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Climate Change 2022: Impacts, Adaptation and Vulnerability

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

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Contents

Front Matter

Foreword	vii
Preface	ix
Dedication	xi

SPM

Summary for Policymakers	3
--------------------------------	---

TS

Technical Summary	37
-------------------------	----

Chapters and Cross-Chapter Papers

Point of Departure and Key Concepts	121
Chapter 1 Terrestrial and Freshwater Ecosystems and Their Services	197
Chapter 2 Oceans and Coastal Ecosystems and Their Services	379
Chapter 3 Water	551
Chapter 4 Food, Fibre and Other Ecosystem Products	713
Chapter 5 Cities, Settlements and Key Infrastructure	907
Chapter 6 Health, Wellbeing and the Changing Structure of Communities	1041
Chapter 7 Poverty, Livelihoods and Sustainable Development	1171
Chapter 8 Africa	1285
Chapter 9 Asia	1457
Chapter 10 Australasia	1581
Chapter 11 Central and South America	1689
Chapter 12 Europe	1817
Chapter 13 North America	1929
Chapter 14 Small Islands	2043
Chapter 15 Biodiversity Hotspots	2123
Cross-Chapter Paper 1 Cities and Settlements by the Sea	2163
Cross-Chapter Paper 2 Deserts, Semiarid Areas and Desertification	2195
Cross-Chapter Paper 3 Mediterranean Region	2233
Cross-Chapter Paper 4 Mountains	2273

Cross-Chapter Paper 5	Polar Regions	2319
Cross-Chapter Paper 6	Tropical Forests	2369
Chapter 16	Key Risks across Sectors and Regions	2411
Chapter 17	Decision-Making Options for Managing Risk	2539
Chapter 18	Climate Resilient Development Pathways	2655

Annexes

Annex I	Global to Regional Atlas	2811
Annex II	Glossary	2897
Annex III	Acronyms	2931
Annex IV	Contributors to the Working Group II Contribution to the IPCC Sixth Assessment Report	2939
Annex V	Expert Reviewers of the Working Group II Contribution to the IPCC Sixth Assessment Report	2965

Index

Index	3005
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Foreword, Preface and Dedication

Foreword

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

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

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

This Working Group II assessment was made possible thanks to the commitment and dedication of many hundreds of experts worldwide,

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

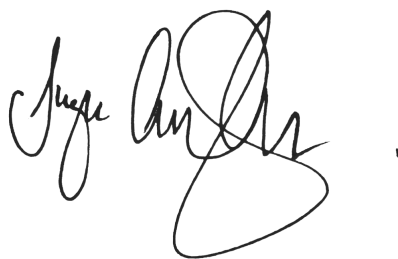
We are also grateful to the governments that supported their scientists' participation in developing this report and that contributed to the IPCC Trust Fund to provide for the essential participation of experts from developing countries and countries with economies in transition. We would like to express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

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

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



Petteri Taalas
Secretary-General
World Meteorological Organization



Inger Andersen
Executive Director
United Nations Environment Programme

Preface

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

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

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

Scope of the Report

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

Structure of the Report

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

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

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

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

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

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

The Process

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

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

Acknowledgements

We express our deepest appreciation for the expertise and commitment shown by the Coordinating Lead Authors and Lead Authors throughout the process. They were ably helped by the many Contributing Authors who supported the drafting of 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. Zafari. 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.

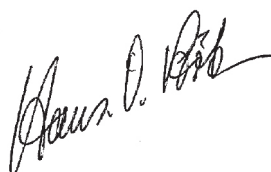
The staff of the IPCC Secretariat based in Geneva provided a wide range of support for which we would like to thank Abdallah Mokssit, Secretary of the IPCC, Deputy Secretaries, Ermira Fida and Kerstin Stendahl, and their colleagues Jesbin Baidya, Laura Biagioni, Annie Courtin, Oksana Ekzarkho, Judith 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, Tijana 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.



Hans-Otto Pörtner
IPCC Working Group II Co-Chair



Debra C. Roberts
IPCC Working Group II Co-Chair

Dedication



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

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

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

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

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

Hamba kahle Bob.



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

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

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

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

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

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

Summary for Policymakers

Summary for Policymakers

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Table of Contents

A: Introduction	5
Box SPM.1 AR6 Common Climate Dimensions, Global Warming Levels and Reference Periods	7
B: Observed and Projected Impacts and Risks	8
Observed Impacts from Climate Change	9
Vulnerability and Exposure of Ecosystems and People	12
Risks in the near term (2021–2040)	13
Mid to Long-term Risks (2041–2100)	14
Complex, Compound and Cascading Risks	18
Impacts of Temporary Overshoot	19
C: Adaptation Measures and Enabling Conditions	20
Current Adaptation and its Benefits	20
Future Adaptation Options and their Feasibility	21
Limits to Adaptation	26
Avoiding Maladaptation	27
Enabling Conditions	27
D: Climate Resilient Development	28
Conditions for Climate Resilient Development	29
Enabling Climate Resilient Development	29
Climate Resilient Development for Natural and Human Systems	31
Achieving Climate Resilient Development	33

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 IPCC¹. The report builds on the WGII contribution to the Fifth Assessment Report (AR5) of the IPCC, three Special Reports², and the Working Group I (WGI) contribution to the AR6 cycle.

This report recognizes the interdependence of climate, ecosystems and biodiversity³, 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 language⁴. 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 risks⁹. {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.

Adaptation¹⁰ 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.

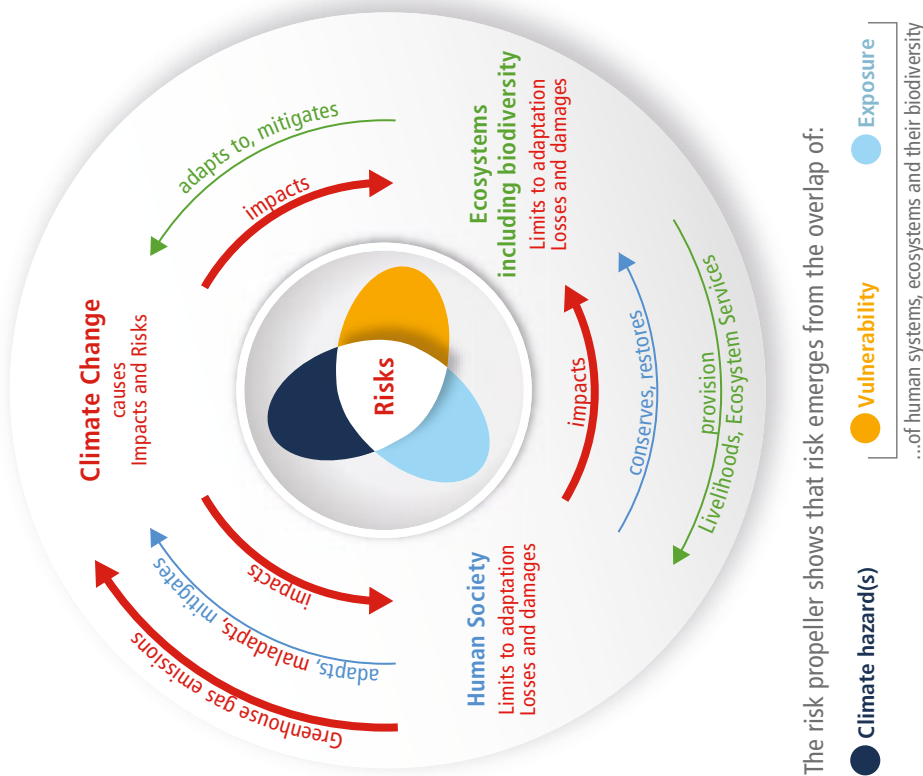
8 Vulnerability in this report is defined as the propensity or predisposition to be adversely affected and encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

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.

