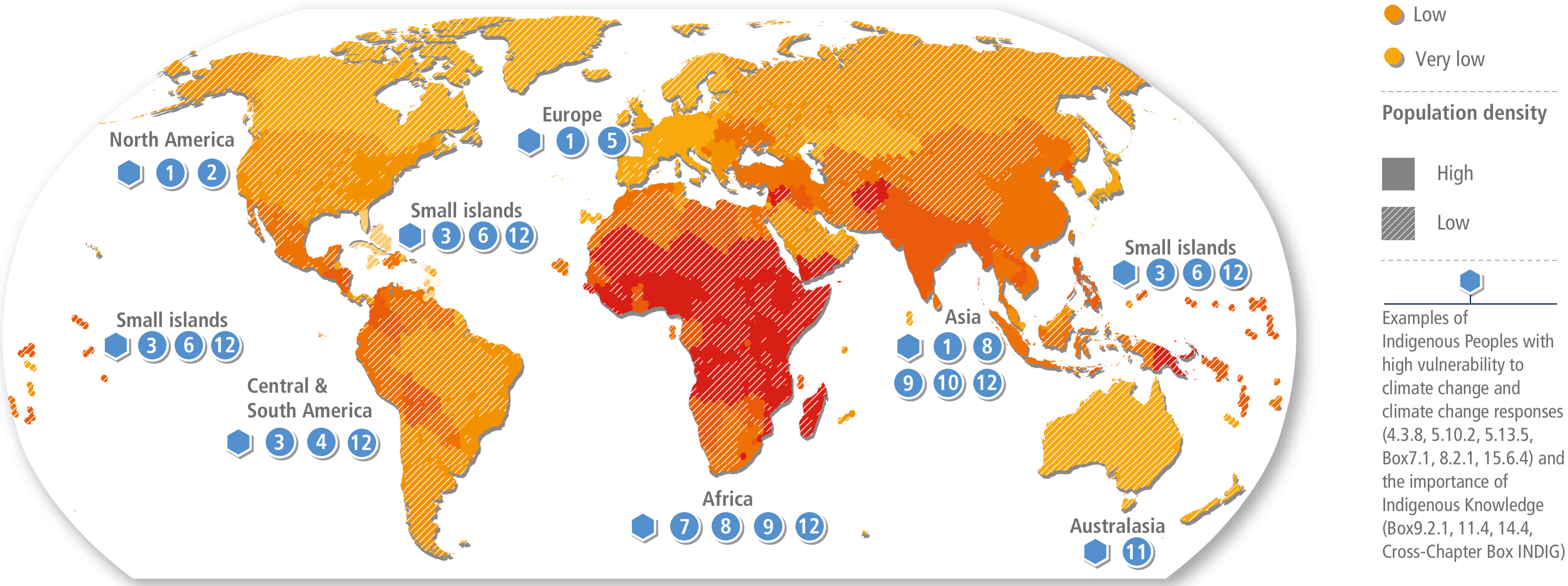


Figure TS.6 FOOD-WATER | (a) {5.4.1.1, Box 5.1, FAQ 5.1, SM5.1, Figure AI.20}. **(b)** Projected increase in the global share of area and population impacted from droughts. Changes are calculated based on the RCP6.0 concentration pathway for Terrestrial Water Storage (TWS) droughts, which can be considered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

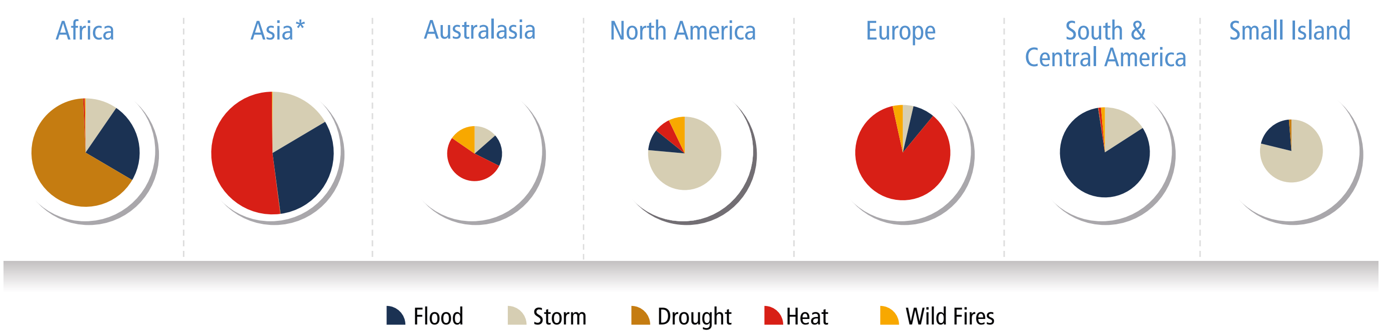


Examples of local vulnerable populations | Examples of some aspects of vulnerability | Chapter references

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

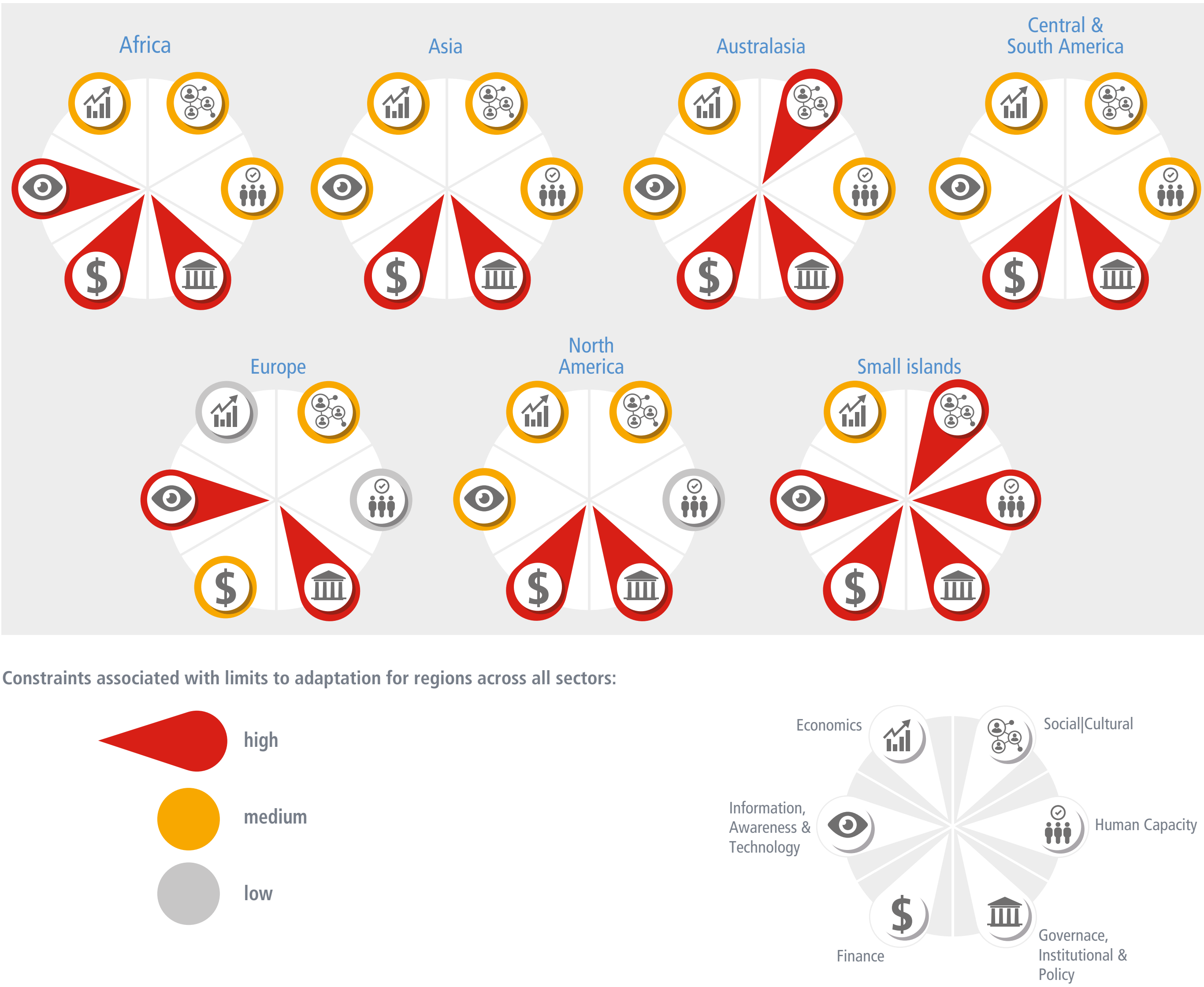


Figure TS.7 VULNERABILITY | (a) The global map of vulnerability is based on two comprehensive global indicator systems, namely INFORM Risk Index and WorldRiskIndex (2019). Climate change hazards and exposure levels are not included in this figure. The relative level of average national vulnerability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

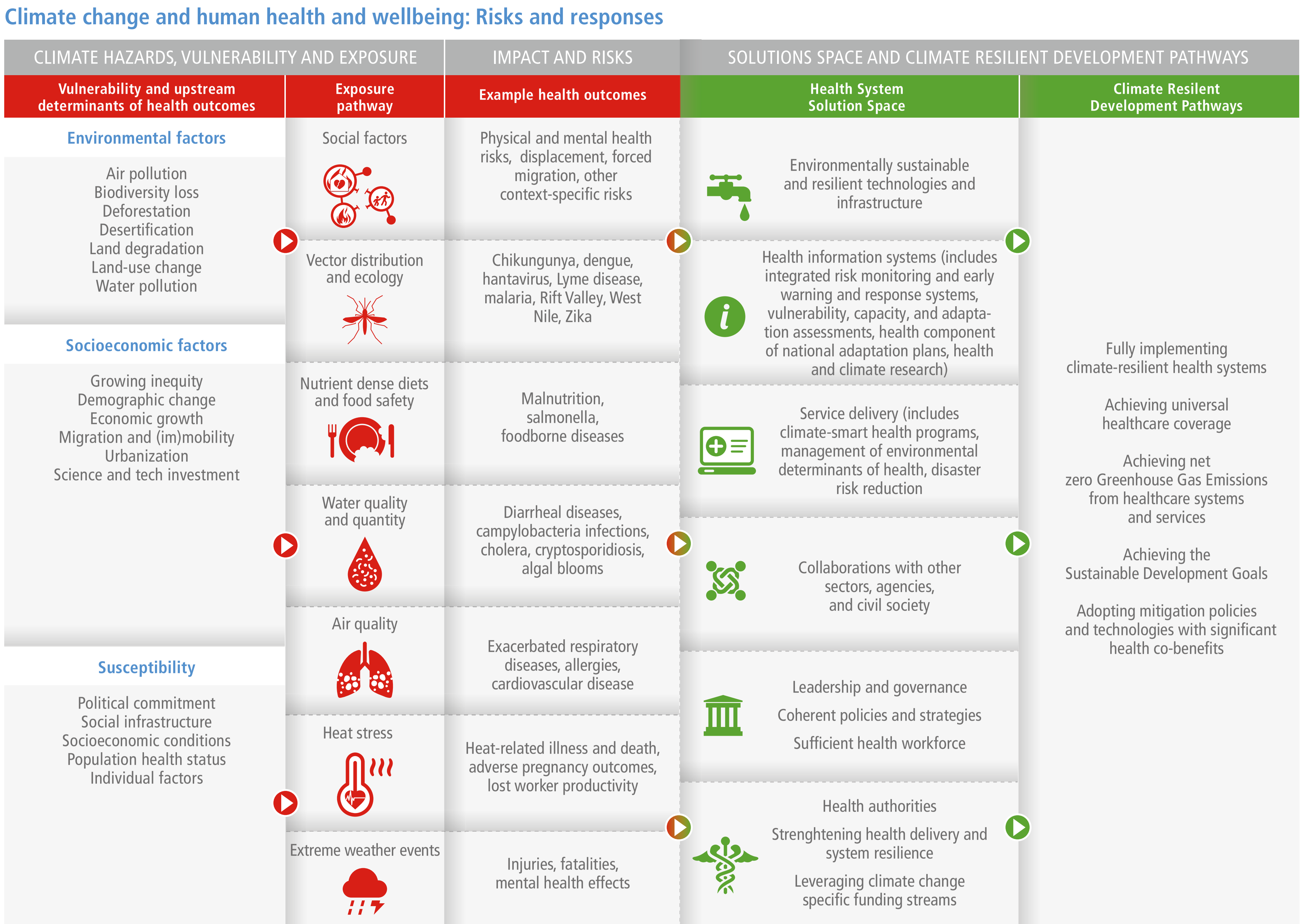
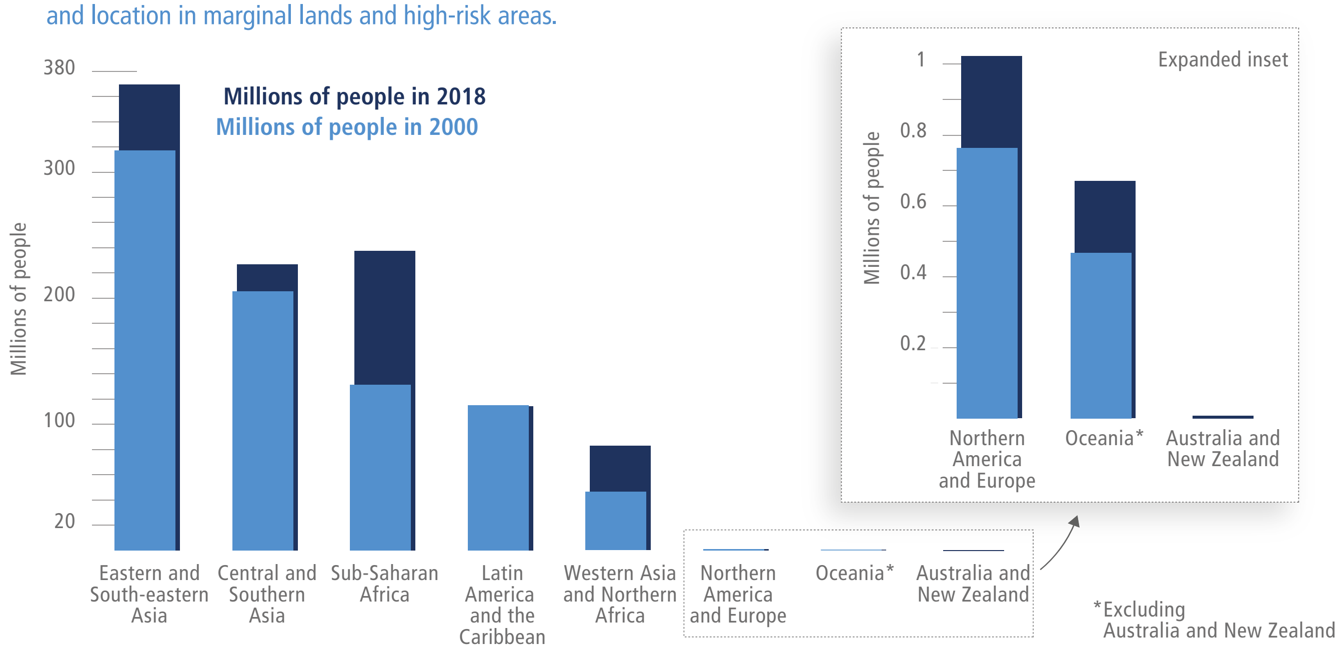


Figure TS.8 HEALTH | Multiple socio-economic and environmental factors interact with climate risks to shape human health and well-being. Achieving climate resilient development requires leveraging opportunities in the solution space within health systems and across other sectors. {7.1.4, 7.1.6, 7.1.7,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

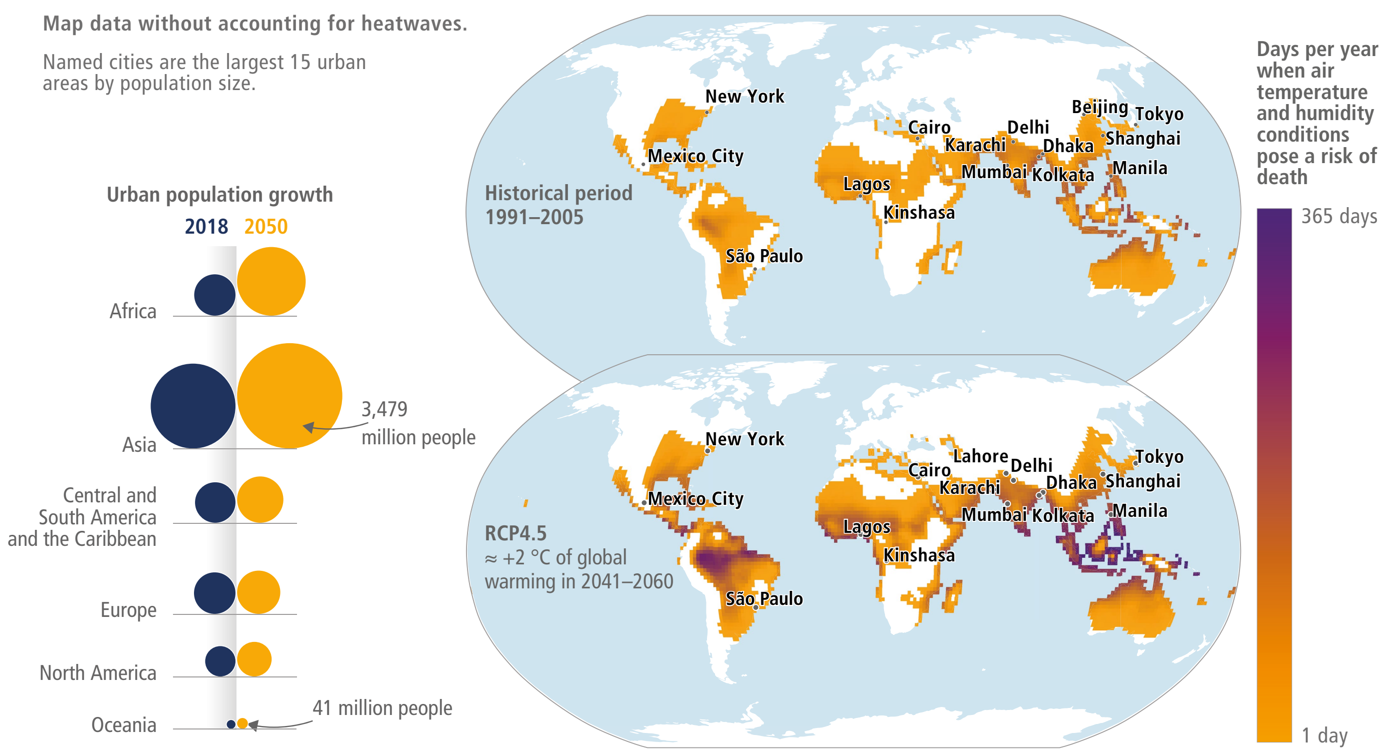
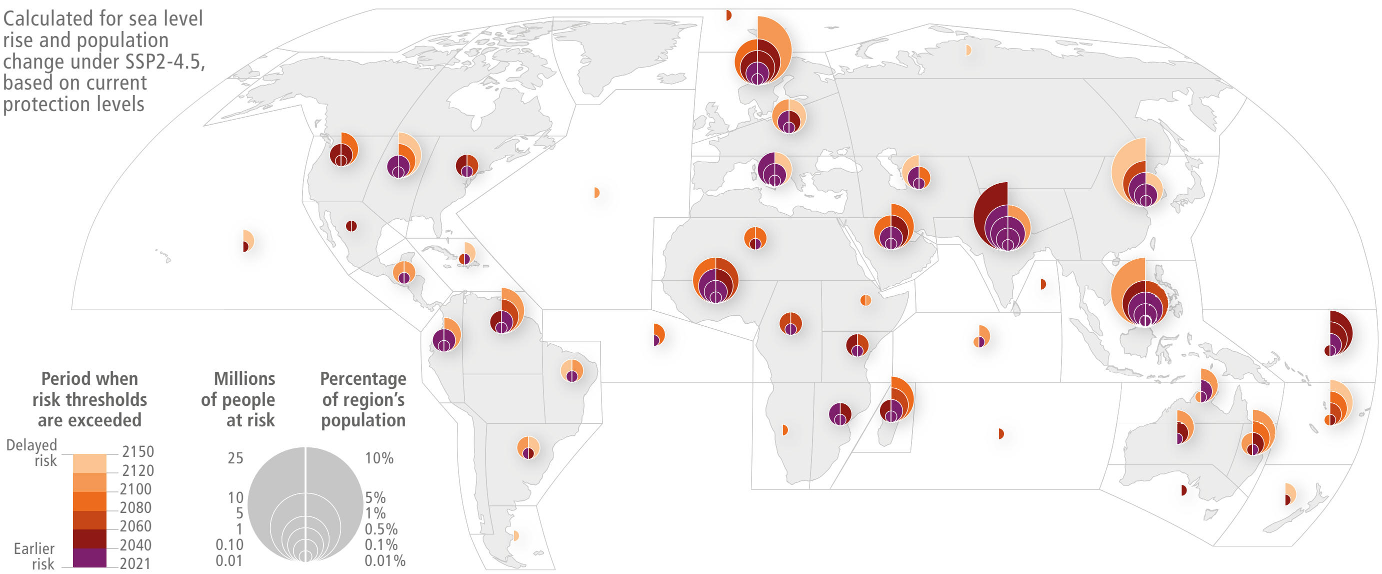