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

(a) Main interactions and trends



The risk propeller shows that risk emerges from the overlap of:



(b) Options to reduce climate risks and establish resilience

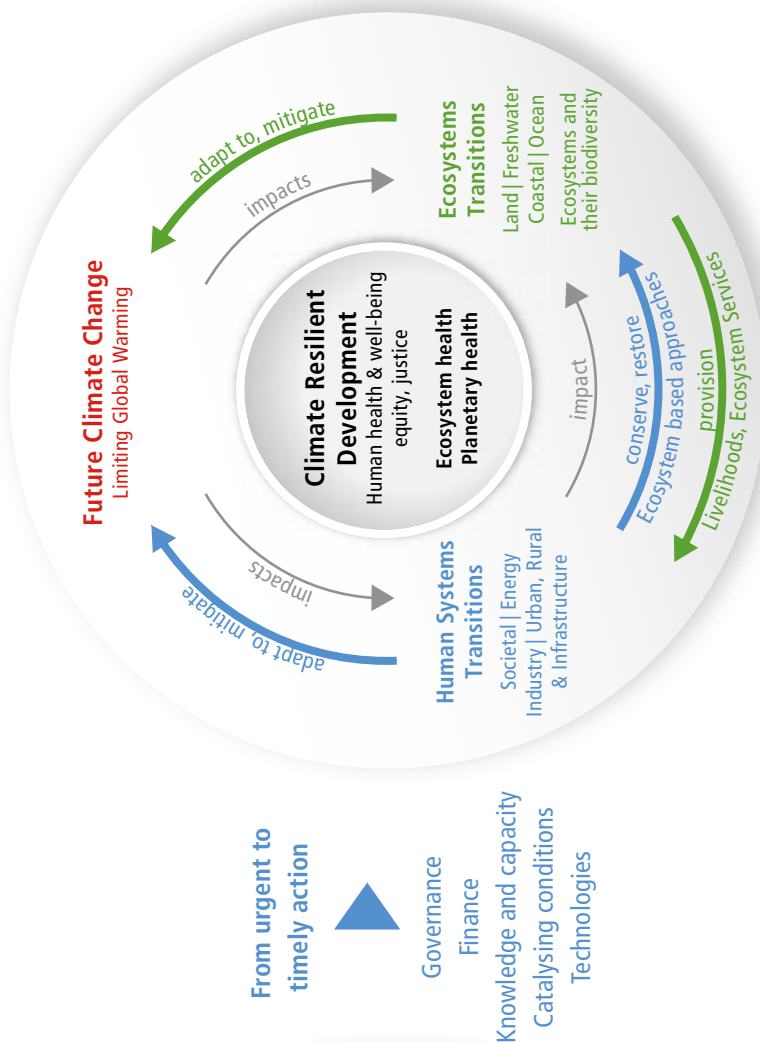


Figure SPM.1 | This report has a strong focus on the interactions among the coupled systems climate, ecosystems (including their biodiversity) and human society. These interactions are the basis of emerging risks from climate change, ecosystem degradation and biodiversity loss and, at the same time, 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 limits¹¹.

Resilience¹² 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, feasible¹³, and conform to principles of justice¹⁴. 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 maladaptation¹⁵.

This report has a particular focus on transformation¹⁶ 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 health¹⁷, and planetary health¹⁸ (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 adaptation¹¹. The report also assesses economic and non-economic losses and damages¹⁹. This report labels the process of implementing mitigation and adaptation together in support of sustainable development for all as climate resilient development²⁰.

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, respectively²³. 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 SSPs²². 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 scenario²⁶. {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 decades²⁷. 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 attributed²⁸ 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 damages¹⁹, have increased due to sea level rise and the increase in heavy precipitation (*medium confidence*). Impacts in natural and human systems from slow-onset processes²⁹ 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 insecurity³⁰ 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}

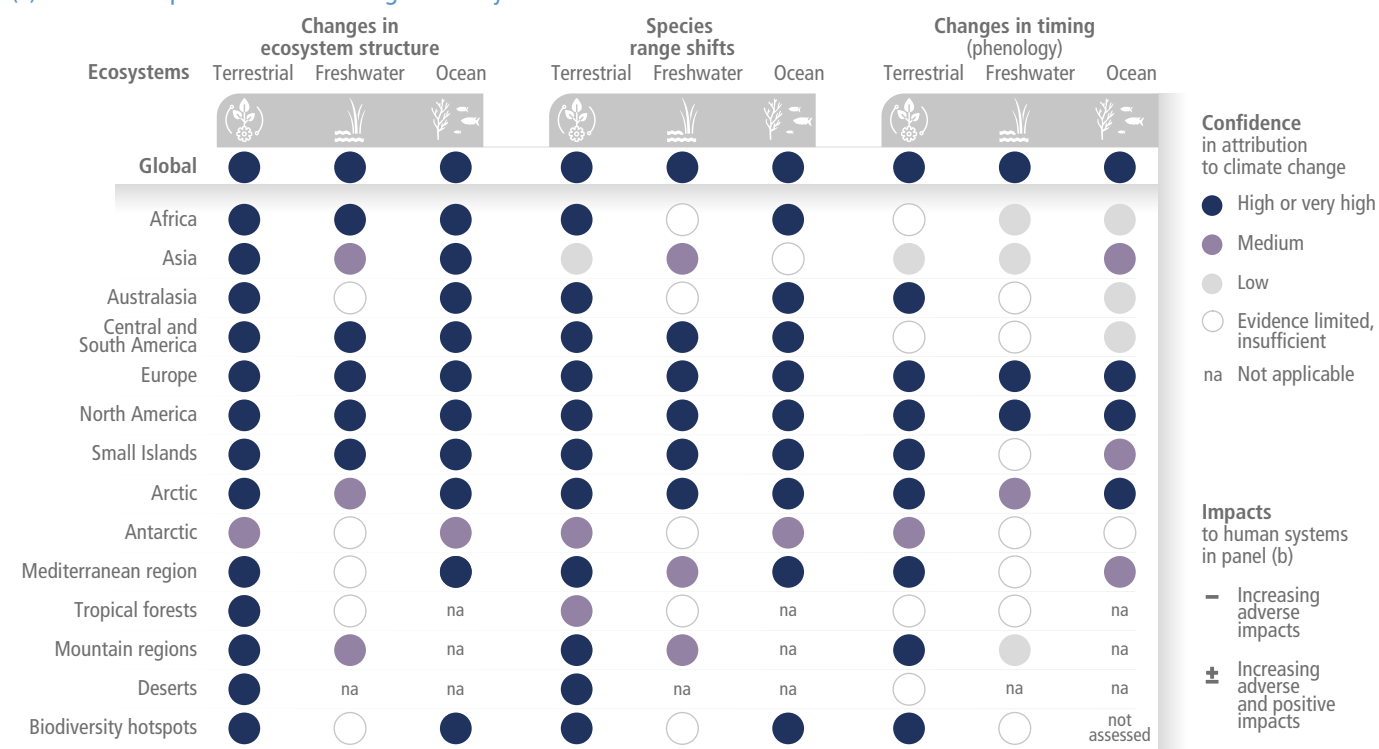
28 Attribution is defined as the process of evaluating the relative contributions of multiple causal factors to a change or event with an assessment of confidence. [Annex II Glossary, CWGB ATTRIB]

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.

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

(a) Observed impacts of climate change on ecosystems



(b) Observed impacts of climate change on human systems

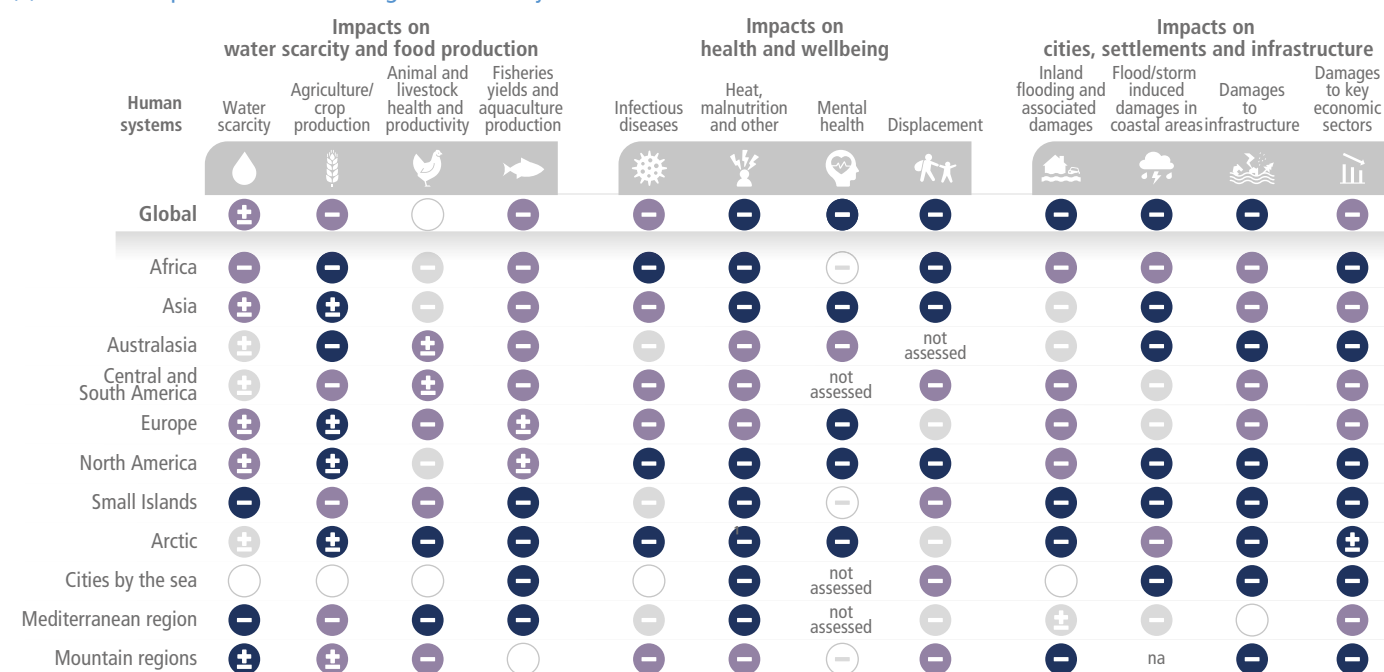


Figure SPM.2 | Observed global and regional impacts on ecosystems and human systems attributed to climate change. Confidence levels reflect uncertainty in attribution of the observed impact to climate change. Global assessments focus on large studies, multi-species, meta-analyses and large reviews. For that reason they can be assessed with higher confidence than regional studies, which may often rely on smaller studies that have more limited data. Regional assessments consider evidence on impacts across an entire region and do not focus on any country in particular.

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

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

- B.1.4** Climate change has adversely affected physical health of people globally (*very high confidence*) and mental health of people in the assessed regions (*very high confidence*). Climate change impacts on health are mediated through natural and human systems, including economic and social conditions and disruptions (*high confidence*). In all regions extreme heat events have resulted in human mortality and morbidity (*very high confidence*). The occurrence of climate-related food-borne and water-borne diseases has increased (*very high confidence*). The incidence of vector-borne diseases has increased from range expansion and/or increased reproduction of disease vectors (*high confidence*). Animal and human diseases, including zoonoses, are emerging in new areas (*high confidence*). Water and food-borne disease risks have increased regionally from climate-sensitive aquatic pathogens, including *Vibrio* spp. (*high confidence*), and from toxic substances from harmful freshwater cyanobacteria (*medium confidence*). Although diarrheal diseases have decreased globally, higher temperatures, increased rain and flooding have increased the occurrence of diarrheal diseases, including cholera (*very high confidence*) and other gastrointestinal infections (*high confidence*). In assessed regions, some mental health challenges are associated with increasing temperatures (*high confidence*), trauma from weather and climate extreme events (*very high confidence*), and loss of livelihoods and culture (*high confidence*). Increased exposure to wildfire smoke, atmospheric dust, and aeroallergens have been associated with climate-sensitive cardiovascular and respiratory distress (*high confidence*). Health services have been disrupted by extreme events such as floods (*high confidence*). {4.3, 5.12, 7.2, Box 7.3, 8.2, 8.3, Box 8.6, Figure 8.10, 9.10, Figure 9.33, Figure 9.34, 10.4, 11.3, 12.3, 13.7, 14.4, 14.5, Figure 14.8, 15.3, 16.2, CCP5.2, Table CCP5.1, CCP6.2, Figure CCP6.3, Table CCB ILLNESS.1}
- B.1.5** In urban settings, observed climate change has caused impacts on human health, livelihoods and key infrastructure (*high confidence*). Multiple climate and non-climate hazards impact cities, settlements and infrastructure and sometimes coincide, magnifying damage (*high confidence*). Hot extremes including heatwaves have intensified in cities (*high confidence*), where they have also aggravated air pollution events (*medium confidence*) and limited functioning of key infrastructure (*high confidence*). Observed impacts are concentrated amongst the economically and socially marginalized urban residents, e.g., in informal settlements (*high confidence*). Infrastructure, including transportation, water, sanitation and energy systems have been compromised by extreme and slow-onset events, with resulting economic losses, disruptions of services and impacts to well-being (*high confidence*). {4.3, 6.2, 7.1, 7.2, 9.9, 10.4, 11.3, 12.3, 13.6, 14.5, 15.3, CCP2.2, CCP4.2, CCP5.2}
- B.1.6** Overall adverse economic impacts attributable to climate change, including slow-onset and extreme weather events, have been increasingly identified (*medium confidence*). Some positive economic effects have been identified in regions that have benefited from lower energy demand as well as comparative advantages in agricultural markets and tourism (*high confidence*). Economic damages from climate change have been detected in climate-exposed sectors, with regional effects to agriculture, forestry, fishery, energy, and tourism (*high confidence*), and through outdoor labour productivity (*high confidence*). Some extreme weather events, such as tropical cyclones, have reduced economic growth in the short-term (*high confidence*). Non-climatic factors including some patterns of settlement, and siting of infrastructure have contributed to the exposure of more assets to extreme climate hazards increasing the magnitude of the losses (*high confidence*). Individual livelihoods have been affected through changes in agricultural productivity, impacts on human health and food security, destruction of homes and infrastructure, and loss of property and income, with adverse effects on gender and social equity (*high confidence*). {3.5, 4.2, 5.12, 6.2, 7.2, 8.2, 9.6, 10.4, 13.10, 14.5, Box 14.6, 16.2, Table 16.5, 18.3, CCP6.2, CCB GENDER, CWGB ECONOMICS}
- B.1.7** Climate change is contributing to humanitarian crises where climate hazards interact with high vulnerability (*high confidence*). Climate and weather extremes are increasingly driving displacement in all regions (*high confidence*), with Small Island States disproportionately affected (*high confidence*). Flood and drought-related acute food insecurity and malnutrition have increased in Africa (*high confidence*) and Central and South America (*high confidence*). While non-climatic factors are the dominant drivers of existing intrastate violent conflicts, in some assessed regions extreme weather and climate events have had a small, adverse impact on their length, severity or frequency, but the statistical association is weak (*medium confidence*). Through displacement and involuntary migration from extreme weather and climate events, climate change has generated and perpetuated vulnerability (*medium confidence*). {4.2, 4.3, 5.4, 7.2, 9.8, Box 9.9, Box 10.4, 12.3, 12.5, 16.2, CCB DISASTER, CCB MIGRATE}

Vulnerability and Exposure of Ecosystems and People

- B.2** Vulnerability of ecosystems and people to climate change differs substantially among and within regions (*very high confidence*), driven by patterns of intersecting socioeconomic development, unsustainable ocean and land use, inequity, marginalization, historical and ongoing patterns of inequity such as colonialism, and governance³¹ (*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 diets³², 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 SRCLL.

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 assessed³³ will *likely* face very high risk of extinction³⁴ 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 $18 \pm 13\%$ 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.

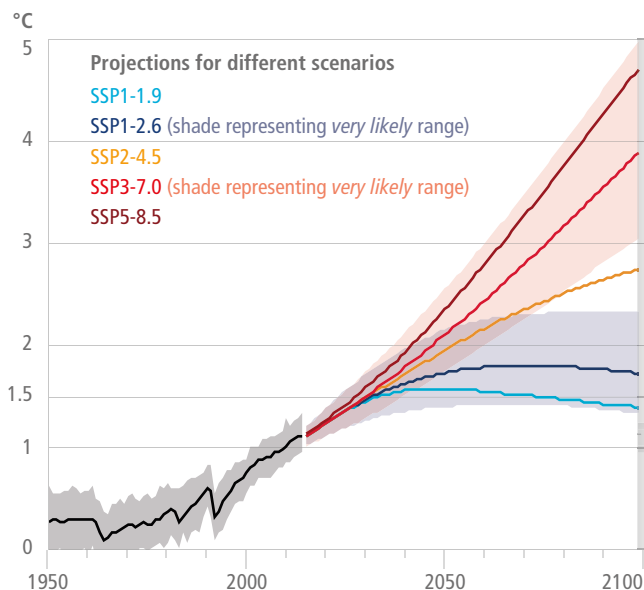
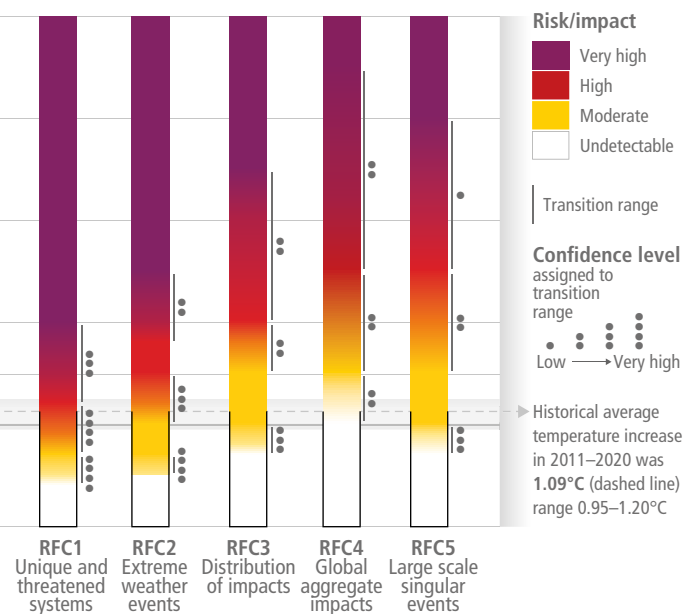
³⁴ The term 'very high risks of extinction' is used here consistently with the IUCN categories and criteria and equates with 'critically endangered'.