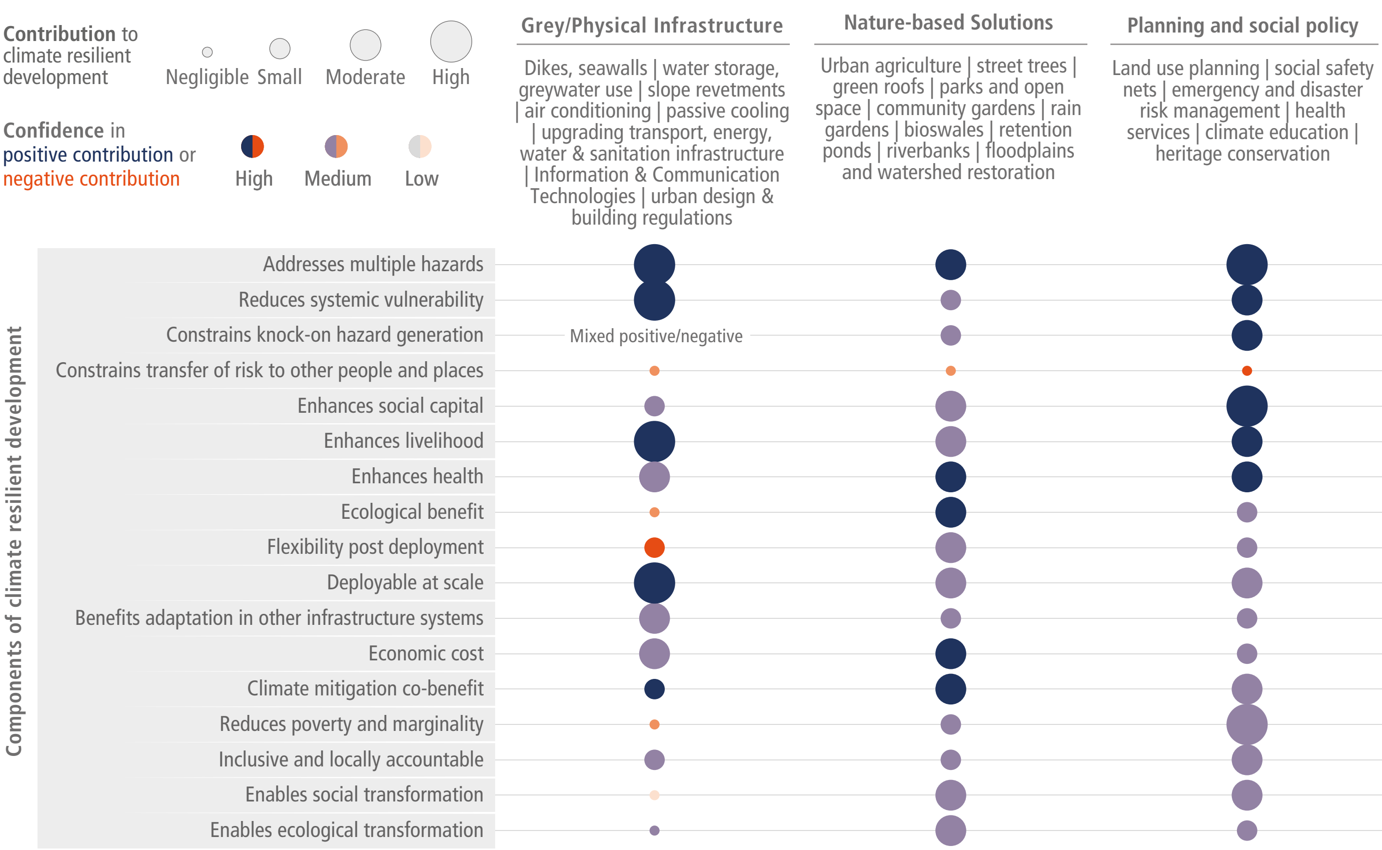
Figure TS.9 URBAN | (a) The regions shown are reflecting the original dataset from UN Habitat and vary from IPCC regions. {6.1.4, 9.9.3, 10.4.6, 12.5.5} **(b)** Heat is a growing health risk due to increasing urbanization and rising temperature extremes. Within cities the urban heat island effect elevates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



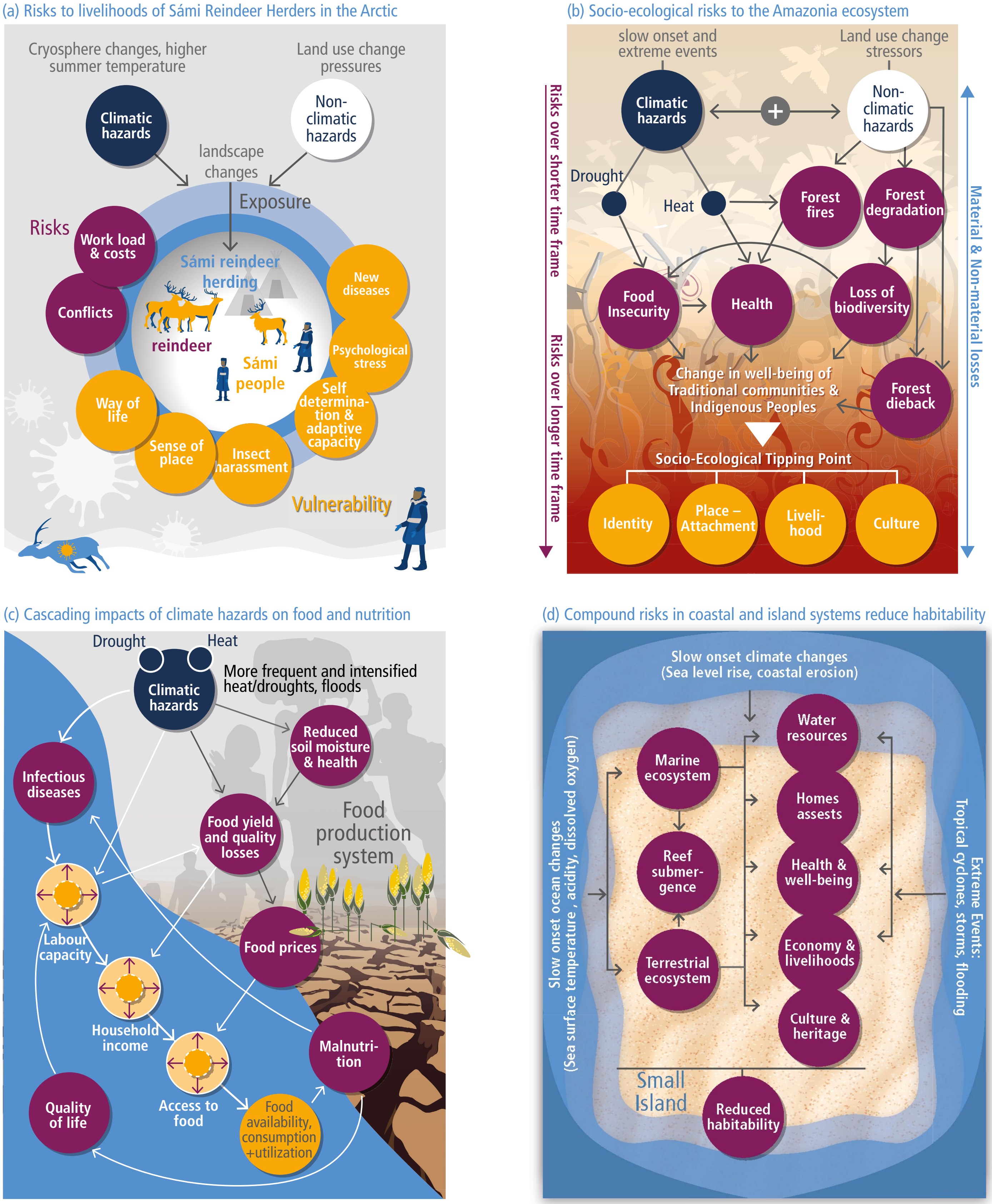
(d) Contributions of urban adaptation options to climate resilient development.