- 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 }

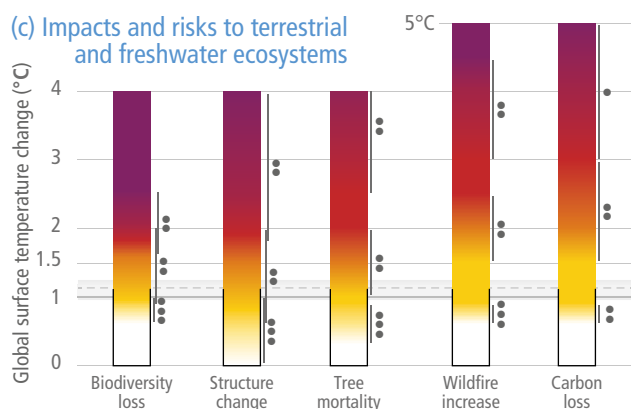
³⁵ The assessment found estimated rates of increase in projected global economic damages that were both greater than linear and less than linear as global warming level increases. There is evidence that some regions could benefit from low levels of warming (*high confidence*). [CWGB ECONOMIC]

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

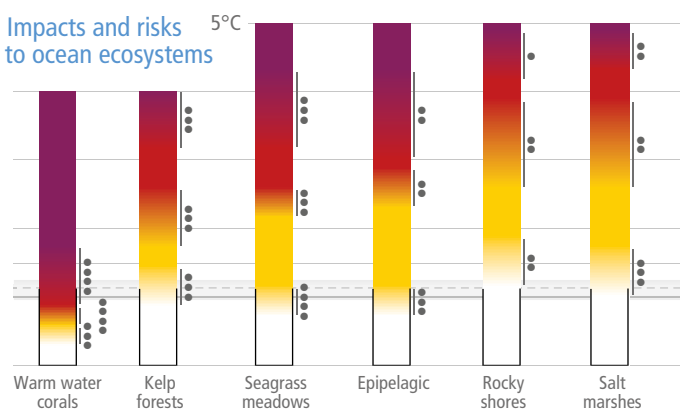
Global and regional risks for increasing levels of global warming

(a) Global surface temperature change
Increase relative to the period 1850–1900(b) Reasons for Concern (RFC)
Impact and risk assessments assuming low to no adaptation

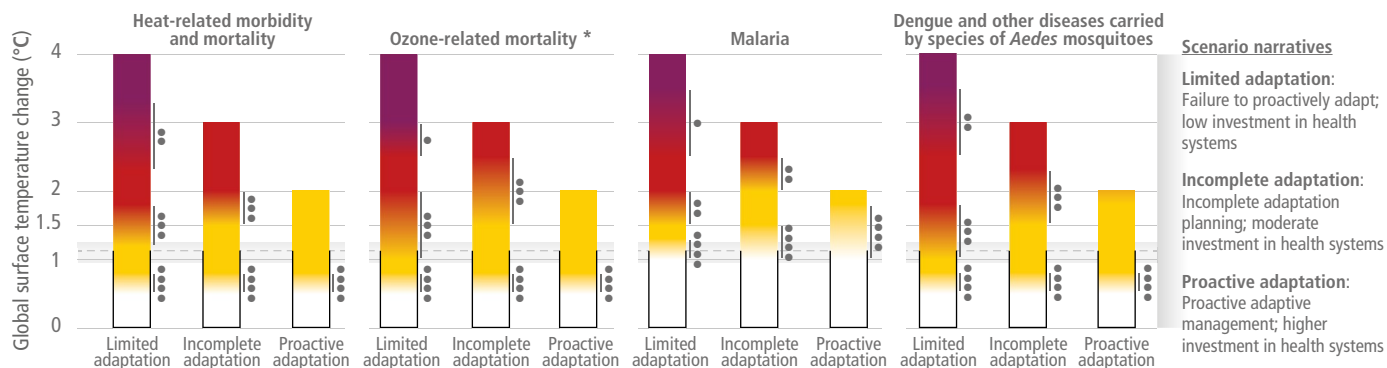
(c) Impacts and risks to terrestrial and freshwater ecosystems



(d) Impacts and risks to ocean ecosystems



(e) Climate sensitive health outcomes under three adaptation scenarios



* 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
Aus-tralasia	- 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

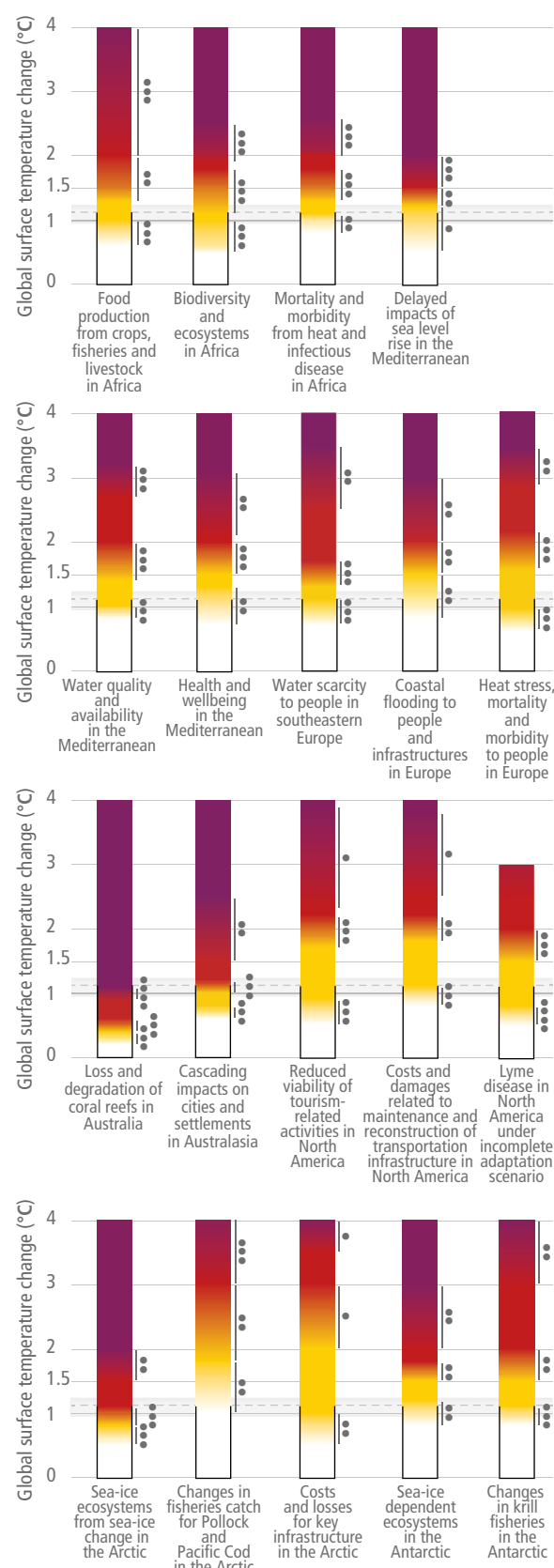


Figure SPM.3 | Synthetic diagrams of global and sectoral assessments and examples of regional key risks. Diagrams show the change in the levels of impacts and risks assessed for global warming of 0–5°C global surface temperature change relative to pre-industrial period (1850–1900) over the range.

(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 CO₂ 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 gaps⁴⁰ (*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 ($-3.4 \pm 0.9 \text{ Gt yr}^{-1}$) than they emit ($+1.6 \pm 0.7 \text{ Gt yr}^{-1}$), a net sink of $-1.9 \pm 1.1 \text{ Gt yr}^{-1}$. 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 feasible⁴¹ and effective⁴² 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 diets³³ (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 forests⁴³ includes conservation, protection and restoration measures. In managed forests⁴³, 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