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.

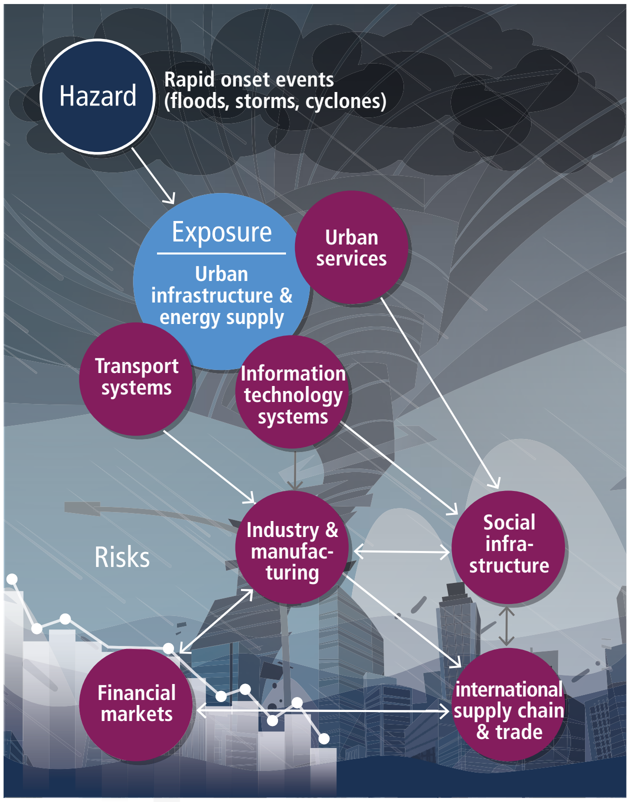


(c) The size of the circle represents the number of people at risk per IPCC region and the colours show the timing of risk based on projected population change and sea level rise under SSP2-4.5. Darker colours indicate earlier in setting risks. The left side of the circles shows absolute projected population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

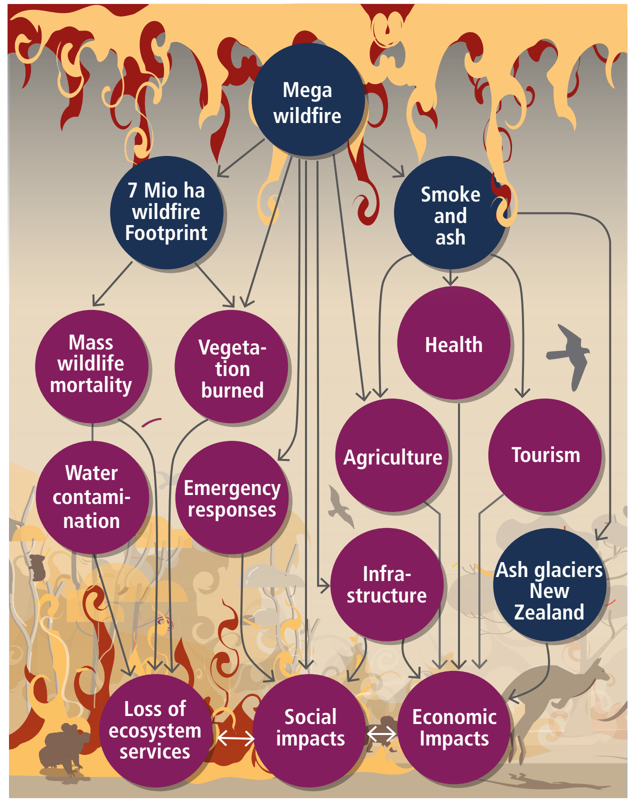
Compound, cascading and transboundary impacts for humans and ecosystems result from the complex interaction of multiple climate hazards, exposures and vulnerabilities



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



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



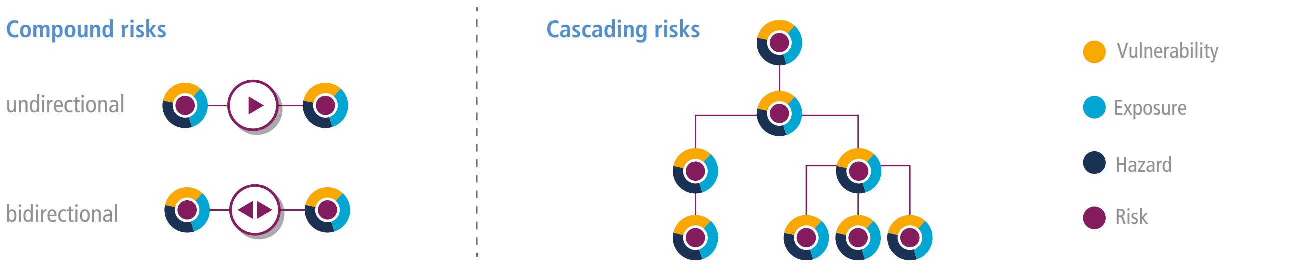


Figure TS.10 COMPLEX RISK | Compound, cascading and transboundary impacts for humans and ecosystems result from exposure to the complex interactions of (1) multiple climatic hazards, including with non-climatic stressors (as seen in panels a, b, c, d), (2) multiple vulnerabilities compounding the effect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

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

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

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

Strengthening the biosphere

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

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

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

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

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

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

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

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

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

Water and food sectors

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

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

NISHIMORI, Motoki
National Agriculture and Food Research Organization
Japan

NIXDORFF, Heather
University of Alberta
Canada

NJOGO, Samuel
Cereal Growers Association
Kenya

NNABUDE, Rosemary
University of Alberta
Canada

NNKO, Happiness
The University of Dodoma
United Republic of Tanzania

NOELLA, Dorevella
University of the South Pacific
Fiji

NOHARA, Daisuke
Kyoto University
Japan

NORMAN, Barbara
University of Canberra
Australia

NORMILE, Caroline
Bay Area Air Quality Management District
USA

NORTH, Michelle
University of KwaZulu-Natal
South Africa

NOURI, Milad
Tarbiat Modares University
Iran

NUGRAHA, Erwin
University of Twente
The Netherlands

NUNES, Ana Luisa
IUCN
UK

NUNES, Ana Raquel
University of Warwick
UK

NUNN, Chloe
Intergovernmental Oceanographic Commission
UK

NWACHUKWU, Linda
Nigerian Meteorological Agency
Nigeria

NYBOER, Elizabeth
Carleton University
Canada

NZEDIEGWU, Christopher
University of Alberta
Canada

O'DONNELL, Tayanah
Australian National University
Australia

O'HARA, Ryan
University of Arizona
USA

OBERHEITMANN, Andreas
FOM University of Applied Sciences
Germany

OBIAKOR, Chinwe Vivien
University of Alberta
Canada

OCHANDA, Valentine
Western Indian Ocean Marine Science Association
United Republic of Tanzania

OCHOA-SÁNCHEZ, Ana
University of Azuay
Ecuador

ODOULAMI, Romaric Christel
University of Cape Town
South Africa

ODUNSI, Oluwafemi
Olabisi Onabanjo University
Nigeria

OETTLÉ, Noel
Science-Policy Interface of the United Nations Convention to Combat Desertification
Germany

OGDEN, Nicholas
Public Health Agency of Canada
Canada

OGEGA, Obed Matundura
The African Academy of Sciences
Kenya

OGUNTUASE, Oluwaseun James
Lagos State University
Nigeria

OHBA, Masamichi
Central Research Institute of Electric Power Industry
Japan

OJEA, Elena
Universidade de Vigo
Spain

OKE, Muritala
National Institute for Policy and Strategic Studies
Nigeria

OKEM, Andrew
IPCC WGII TSU/ University of KwaZulu-Natal
South Africa/Nigeria

OLAGOKE, Olawande
Universidade Federal de Santa Maria
Brazil

OLANIYI, Akeem
Kaduna State University
Nigeria

OLAZABAL, Marta
Basque Centre for Climate Change
Spain

OLIVARES, Jaime
Economic Commission for Latin America and the Caribbean
Mexico

OLIVEIRA, Fabiana
Universidade Federal Fluminense
Brazil

OLIVERAS MENOR, Imma
University of Oxford
UK

OLLIVIERRE, Alison
Tombolo Maps & Design
USA

OLOYEDE, Mary
Covenant University
Nigeria

OLUSEGUN, Christiana
Centre for Atmospheric Research/ National Space Research and Development Agency
Nigeria

ONAFESO, Olumide
Olabisi Onabanjo University
Nigeria

ÖNENLI, Özge
Middle East Technical University / Engie
Turkey

ONO, Tsuneo
Japan Fisheries Research and Education Agency
Japan

ONYANGO, Esther
Griffith University
Australia

OO, Kyaw Lwin
Department of Meteorology and Hydrology
Myanmar

OPPENHEIMER, Michael
Princeton University
USA

OREJAS SACO DEL VALLE, Covadonga
Spanish Institute of Oceanography
Spain

ORLOVE, Ben
Columbia University
USA

ORMHAUG, Christin Marsh
Norwegian Directorate of Health
Norway

ORR, Barron Joseph
United Nations Convention to Combat Desertification
Germany

ORTEGA CISNEROS, Kelly
University of Cape Town
South Africa

ORTEGA, Horacio
Engineering Consultant
Ecuador

ORTEGA, Miguel
PLANACC-PNUD
Ecuador

OSELAND, Karen Marie
International Centre for Integrated Mountain Development
USA

OSTOLAZA BEYTIA, Jocelyn Patricia
COSUDE
Peru

OTTERSEN, Geir
Institute of Marine Research
Norway

OTTO, Friederike
University of Oxford
UK

OUSTADI, Karima
Independent Expert on Climate Finance
Italy

PABON-CAICEDO, Jose Daniel
National University of Colombia
Colombia

PADILLA, Danilo
Omega Proyectos/ITCC
Honduras

PADIYEDATH GOPALAN, Saritha
National Institute for Environmental Studies
Japan

PAHL-WOSTL, Claudia
University of Osnabrück
Germany

PAIXAO, Susana
Polytechnic Institute of Coimbra / Coimbra Health School
Portugal

PAKDAMAN, Morteza
Climatological Research Institute
Iran

PALMEIRO SILVA, Yasna
University College London
UK

PALUTIKOF, Jean
Griffith University
Australia

PANDA, Subhabrata
Bidhan Chandra Krishi Viswavidyalaya
India

PANDEY, Vishnu
International Water Management Institute
Nepal

PANTHOU, Geremy
Université Grenoble Alpes, Institute of Environmental Geosciences
France

PAOLINI, Leonardo
The University of Auckland
New Zealand

PAOLO, Bertoldi
European Commission
Italy

PARDO PASCUAL, Josep Eliseu
Universitat Politècnica de València
Spain

PAREJA, Marlon
De La Salle University–Dasmariñas
Philippines

PARIHAR, Anuj
Meghalaya Basin Development Authority
India

PARIKH, Jaimin
United Nations SDSN/ University of Delhi/ European Institute of Policy Research and Human Rights
India

PARK, Chul Ho
Green Technology Center
Republic of Korea

PARK, Go Eun
National Institute of Forest Science
Republic of Korea

PARK, Hun
Seoul National University
Republic of Korea

PARKER, Andrew
University of Bristol
UK

PARRA DE LA TORRE, Antonio
University of Castilla-La Mancha
Spain

PARRA, Gema
University of Jaen
Spain

PARRY, Martin
Imperial College London
UK

PARTONEN, Timo
National Institute for Health and Welfare
Finland

PASCAL, Mathilde
Santé publique France
France

PASCAL, Nahasi
KWIA
Kenya

PATHAK, Minal
IPCC WGIII TSU/ Ahmedabad University
India

PATTERSON, Kaitlin
University of Alberta
Canada

PATWARDHAN, Anand
University of Maryland
USA

PAUL, Frank
University of Zurich
Switzerland

PAYEN, Gerard
National Academy of Technology of France
France

PAYNE, Mark
Technical University of Denmark
Denmark

PEARCE-HIGGINS, James
British Trust for Ornithology
UK

PEARLMAN, Isaac
University of California, Santa Barbara
USA

PEDACE, Roque
University of Buenos Aires
Argentina

PEGRAM, Geoffrey
University of KwaZulu-Natal
South Africa

PELEJERO, Carles
ICREA/Institut de Ciències del Mar, CSIC
Spain

PENDLETON, Simon
Woods Hole Oceanographic Institution
USA

PERALVO, Manuel
CONDESAN
Ecuador

PEREZ DE MADRID, Marta
UN Environment
Costa Rica

PÉREZ-BLANCO, Carlos Dionisio
Universidad de Salamanca
Spain

PETRASEK MACDONALD, Joanna
Inuit Circumpolar Council
Canada

PETZOLD, Jan
University of Hamburg
Germany

PEZZOLI, Alessandro
DIST/ Università di Torino
Italy

PFALZ, Gregor
Alfred Wegener Institute
Germany

PFORR, Tobias
Red Cross Red Crescent Climate Centre/ Columbia University
USA

PHELPS, Leanne
University of Edinburgh/ Royal Botanic Garden Edinburgh
UK

PIACENTINI, Rubén D
CONICET/ National University of Rosario
Argentina

PICAS, Jessica
University of the Witwatersrand
South Africa

PICHAT, Sylvain
Max Planck Institute for Chemistry
Germany

PICOURT, Loreley
Ocean and Climate Platform
France

PIERACCINI, Margherita
University of Bristol
UK

PIETRAPERTOSA, Filomena
National Research Council
Italy

PIGUET, Etienne
University of Neuchâtel
Switzerland

PILECI, Rosaria Erika
Paul Scherrer Institut
Switzerland

PINTO, Izidine
University of Cape Town
South Africa

PINZON, Reinhardt
Universidad Tecnologica de Panama
Panama

PLANCHAT, Alban
Polytechnique
France

PLANE, Alice
Former Climate Coordinator at France MoFA,
USA

PLENCOVICH, María Cristina
University of Buenos Aires
Argentina

PLINKE, Charlotte
Climate Analytics
Germany

POHJOLA, Veijo
Uppsala University
Sweden

POHLE, Ina
Senate Department for the Environment, Transport and Climate Protection/ LAWA
Germany

POKAM, Wilfried
University of Yaounde
Cameroon

POKHREL, Yadu
Michigan State University
USA

POLO, Maria J.
University of Cordoba
Spain

POLOCZANSKA, Elvira S.
IPCC WGII TSU/ Alfred Wegener Institute
Germany/UK/Australia

POLONSKY, Alexander
Research Institute
Russian Federation

POPOVA, Elena
Institute of Geography of the Russian Academy of Sciences
Russian Federation

PORRINI, Donatella
Università del Salento
Italy

PORTILLA GAMBOA, Modesto
National University of Colombia
Colombia

PÖRTNER, Hans-Otto
IPCC WGII Co-Chair/ Alfred Wegener Institute
Germany

POSEY, John
East-West Gateway Council of Governments
USA

POUILLE, Sophie
Université de Montréal
Canada

POWELL, Bronwen
Penn State University
USA

PRAKASH, Anjal
Indian School of Business
India

PRASATH, R. Arun
Ministry of Earth Sciences
India

PRATER, Isabel
Technical University of Munich
Germany

PRETTY, Jules
University of Essex
UK

PREUSCHMANN, Swantje
Climate Service Center Germany
Germany

PRINGLE, Patrick
SPREP/ Griffith University
UK

PRIYANKA, Priyanka
TERI University
India

PROCTER, Andrea
Memorial University of Newfoundland
Canada

PULIDO VELÁZQUEZ, David
Instituto Geológico y Minero
Spain

QIAN, Budong
Agriculture and Agri-Food Canada
Canada

QUAGLIAROTTI, Desirée A.L.
National Research Council
Italy

QUEIROS, Ana
Plymouth Marine Laboratory
UK

QUEIROZ ALVES, Eduardo
Alfred Wegener Institute
Germany

QUENTA, Estefania
Universidad Mayor de San Andrés
Bolivia

QUIAMBAO, Krisha
University of Alberta
Canada

QUIGGIN, John
The University of Queensland
Australia

QUINN, John
Red Cross Red Crescent Climate Centre/
Columbia University
USA

RABANAL, Valentina
University of Buenos Aires
Argentina

RACAULT, Marie-Fanny
Plymouth Marine Laboratory
UK

RACZEK, Tracy
TR Climate
USA

RADUNSKY, Klaus
Retired
Austria

RAEZ-VILLANUEVA, Sergio
McMaster University
Canada

RAGAZZOLA, Federica
University of Portsmouth
UK

RAHMAN, Mohammad Mahbubur
Lancaster University
UK

RAJABHOJ, Sakshi
TERI School of Advanced Studies
India

RAJIC, Mladen
NGO Indjijativa
Serbia

RAJU, Emmanuel
University of Copenhagen
Sweden

RAMA, Bardhyl
IPCC WGII TSU/ Alfred Wegener Institute
Germany/Kosovo

RAMACHANDRAN, Arthi
Concordia University
Canada

RAMACHANDRAN, Gopichandran
NTPC School of Business
India

RAMCHANDRAN, Neeraj
Independent Researcher
India

RAMM, Timothy
University of Tasmania
Australia

RAMPRASAD, Vijay
University of Minnesota
USA

RAMSEY, Victoria
Met Office
UK

RAMSING, Rebecca
Johns Hopkins School of Public Healthe
USA

RANASINGHE, Roshanka
IHE Delft Institute for Water Education
The Netherlands

RAO, Usha
Saint Joseph's University
USA

RASHAD, Amin
Triple A Consultancy
Egypt

RASUL, Golam
International Centre for Integrated Mountain
Development
Nepal

RATEB, Samy
Egyptian Meteorological Authority
Egypt

RATSIMANDRESY, Andry William
Government Research Center
Canada

RAVINDRANATH, Nijavalli
Science-Policy Interface of the United Nations
Convention to Combat Desertification
Germany

RAWLINS, Jonathan
OneWorld Sustainable Investments
South Africa

RAY, Saon
ICRIER
India

RAZA, Tabassam
Philippine School of Business Administration, Manila
Philippines

RECKIEN, Diana
Universiteit Twente
Germany

REDDY, Uday Bhaskar
National Institute of Rural Development, Panchayati Raj
India

REGARDS, Sienna
Red Cross Red Crescent Climate Centre/ Columbia University
USA

REGUERO, Borja
University of California Santa Cruz
USA

REIFENBERG, Simon Felix
Alfred Wegener Institute
Germany

REISINGER, Andy
University of Copenhagen
New Zealand

RESCO DE DIOS, Victor
Southwest University of Science and Technology
China

REUTEN, Christian
RWDI AIR Inc.
Canada

REUTER, Thomas
University of Melbourne
Germany

REYER, Christopher
Potsdam Institute for Climate Impact Research
Germany

REYNOLDS, Jesse
University of California
The Netherlands

RIBEIRO PEREIRA NUNES, Claudia
Universidade Federal do Amazonas/ Yale University
USA

RICA, Bernardino
University Jaume I
Spain

RIEDLER, Wolfgang
University of Alberta
Canada

RIIHELÄ, Aku
Finnish Meteorological Institute
Finland

RISING, James
London School of Economics
UK

RISTIC, Ratko
Science-Policy Interface of the United Nations Convention to Combat Desertification
Germany