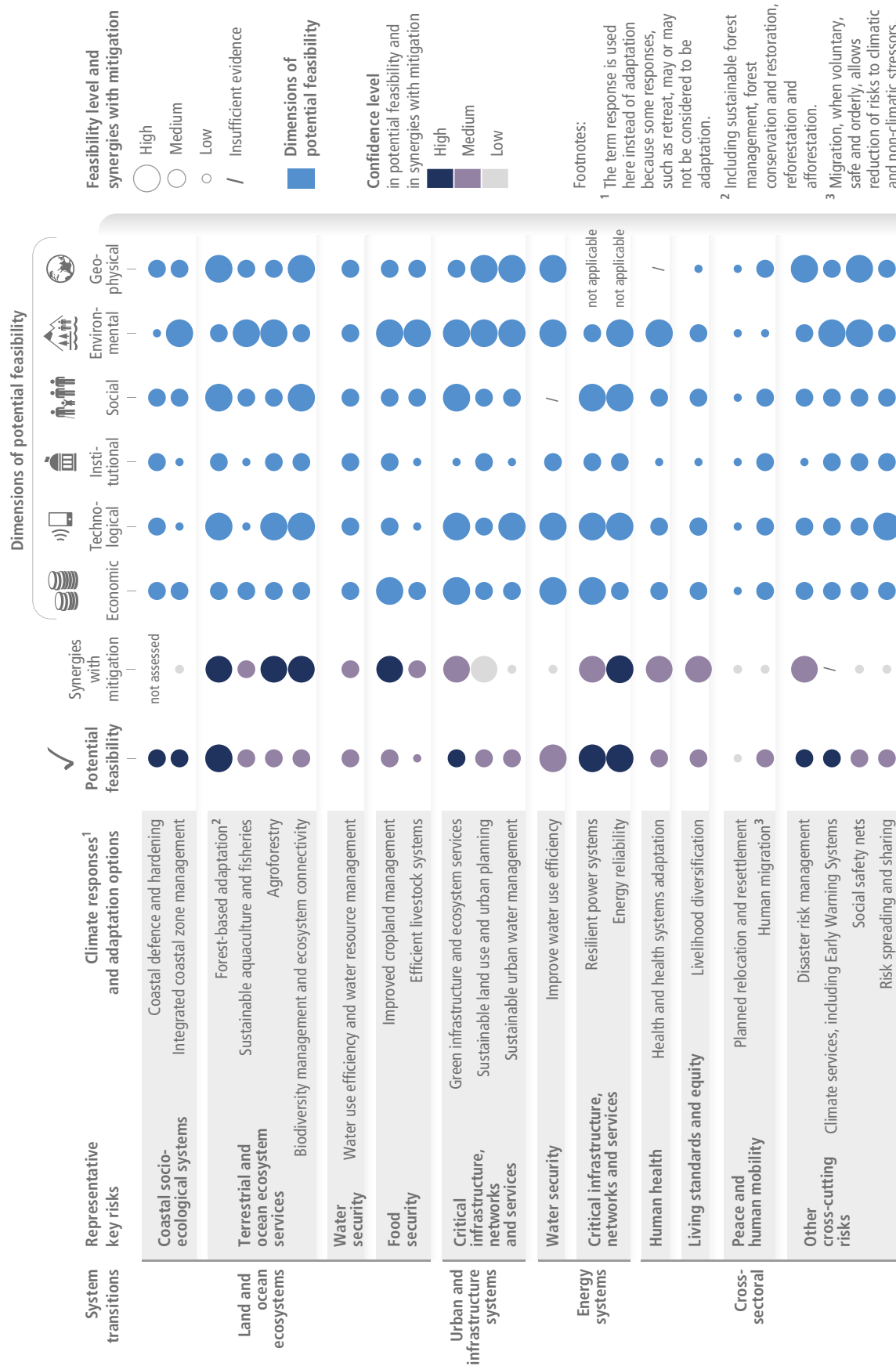
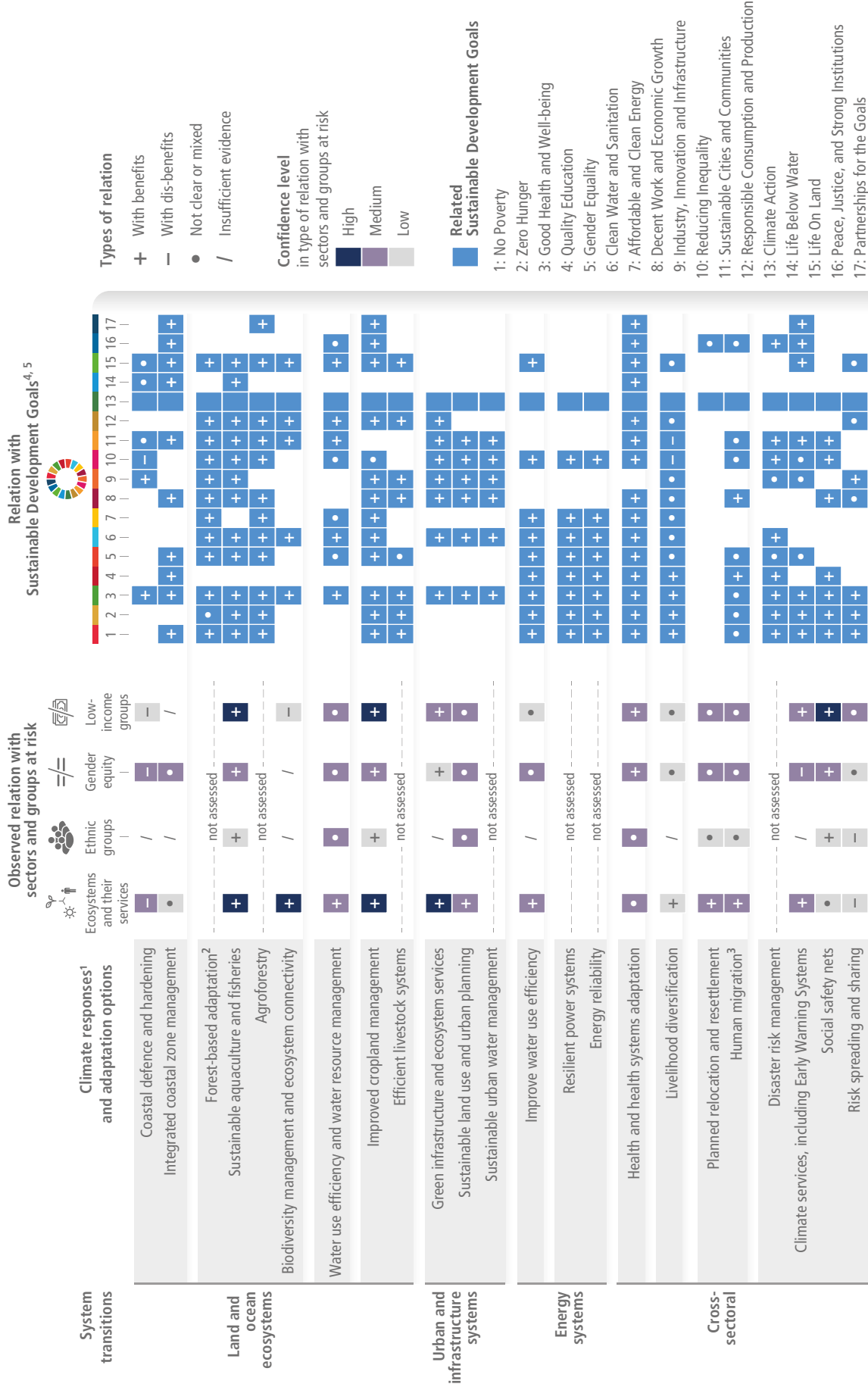


Figure SPM.4 | (a) Climate responses and adaptation options, organized by System Transitions and Representative Key Risks (RKR), are assessed for their multidimensional feasibility at global scale, in the near term and up to 1.5°C global warming. As literature above 1.5°C is limited, feasibility at higher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



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}

SPM

- 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 Adaptation⁴⁴ 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, CCP3.2, 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 literacy⁴⁶ 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 maladaptation¹⁵ 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-regret⁴⁷ 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.

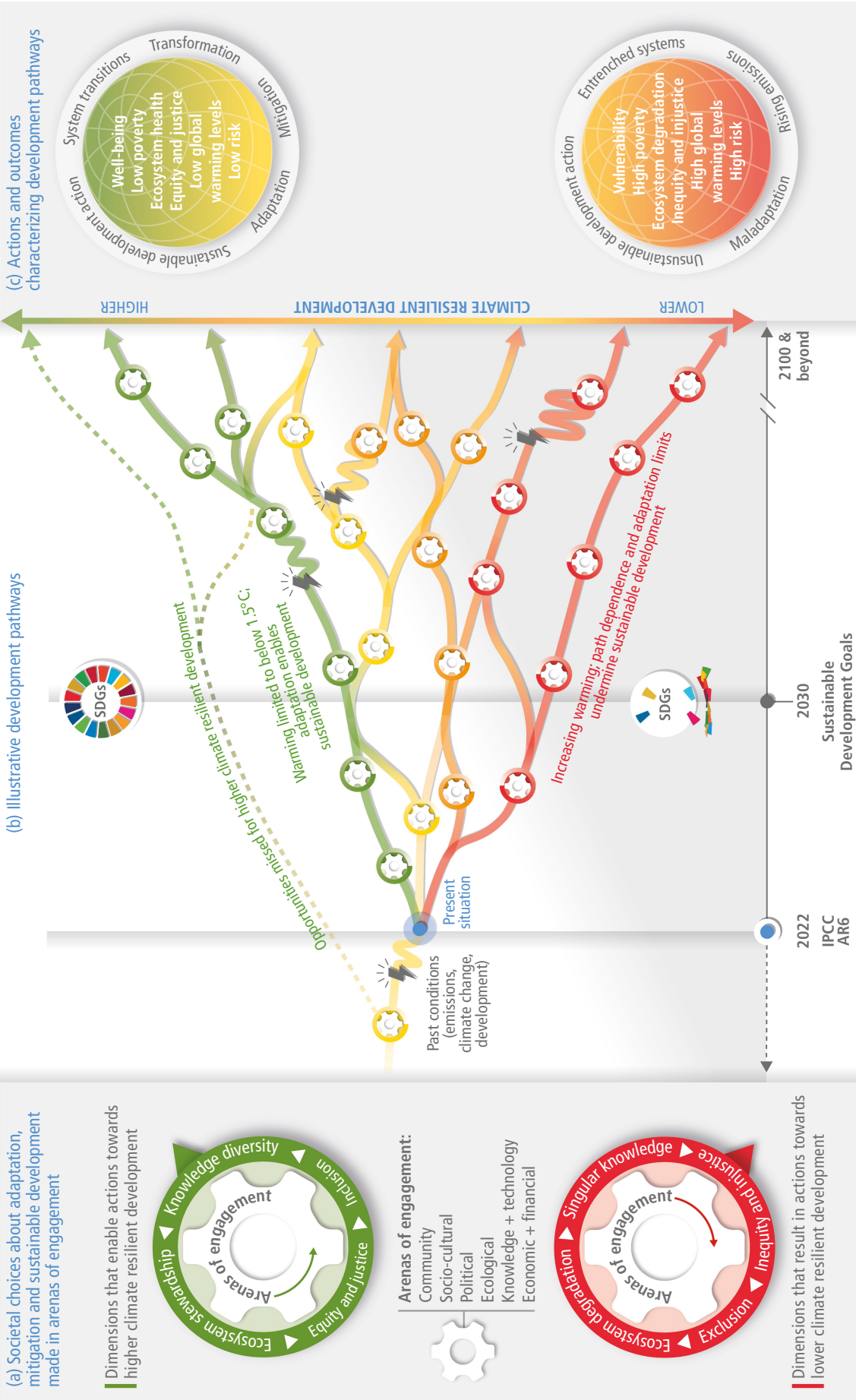
Conditions for Climate Resilient Development