RISTROPH, Elizaveta Barrett
Ristroph Law, Planning, and Research
USA

RIVERA, Juan Antonio
IANIGLA – CONICET
Argentina

ROBERTS, Debra
IPCC WGII Co-Chair/ eThekwini Municipality
South Africa

ROBOCK, Alan
Rutgers University
USA

ROBSON, S. Tigona
University of the South Pacific
Fiji

ROCA, Bernardino
Hospital General Universitario de Castellón
Spain

ROCK, Joachim
Thuenen-Institute of Forest Ecosystems
Germany

ROCKLÖV, Joacim
Umeå University
Sweden

ROCKMAN, Marcy
ICOMOS
USA

RODE, Ashwin
University of Chicago
USA

RODÓ, Xavier
ISGlobal
Spain

RODOLFO, Gentili
University of Milano-Bicocca
Italy

RODRIGUES, Helena
Pontifícia Universidade Católica do Rio de Janeiro/ Climate Policy Initiative
Brazil

ROEHM, Charlotte
Western Resource Advocates
USA

ROFFE, Sarah
University of the Witwatersrand
South Africa

ROGERS, Alex David
REV Ocean
UK

ROGGERO, Matteo
Humboldt-Universität zu Berlin
Germany

ROHMER, Jeremy
BRGM
France

ROL, Chris
Insurance Bureau of Canada
Canada

ROLLIE WILLIAMS, James
Columbia University
USA

ROMAN-CUESTA, Rosa Maria
Wageningen University
Peru

ROMERO LANKAO, Patricia
National Renewable Energy Laboratory
USA

RONCOLI, Carla
Emory University
USA

ROPERT-COUDERT, Yan
CNRS/ CEBC
France

ROSALES, Jon
St. Lawrence University
USA

ROSEN, Richard
Tellus Institute (Retired)
USA

ROSENBAUM, Paul
Uppsala University
Sweden

ROSENTRETER, Judith
Yale University
USA

ROST, Björn
Alfred Wegener Institute
Germany

ROWELL, David
Met Office Hadley Centre
UK

ROY, Arindam
South Asian Forum for Environment
India

ROY, Rene
Hydro Meteo
Canada

RUANE, Alexander
NASA Goddard Institute for Space Studies
USA

RUDIGER, Christoph
Monash University
Australia

RUDRAM, Brigitte
Red Cross Red Crescent Climate Centre/
Columbia University
USA

RUFAT, Samuel
CY Cergy Paris University
France

RUGIU, Luca
University of Gothenburg
Sweden

RUIZ PEREIRA, Sebastián
Pontifical Catholic University
Chile

RUIZ-RAMOS, Margarita
Universidad Politécnica de Madrid
Spain

RUNKLE, Benjamin
University of Arkansas
USA

RUSSEL, Duncan
University of Exeter
UK

RUSTOGI, Paridhi
University of Hamburg
Germany

RYDER-BURBIDGE, Charlotte
University of Alberta
Canada

SAAD, Mohie
Applied Climate Department
Egypt

SAEDI, Kazem
Research Institute of Forests and Rangelands
, Agricultural Research, Education &
Extension Organization
Iran

SAEIJS, Harm
Dutch Association of Mental Health and
Addiction Care/ Independent Economist and
Consultant
The Netherlands

SAGAR, Aarsi
Global Green Growth Institute
Republic of Korea

SAHA, Sebak Kumar
Shahjalal University of Science and
Technology
Bangladesh

SAHAY, Samraj
Partners in Prosperity
India

SAIDALIYEVA, Zarina
University of Reading
UK

SAINZ DE MURIETA, Elisa
Basque Centre for Climate Change
Spain

SALA, Hernan Edgardo
Argentine Antarctic Institute
Argentina

SALADIN, Claire
IUCN SSC / IUCN WCEL
France

SALIERNO, Gabriel
Abo Akademi University
Finland

SALIM, Emmanuel
Université Savoie Mont Blanc
France

SALINAS-RODRÍGUEZ, Sergio
WWF/ Delft University of Technology
Mexico

SAMANIEGO, Luis
Helmholtz-Centre for Environmental
Research – UFZ
Germany

SAMANTA, Dhrubajyoti
Nanyang Technological University
Singapore

SAMPATH, Dissanayake
Universidade do Algarve
Portugal

SAMYN, Denis
International Centre for Integrated Mountain
Development
Nepal

SÁNCHEZ RENDÓN, Jorge Alberto
Institute of Ecology and Systematics, Ministry
of Science, Technology and Environment
Cuba

SANCHEZ, Maria E.
University of Saskatchewan
Canada

SANJUÁN, Miguel Angel
Technical University of Madrid
Spain

SANNI, Maruf
National Centre for Technology Management
Nigeria

SANTIAGO, José M.
Universidad Politécnica de Madrid
Spain

SANTO, Raychel
Johns Hopkins Center for a Livable Future
USA

SATOH, Yusuke
National Institute for Environmental Studies
Japan

SATTERTHWAITE, David
IIED
UK

SAUERBORN, Rainer
Heidelberg University
Germany

SAUKA, Siyasanga
C40
South Africa

SAVAGLIA, Valentina
University of Liège / Ghent University
Belgium

SAVAŞAN, Zerrin
Selcuk University
Turkey

SAVE MONSERRAT, Robert
IRTA
Spain

SCHAEFER, Laura Maria
Germanwatch
Germany

SCHALATEK, Liane
Heinrich Boell Stiftung Washington, DC
USA

SCHARFFENBERG, Martin
University of Hamburg
Germany

SCHAUWECKER, Simone
CEAZA
Chile

SCHLAEFFER, Alois
Climate and Energy Model Region Saalachtal
Austria

SCHLEUSSNER, Carl-Friedrich
Climate Analytics
Germany

SCHLOSS, Irene
CONICET/ Universidad Nacional de Tierra del Fuego
Argentina

SCHMELTZ, Michael
California State University East Bay
USA

SCHMITT OLABISI, Laura
Michigan State University
USA

SCHNEIDER, Alexandra
Helmholtz-Zentrum München
Germany

SCHNEIDER, Claudia
University of Oxford
UK

SCHNEIDER, Claudia
Red Cross Red Crescent Climate Centre/ Columbia University
USA

SCHNITZLER, Tobias
Institute for Ecological Economics
Austria

SCHOEMAN, David
University of the Sunshine Coast
Australia

SCHOLES, Robert
University of the Witwatersrand
South Africa

SCHULZ, Kai
Southern Cross University
Australia

SCHUSTER-WALLACE, Corinne
University of Saskatchewan
Canada

SCHUSTER, Christian
Federal Environment Agency
Germany

SCHWINGSHACKL, Clemens
CICERO Center for International Climate Research
Norway

SCOBIE, Michelle
The University of the West Indies
Trinidad and Tobago

SCOVRONICK, Noah
Emory University
USA

SEEBAUER, Sebastian
Joanneum Research Forschungsgesellschaft
Austria

SEGOVIA, Maria
University of Malaga
Spain

SEIDL, Rupert
Technical University of Munich
Germany

SELVEY, Linda
The University of Queensland
Australia

SENGUPTA, Aditi
California Lutheran University
USA

SERDECZNY, Oliwia
Climate Analytics
Germany

SERRAO-NEUMANN, Silvia
University of Waikato
New Zealand

SETIADI, Rukuh
Universitas Diponegoro
Indonesia

SETO, Karen
Yale University
USA

SEYED MUHAMMADREZA, Tabatabaei
University of Tehran
Iran

SHACKELL, Nancy
Bedford Institute of Oceanography/ Fisheries and Oceans Canada
Canada