- 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



Narrowing window of opportunity for higher CRD

Illustrative climatic or non-climatic shock, e.g. COVID-19, drought or floods, that disrupts the development pathway

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’ options⁴⁷ 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. Institutions⁴⁸ 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 Zone⁴⁹ 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 integrity⁵⁰ can maintain benefits for people, including livelihoods, human health and well-being and the provision of food, fibre and water, as well as contributing to disaster risk reduction and climate change adaptation and mitigation. {2.2, 2.5, 2.6, Table 2.6, Table 2.7, 3.5, 3.6, 5.8, 5.13, 5.14, Box 5.11, 12.5, CCP5.4, CCB COVID, CCB GENDER, CCB ILLNESS, CCB INDIG, CCB MIGRATE, CCB NATURAL}
- D.4.2** Protecting and restoring ecosystems is essential for maintaining and enhancing the resilience of the biosphere (*very high confidence*). Degradation and loss of ecosystems is also a cause of greenhouse gas emissions and is at increasing risk of being exacerbated by climate change impacts, including droughts and wildfire (*high confidence*). Climate resilient development avoids adaptation and mitigation measures that damage ecosystems (*high confidence*). Documented examples of adverse impacts of land-based measures intended as mitigation, when poorly implemented, include afforestation of grasslands, savannas and peatlands, and risks from bioenergy crops at large scale to water supply, food security and biodiversity (*high confidence*). {2.4, 2.5, Box 2.2, 3.4, 3.5, Box 3.4, Box 9.3, CCP7.3, CCB NATURAL, CWGB BIOECONOMY}

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

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

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

Achieving Climate Resilient Development

- D.5** It is unequivocal that climate change has already disrupted human and natural systems. Past and current development trends (past emissions, development and climate change) have not advanced global climate resilient development (*very high confidence*). Societal choices and actions implemented in the next decade determine the extent to which medium- and long-term pathways will deliver higher or lower climate resilient development (*high confidence*). Importantly climate resilient development prospects are increasingly limited if current greenhouse gas emissions do not rapidly decline, especially if 1.5°C global warming is exceeded in the near-term (*high confidence*). These prospects are constrained by past development, emissions and climate change, and enabled by inclusive governance, adequate and appropriate human and technological resources, information, capacities and finance (*high confidence*). {Figure TS.14d, 1.2, 1.4, 1.5, 2.6, 2.7, 3.6, 4.7, 4.8, 5.14, 6.4, 7.4, 8.3, 8.5, 8.6, 9.3, 9.4, 9.5, 10.6, 11.8, 12.5, 13.10, 13.11, 14.7, 15.3, 15.6, 15.7, 16.2, 16.4, 16.5, 16.6, 17.2–17.6, 18.2–18.5, CCP2.3–2.4, CCP3.4, CCP4.4, CCP5.3, CCP5.4, Table CCP5.2, CCP6.3, CCP6.4, CCP7.5, CCP7.6, CCB DEEP, CCB HEALTH, CCB INDIG, CCB NATURAL, CCB SLR}
- D.5.1** Climate resilient development is already challenging at current global warming levels (*high confidence*). The prospects for climate resilient development will be further limited if global warming levels exceeds 1.5°C (*high confidence*) and not be possible in some regions and sub-regions if the global warming level exceeds 2°C (*medium confidence*). Climate resilient development is most constrained in regions/subregions in which climate impacts and risks are already advanced, including low-lying coastal cities and settlements, small islands, deserts, mountains and polar regions (*high confidence*). Regions and subregions with high levels of poverty, water, food and energy insecurity, vulnerable urban environments, degraded ecosystems and rural environments, and/or few enabling conditions, face many non-climate challenges that inhibit climate resilient development which are further exacerbated by climate change (*high confidence*). {Figure TS.14d, 1.2, Box 6.6, 9.3, 9.4, 9.5, 10.6, 11.8, 12.5, 13.10, 14.7, 15.3, CCP2.3, CCP3.4, CCP4.4, CCP5.3, Table CCP5.2, CCP6.3, CCP7.5}
- D.5.2** Inclusive governance, investment aligned with climate resilient development, access to appropriate technology and rapidly scaled-up finance, and capacity building of governments at all levels, the private sector and civil society enable climate resilient development. Experience shows that climate resilient development processes are timely, anticipatory, integrative, flexible and action focused. Common goals and social learning build adaptive capacity for climate resilient development. When implementing adaptation and mitigation together, and taking trade-offs into account, multiple benefits and synergies for human well-being as well as ecosystem and planetary health can be realised. Prospects for climate resilient development are increased by inclusive processes involving local knowledge and Indigenous Knowledge as well as processes that coordinate across risks and institutions. Climate resilient development is enabled by increased international cooperation including mobilising and enhancing access to finance, particularly for vulnerable regions, sectors and groups. (*high confidence*) (Figure SPM.5) {2.7, 3.6, 4.8, 5.14, 6.4, 7.4, 8.5, 8.6, 9.4, 10.6, 11.8, 12.5, 13.11, 14.7, 15.6, 15.7, 17.2–17.6, 18.2–18.5, CCP2.3–2.4, CCP3.4, CCP4.4, CCP5.4, CCP6.4, CCP7.6, CCB DEEP, CCB HEALTH, CCB INDIG, CCB NATURAL, CCB SLR}
- D.5.3** The cumulative scientific evidence is unequivocal: Climate change is a threat to human well-being and planetary health. Any further delay in concerted anticipatory global action on adaptation and mitigation will miss a brief and rapidly closing window of opportunity to secure a liveable and sustainable future for all. (*very high confidence*) {1.2, 1.4, 1.5, 16.2, Table SM16.24, 16.4, 16.5, 16.6, 17.4, 17.5, 17.6, 18.3, 18.4, 18.5, CCB DEEP, CWGB URBAN, WGI AR6 SPM, SROCC SPM, SRCCL SPM}

Technical Summary

TS

Technical Summary

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Table of Contents

TS.A Introduction	40	Justice, equity and governance	96
TS.A.1 Background	40	Enabling implementation	97
TS.A.2 TS Structure of the Report	40	System transitions and transformational adaptation	99
TS.A.3 Key Developments Since AR5	40		
Box TS.1 Core Concepts of the Report	43	TS.E Climate Resilient Development	100
Box TS.2 AR6 Climate Dimensions, Global Warming Levels and Reference Periods	44	Sustainable development, equity and justice	100
		Enablers of societal resilience	108
TS.B Observed Impacts	44	Ecosystem health and resilience	109
Ecosystems and biodiversity	45	Governance	110
Food systems, food security and forestry	48	Transformation towards climate resilient development	111
Water systems and water security	49		
Health and well-being	50	Appendix TS.AI: List and Location of WGII AR6 Cross-Chapter Boxes (CCBs) and Cross-Working Group Boxes (CWGBs)	112
Migration and displacement	52		
Human vulnerability	52	Appendix TS.AII: Aggregated Climate Risk Assessments in WGII AR6	113
Cities, settlements and infrastructure	53	TS.AII.1 Key Risks and Representative Key Risks	113
Economic sectors	54	TS.AII.2 Assessment of Severity Conditions for Representative Key Risks	113
		TS.AII.3 Framework and Approach for Assessment of Burning Embers for Reasons for Concern	114
TS.C Projected Impacts and Risks	55	TS.AII.4 Relationship between Representative Key Risks and Reasons for Concern	114
Ecosystems and biodiversity	55		
Food systems and food security	57	Storyline Figures	
Water systems and water security	61	Ecosystems	72
Risks from sea level rise	62	Food-Water	74
Health and well-being	63	Vulnerability	76
Migration and displacement	64	Health	79
Human vulnerability	65	Urban	80
Cities, settlements and infrastructure	65	Complex Risk	82
Economic sectors	66		
Compound, cascading and transboundary risks	67		
Reasons for concern (RFC)	68		
Temporary overshoot	69		
TS.D Contribution of Adaptation to Solutions	71		
Adaptation progress and gaps	71		
Limits to adaptation	84		
Maladaptation	85		
Strengthening the biosphere	86		
Water and food sectors	87		
Cities, settlements and infrastructure	91		
Sea level rise	94		
Health, well-being, migration and displacement	95		