SHAH, Ankita
Youth Innovation Lab
Nepal

SHAH, Mohammad Aminur Rahman
University of Glasgow
UK

SHAHZAD, Naeem
National University of Sciences and Technology
Pakistan

SHAKIL, Sarah
University of Alberta
Canada

SHAMMIN, Md
Oberlin College
USA

SHARIFI, Ayyoob
Hiroshima University
Japan

SHARMA, Bharat Raj
International Water Management Institute
India

SHARMA, Kirti
Jawaharlal Nehru University
India

SHARMA, Sanchi
Red Cross Red Crescent Climate Centre/ Columbia University
USA

SHARMA, Vishal
National Renewable Energy Laboratory
USA

SHEEHAN, Timothy
Conservation Biology Institute/ Oregon State University
USA

SHEPHERD, John
University of Southampton
UK

SHERPA, Sonam
Virginia Polytechnic Institute/ State University
USA

SHI, Haiyun
Southern University of Science and Technology
China

SHI, Zhiyuan
Nord University
China

SHIM, Kyo-Moon
National Institute of Agricultural Sciences
Republic of Korea

SHIRATO, Yasuhito
National Agriculture and Food Research Organization
Japan

SHRIDHARAN, Rishi
University of California, Davis
USA

SHYUR, Yomay
Keith Group/ Harvard University
USA

SIDHU, Balsher Singh
The University of British Columbia
Canada

SIEG, Tobias
University of Potsdam
Germany

SIERPE GONZÁLEZ, Camilo
University of Concepción
Chile

SIETZ, Diana
Potsdam Institute for Climate Impact Research
Germany

SIIRA, Olli-Pekka
University of Helsinki
Finland

SILLMANN, Jana
CICERO Center for International Climate Research
Norway

SIMON, David
Royal Holloway University of London
UK

SIMON, Mcgree
Bureau of Meteorology
Australia

SIMONSSON, Helen
The Swedish National Heritage Board
Sweden

SIMPKIN, Piers
Self-employed
Kenya

SINGER, Katrin
University of Hamburg
Germany

SINGH-PETERSON, Lila
The University of Queensland
Australia

SINGH, Bhawan
Retired-University of Montreal
Canada

SINGH, Minerva
Imperial College London
UK

SINGH, Pramod
Institute of Rural Management Anand
India

SINGH, Ranjay K
ICAR-Central Soil Salinity Research Institute
India

SINGHA, Sutandra
Jawaharlal Nehru University
India

SINGLEY, Joel
University of Colorado Boulder
USA

SIONE, Folau
University of the South Pacific
Fiji

SIVARAJAH, Branaavan
Queen's University
Canada

SJOGERSTEN, Sofie
University of Nottingham
UK

SJÖSTRÖM, Åsa
Swedish Meteorological and Hydrological Institute
Sweden

SKEA, Jim
IPCC WG III Co-Chair/ Centre for Environmental Policy
UK

SKERN-MAURITZEN, Mette
Institute of Marine Research
Norway

SMITH, Adam
NOAA/ NCEI
USA

SMITH, Donald
McGill University
Canada

SMITH, Inga
University of Otago
New Zealand

SMITH, Jennifer
Institute for Marine and Antarctic Studies
Australia

SMITH, Joel
Abt Associates
USA

SMITH, Madison
University of Washington
USA

SMITH, Sharon
Geological Survey of Canada, Natural Resources Canada
Canada/Chad

SMITH, Ward
Agriculture and Agri-Food Canada
Canada

SMITHERS, Scott
James Cook University
Australia

SMUCKER, Thomas
Ohio University
USA

SOLERA UREÑA, Miriam
UNED
Germany

SOMANJE, Albert Novas
Ministry of Agriculture
Zambia

SOME, Shreya
Ahmedabad University/ Jadavpur University
India

SONG, Chunlin
Sichuan University
China

SONG, Su
Young Crane Consulting
China

SONG, Young-Il
Korea Environment Institute
Republic of Korea

SÖRENSSON, Anna
Centro de Investigaciones del Mar y la Atmósfera
Argentina

SORIANO-QUEVEDO, Angela
Independent Consultant
Peru

SOTERES, Rodrigo Léon
Pontificia Universidad Católica de Chile
Chile

SOUSA, Arturo
Universidad de Sevilla
Spain

SPAGNOLO, Matteo
University of Aberdeen
UK

SPAGNUOLO, Francesca
Scuola Superiore Sant'Anna
Italy

SPENCER, Thomas
Cambridge University
UK

SPIERENBURG, Marja
Radboud University
The Netherlands

SPIRES, Meggan
ICLEI Africa
South Africa

SPRINGMANN, Marco
University of Oxford
UK

SRINIVASAN, Govindarajalu
Regional Integrated Multihazard Earlywarning System for Africa and Asia
Thailand

ST-PIERRE, Yves
INRS-Institut Armand-Frappier
Canada

STEFANER, Moritz
Truth & Beauty
Germany

STEINER, Jakob
Utrecht University
The Netherlands/Nepal

STEINER, Nadja
Fisheries and Oceans Canada
Canada

STEINHAUSER, Jan
University of Hamburg
Germany

STENMARK, Aurora
Norwegian Environment Agency
Norway

STETKIEWICZ, Maciej
Yukon College
Canada

STEVENS, Madison
The University of British Columbia
Canada

STEVENS, Nicola
University of Oxford
UK

STEVENSON, Linda Anne
Asia-Pacific Network for Global Change Research
Japan

STEWART-HARAWIRA, Makere
University of Alberta
Canada

STEWART, Mary
Energetics
Australia

STOLLE, Jacob
Institut National de la Recherche
Canada

STORBJÖRK, Sofie
Centre for Climate Science and Policy Research
Sweden

STRACHAN, Kate
ICLEI Africa
South Africa

STROOMBERGEN, Adolf
Economics Consultancy Company
New Zealand

STRYDOM, Sheldon
University of KwaZulu-Natal
South Africa

STUART-LEE, Alice
Royal Netherlands Institute for Sea Research
The Netherlands

SU, Bo
Beijing Normal University
China

SUBRAMANIAM, Roshni
Sydney Institute of Marine Science
Australia

SUGDEN, Scott
University of Alberta
Canada

SUGGITT, Andrew
Northumbria University
UK

SUGIURA, Toshihiko
National Agriculture and Food Research Organization
Japan

SUGIYAMA, Satoka
TDK Safety & Environment Group
Japan

SULTAN, Benjamin
IRD
France

SUN, Lu
National Institute for Environmental Studies
Japan

SUNDARAM, Suchithra
Independent Researcher
India

SUNEJA, Vanita
WaterAid
India

SURESH, Lavanya
Birla Institute of Technology & Science, Pilani
India

SUTHERLAND, Michael
The University of the West Indies
Trinidad and Tobago

SWAIN, Sabyasachi
Indian Institute of Technology Roorkee
India

SWEENEY, John
Maynooth University
Ireland

SZOLGAY, Jan
Slovak University of Technology in Bratislava
Slovakia

SZOPA, Sophie
LSCE
France

TACONET, Nicolas
ENPC
France

TADESSE, Tsegaye
University of Nebraska-Lincoln
USA

TAGLIARI, Mário
Universidade Federal de Santa Catarina
Brazil

TAJBAKHSH, Kian
Columbia University
USA

TAKAGI, Hiroshi
Tokyo Institute of Technology
Japan

TAKAHASHI, Kiyoshi
National Institute for Environmental Studies
Japan

TAKAKURA, Jun'Ya
National Institute for Environmental Studies
Japan

TAKANO, Kohei
Nagano Environmental Conservation Research Institute
Japan

TAKAYABU, Izuru
Meteorological Research Institute/ JMA
Japan

TAMALAVAGE, Anne
Texas A&M University
USA

TAMURA, Makoto
Ibaraki University
Japan

TANAKA, Tetsuji
Setsunan University
Japan

TANGORA-SCHLACHTER, Christina
Oregon State University
USA

TANIGUCHI, Makoto
Research Institute for Humanity and Nature
Japan

TAO, Fulu
CAS
China

TAPIA BALDIS, Carla
CONICET
Argentina

TARIN, Tonantzin
University of Delaware
USA

TAYLOR, Richard
University College London
UK

TEMMERMAN, Stijn
University of Antwerp
Belgium

TEMPLEMAN, Sienna
Red Cross Red Crescent Climate Centre/ Columbia University
USA

TENVEEN, Rianne
Green Creation
The Netherlands

TENZING, Janna
London School of Economics
UK

TERÄMÄ, Emma
Finnish Environment Institute
Finland

TERRY, James
Zayed University
United Arab Emirates

TETZNER, Dieter
British Antarctic Survey
UK

THAJUDEEN, Jabir
National Center for Polar and Ocean Research
India

THALER, Thomas
University of Natural Resouces and Life Sciences
Austria

THALHEIMER, Lisa
Oxford University
Germany

THAMPANISHVONG, Kannika
Thailand Development Research Institute
Thailand

THANDLAM, Venugopal
Uppsala University
Sweden

THAPA, Bhuwan
University of Missouri Columbia
USA

THEOKRITOFF, Emily
Climate Analytics/ Humboldt-Universität zu Berlin
Germany

THIELEN, Dirk
IVIC
Venezuela

THIESSEN, Ryan
University of Alberta
Canada

THOMAS, Adelle
University of The Bahamas
Bahamas

THOMAS, Thaler
University of Natural Resources and Life Sciences
Austria

THOMSON, Ian
University of Birmingham
UK

THONI, Terese
Helmholtz-Centre for Environmental Research – UFZ/ Lund University
Germany

THONICKE, Kirsten
Potsdam Institute for Climate Impact Research
Germany

THORNTON, James
Université de Neuchâtel / Mountain Research Initiative
Switzerland

TIBIG, Lourdes
Climate Change Commission
Philippines

TIDWELL, Vincent
Sandia National Laboratories
USA

TIGNOR, Melinda
IPCC WGII TSU/ Alfred Wegener Institute
Germany/USA

TILMES, Simone
National Center for Atmospheric Research
USA

TIMMERS, Jean-François
WWF
Brazil

TINDALL, David
The University of British Columbia
Canada

TINNER, Willy
University of Bern/ OCCR
Switzerland

TIRADO, Maria
Loyola Marymount University
USA

TIWARI, Achyut
Tribhuvan University
Nepal

TOIVONEN, Johanna
University of Turku
Finland

TOLASZ, Radim
Czech Hydrometeorological Institute
Czech Republic

TÖLLE, Merja
CESR University of Kassel
Germany

TONGWANE, Mphethe
Agricultural Research Council
South Africa

TOROK, Simon
Scientell
Australia

TORQUEBIAU, Emmanuel
CIRAD
France

TORRES, Pedro Henrique
University of California Santa Barbara/ São Paulo University
USA

TOUZARD, Jean-Marc
INRA
France

TRACEY, Dianne
National Institute of Water and Atmospheric Research
New Zealand

TRAN, Minh
Stockholm Environment Institute
Thailand

TREBILCO, Rowan
CSIRO
Australia

TREGUIER, Anne Marie
CNRS
France

TREWIN, Blair
Bureau of Meteorology
Australia

TSAO, Jung-Hsuan
National Taiwan University
China

TSCHAKERT, Petra
The University of Western Australia
Australia

TSUTSUI, Junichi
Central Research Institute of Electric Power Industry
Japan

TULKENS, Philippe
European Union – DG Research
Belgium

TURLEY, Carol
Plymouth Marine Laboratory
UK

TURNER, Beth
Université du Québèc à Montréal
Canada

TURTON, Stephen
Central Queensland University
Australia

TUUHOLOAKI, Moleni
University of the South Pacific
Tonga

UCHIYAMA, Christmas
Kobe University/ Asia-Pacific Network for Global Change Research
Japan

ULIBARRI, Nicola
University of California Irvine
USA

UNA, Baro
University of the South Pacific
Fiji

UNDORF, Sabine
Stockholm University
Sweden

UNNIKRISHNAN, Seema
National Institute of Industrial Engineering
India

URIBE-HERNÁNDEZ, Raúl
Instituto Mexicano del Petróleo
Mexico

URYUPOVA, Ekaterina
Reserch Institute for Fishery and Oceanography
Russian Federation

VALBUENA, Ruben
Bangor University
UK

VALDOVINOS, Claudio
University of Concepción
Chile

VAN 'T WOUT, Tamara
Food and Agriculture Organization of the United Nations
Qatar

VAN DER VELDE, Marijn
European Commission, JRC
Italy

VAN GARDEREN, Linda
Helmholtz-Zentrum Geesthacht
Germany

VAN KLAVEREN, Nikki
University of Alberta
Canada

VAN MAANEN, Nicole
Climate Analytics
Germany

VAN MOORSEL, Sofia
University of Zurich
Switzerland

VAN RUIJVEN, Bas
IIASA
Austria

VAN SOEST, Maud
Loughborough University
UK

VAN VALKENGOED, Anne
University of Groningen
The Netherlands

VAN WYK DE VRIES, Maximillian
University of Minnesota
USA

VAN YPERSELE, Jean-Pascal
Université Catholique de Louvain
Belgium

VANCE, Gabrielle
Mountain Research Initiative
Switzerland

VARGO, Lauren
Victoria University of Wellington
New Zealand

VARQUEZ, Alvin Christopher
Tokyo Institute of Technology
Japan

VASQUEZ-ARROYO, Eveline
COPPE_UFRJ
Brazil

VAUTARD, Robert
IPSL, CNRS
France

VERHAGEN, Willem
University of Denver
USA

VIANA, Thiago
Universidade do Estado do Rio de Janeiro
Brazil

VICEDO CABRERA, Ana Maria
University of Bern
Switzerland

VICENTE-SERRANO, Sergio
Science-Policy Interface of the United Nations Convention to Combat Desertification
Germany

VIDAL-GONZÁLEZ, Pablo
Catholic University of Valencia
Spain

VIDAL, Florian
University of Paris
France

VIDAL, Jean-Philippe
INRAE
France

VIEIRA DE SOUSA, Natanael
CPTEC/INPE
Brazil

VIGO, Ilaria
Barcelona Supercomputing Center
Spain

VIGUIE, Vincent
Ecole des Ponts ParisTech
France

VIJAYANATHAN, Jeyanny
Forest Research Institute Malaysia
Malaysia

VILLARROEL, Cristian Daniel
National Council for Scientific and Technical Research
Argentina

VILLATE DAZA, Diego Andres
Armada Nacional
Colombia

VISIONI, Daniele
Cornell University
USA

VIVERO-POL, Jose Luis
UN World Food Programme
Ireland

VIVIROLI, Daniel
University of Zurich
Switzerland

VON MALTITZ, Graham Paul
United Nations Convention to Combat Desertification/ University of Stellenbosch
South Africa

VON OELREICH, Jacob
Swedish Meteorological and Hydrological Institute
Sweden

VON UEXKULL, Nina
Stockholm University
Sweden

VUKOVIĆ, Ana
Science-Policy Interface of the United Nations Convention to Combat Desertification
Germany

VULLIERME, Magali
Université Trent
Canada

VURAL, Deniz
University of Potsdam
Germany

WABNITZ, Colette
Stanford University;The University of British Columbia
Canada

WADE, Andrew
University of Reading
UK

WAHA, Katharina
CSIRO
Australia

WAHL, Martin
GEOMAR Helmholtz Centre for Ocean Research Kiel
Germany

WALKER, Catherine
Woods Hole Oceanographic Institution
USA

WALLIMANN-HELMER, Ivo
Universität Freiburg
Switzerland

WALTER, Andreas
German Meteorological Service
Germany

WANG, Pengling
China Meteorological Administration
China

WANG, Xander
University of Prince Edward Island
Canada

WANG, Xiaoming
Chinese Academy of Science
Australia

WARD, Robert
London School of Economics and Political Science
UK

WARNER, Koko
UNFCCC
Germany

WATSON, Charlene
ODI
Switzerland

WATSON, Peter
Bristol University
UK

WEBB, Ryan
University of New Mexico
USA

WEBER, Eberhard
University of the South Pacific
Fiji

WEBER, Theodore
Defenders of Wildlife
USA

WEBER, Torsten
Climate Service Center Germany, Helmholtz-Zentrum Geesthacht
Germany

WEEN, Rebekka Eriksen
The Arctic University of Norway
Norway

WEHRLI, Andre
Swiss Government
Kazakstan

WEI, Taoyuan
CICERO Center for International Climate Research
Norway

WEICHSELGARTNER, Juergen
HWR Berlin, Department of Police and Security Management
Germany

WEIR, Tony
Australian National University
Australia

WEISSENBERGER, Sebastian
Université Téluq
Canada

WEISSER, Britta
University of Stuttgart
Germany

WEN, Jiabi
University of Alberta
Canada

WEN, Philippe
French Ministry for Economy, Finance and Recovery
France

WERNERS, Saskia
UNU-EHS
The Netherlands

WESTENGEN, Ola
Norwegian University of Life Science
Norway

WESTER, Philippus
International Centre for Integrated Mountain Development
Nepal

WEYHENMEYER, Gesa
Uppsala University
Sweden

WHEATER, Howard
University of Saskatchewan/ Imperial College London
UK

WHITE, Iain
University of Waikato
New Zealand

WHITTAKER, Steve
Holistic Education Research & Conservation
Saint Kitts and Nevis

WIGLEY, Benjamin
Sapienza University of Rome/ Nelson Mandela University
South Africa

WIJENAYAKE, Vositha
SLYCAN Trust
Sri Lanka

WILLIAMS, David Samuel
Sabancı University
Turkey

WILSON, Lynn
SeaTrust Institute
USA

WINTER, Gerd
University of Bremen
Germany

WISE, Russell
CSIRO
Australia

WITHANACHCHI, Sisira
University of Kassel
Germany

WOINARSKI, John
Charles Darwin University
Australia

WONG, Liwah
MCC/ EIT
Germany

WONG, Poh Poh
University of Adelaide
Singapore

WOOD, Bryn
NunatuKavut Community Council
Canada

WOOD, Nick
Energetics
Australia

WOODWORTH-JEFCOATS, Phoebe
NOAA Fisheries Pacific Islands Fisheries Science Center
USA

WORKU, Gebrekidan
Addis Ababa University
Ethiopia

WORONIECKI, Stephen
Linköping University
Sweden

WRATT, David
National Institute of Water and Atmospheric Research
New Zealand

WU, Jianguo
Chinese Research Academy of Environmental Sciences
China

WU, Mousong
Nanjing University
China

WUITE, Jan
ENVEO
Austria

XIA, Lili
Rutgers University
USA

XIE, Liyong
Sheyang Agricultural University
China

XU, Yinlong
Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences
China

YAMAGUCHI, Mitsutsune
Research Institute of Innovative Technology for the Earth
Japan

YAMAMOTO, Shelby
University of Alberta
Canada

YANDA, Pius
University of Dar es Salaam
Kenya

YANEZ, Eleuterio
PUCV
Chile

YANG, Chien-Cheng
Buddhist Tzu Chi Foundation
USA

YANG, Hong
Swiss Federal Institute of Aquatic Science and Technology
Switzerland

YASJUKEVICH, Victor
Yu. A. Izrael Institute of Global Climate and Ecology
Russian Federation

YOHE, Gary
Wesleyan Univesity Emeritus
USA

YOKOHATA, Tokuta
National Institute for Environmental Studies
Japan

YONETANI, Michelle
UNHCR
France

YOON, Seung-Tae
Korea Polar Research Institute
Republic of Korea

YOUNG, Erik
Simon Fraser University
Canada

YOUNG, Helen
Tufts University
UK

YOUNG, Sera
Northwestern University
USA

YULE, Catherine
University of the Sunshine Coast
Australia

YULIZAR, Yulizar
Universitas Pertamina
Indonesia

YUMAGULOVA, Lilia
SFU/UBC
Canada

ZAELKE, Durwood
Institute for Governance & Sustainable Development
USA

ZAJAC, Joseph
Retired
USA

ZANNONI, Nora
Max Planck Institute for Chemistry
Germany

ZANUSO, Vittoria
Mayors Migration Council
USA

ZARGARLELLAHI, Hanieh
Geological Survey of Iran
Iran

ZEKOLLARI, Harry
TU Delft
Belgium

ZENG, Zhenzhong
Southern University of Science and Technology
China

ZETTER, Scarlett
Arctic University of Norway, Tromsø
Norway

ZEYAEYAN, Sadegh
I.R. of Iran Meteorological Organization
Iran

ZHANG, Chengyi
China Meteorological Administration
China

ZHANG, Fan
Chinese Academy of Sciences
China

ZHANG, Wenlan
Imperial College London
China

ZHANG, Wenxin
Lund University
Sweden

ZHENG, Ruyi
University of Kansas
USA

ZHENG, Yiyu
University of Hamburg
Germany

ZHUO, Zhihong
University of Oslo
Norway

ZIMMER, Anne
Climate Analytics
Germany

ZIMNY-SCHMITT, Daniel
National Renewable Energy Laboratory
USA

ZINKANN, Ann-Christine
NOAA
USA

ZIVIAN, Anna
Ocean Conservancy
USA

ZOLKOS, Scott
Woods Hole Research Center
USA

ZOMMERS, Zinta
United Nations Office for Disaster Risk Reduction
Germany

ZULETA, Gustavo
Maimonides University
Argentina

Index

Index

This index should be cited as:

IPCC, 2022: Index. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3005–3056, doi:10.1017/9781009325844.033.

Note: * indicates the term also appears in the Glossary (Annex II). Bold page numbers indicate page spans for entire chapters. Italicized page numbers denote tables, figures and boxed material.

A

Index

Index

B

C

Index

Index

Index

E

H

I

J

K

L

M

Index

Index

O

R

S

Index

T

Index

U

V

W

Y

Z