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

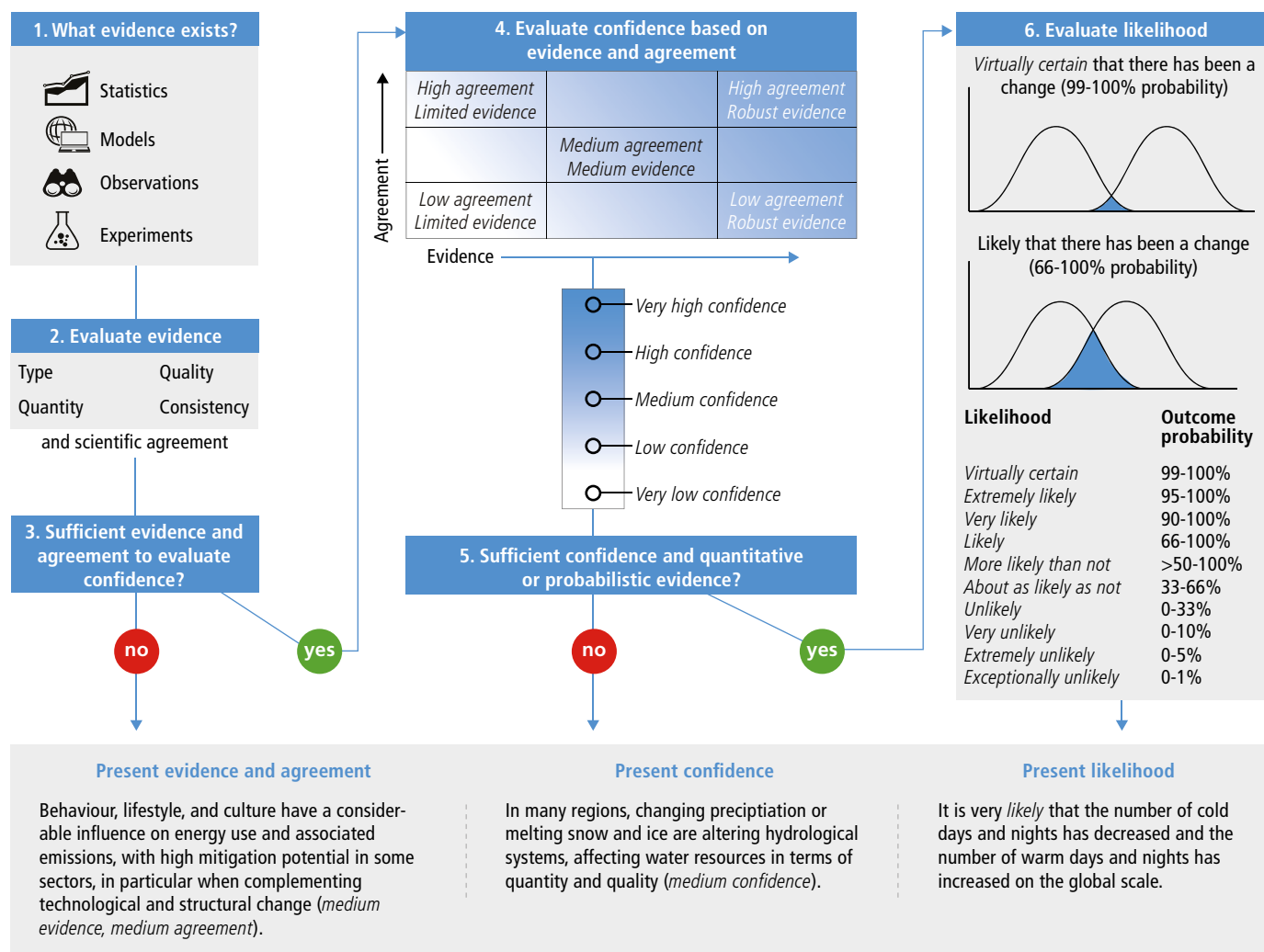


Figure TS.1 | The IPCC AR5 and AR6 framework for applying expert judgement in the evaluation and characterisation of assessment findings. This illustration depicts the process assessment authors apply in evaluating and communicating the current state of knowledge. (Figure 1.6)

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

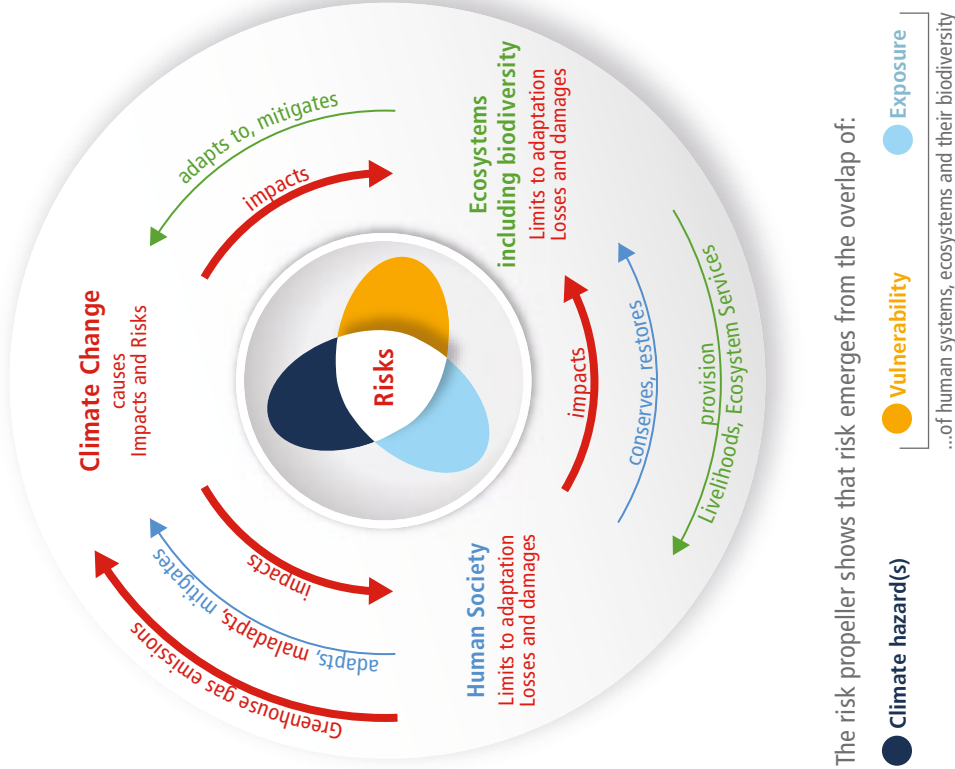
progress. In this report, expanded attention is given to inequity in climate vulnerability and responses, the role of power and participation in processes of implementation, unequal and differential impacts and climate justice. The historic focus on scientific literature has also been increasingly accompanied 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.

(a) Main interactions and trends

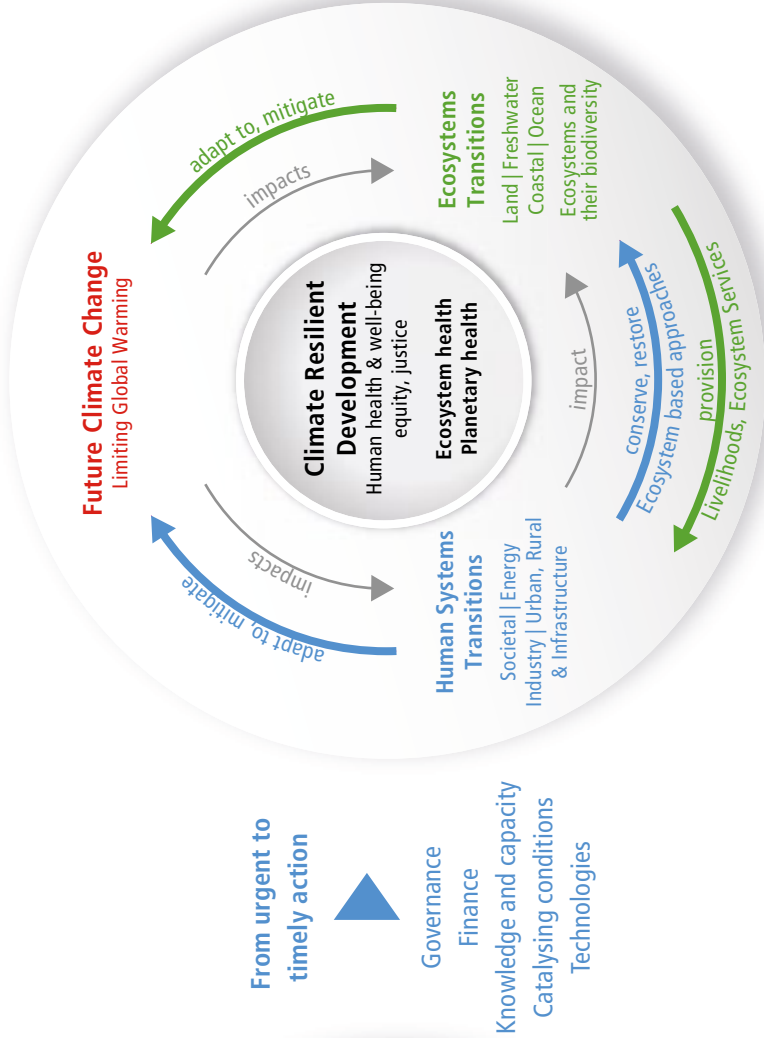


The risk propeller shows that risk emerges from the overlap of:

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}

(b) Options to reduce climate risks and establish resilience



- 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, respectively³. 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 SSPs². 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]⁵ °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 scenario⁶. {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 2.5.1, 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, CCP5.2.7, CCP6.2.1, CCP7.3.2, CCB EXTREMES, CCB ILLNESS, CCB MOVING PLATE}

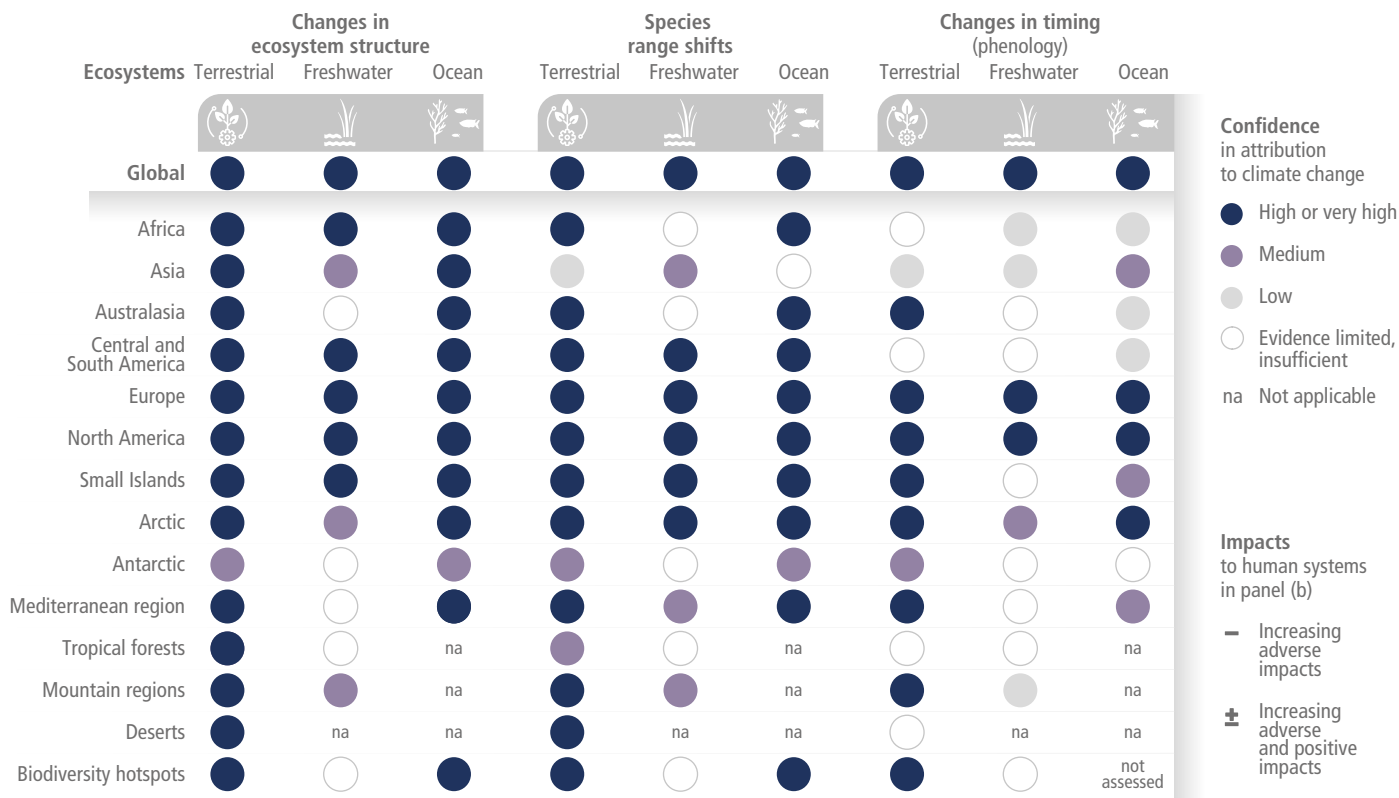
TS.B.1.2 Observed responses of species to climate change have altered biodiversity and impacted ecosystem structure and resilience in most regions (*very high confidence*). Range shifts reduce biodiversity in the warmest regions and locations as adaptation limits are exceeded (*high confidence*). Simultaneously, 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

(a) Observed impacts of climate change on ecosystems



(b) Observed impacts of climate change on human systems

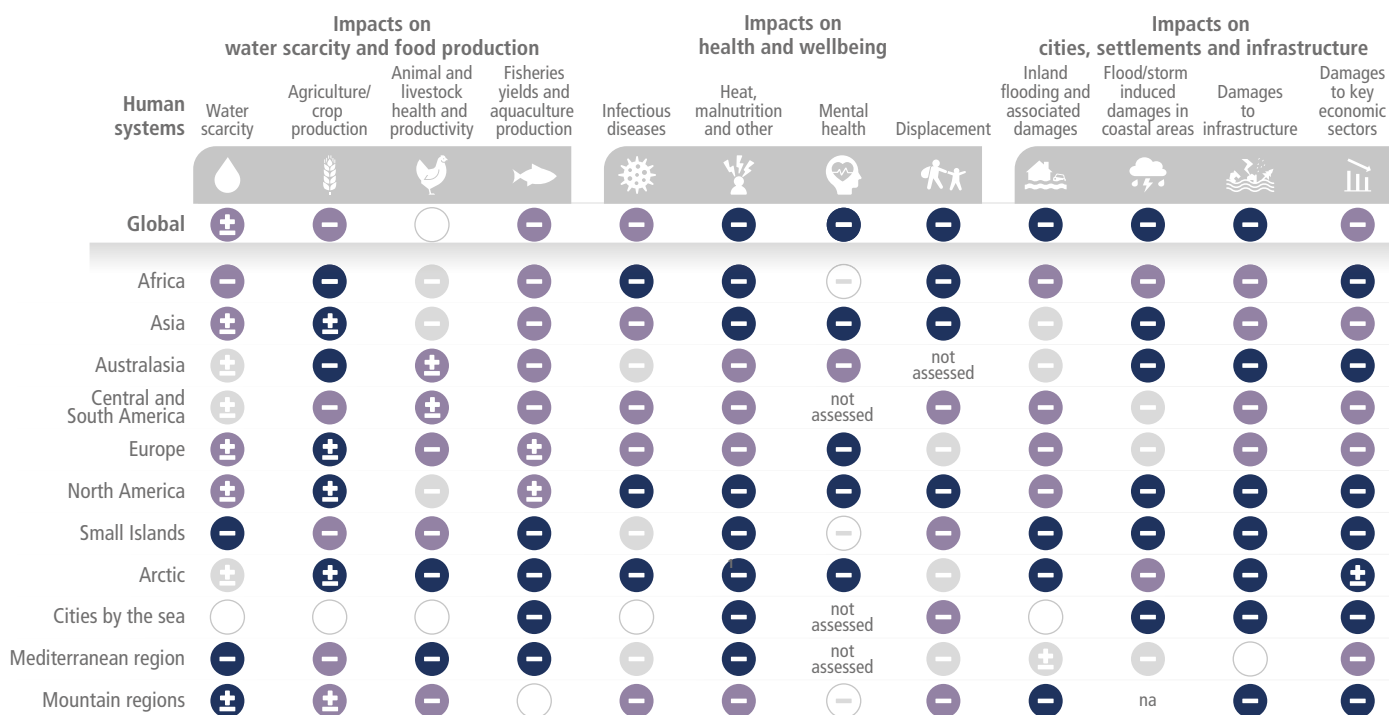


Figure TS.3 | Observed global and regional impacts on ecosystems and human systems attributed to climate change. Confidence levels reflect uncertainty in attribution of the observed impact to climate change. Global assessments focus on large studies, multi-species, meta-analyses and large reviews. For 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 CO₂ 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 CO₂, 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 CO₂ 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 2.5. 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 scar-

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

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

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

(*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 voluntariness 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 confidence*). (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, RKR) 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 CO₂ 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 CO₂ losses by 2100 by 24.2 GtC (*low confidence*). A temperature rise of 4°C by 2100 is projected to increase global burned area 50–70% and fire frequency by approx. 30%, potentially releasing 11–200 GtC from the Arctic alone (*medium confidence*). Changes in plankton community structure and productivity are projected to reduce carbon sequestration at depth (*low to medium confidence*). {2.5.2, 2.5.3, 2.5.4, Figure 2.11, Table 2.5, 3.4.2, 3.4.3, 3.4.2, 4.2.4, 13.3.1, 13.4.1, Box 14.7, Box 3.4}

TS.C.2.4 Climate change impacts on marine ecosystems are projected to lead to profound changes and irreversible losses in many regions, with negative consequences for human ways of life, economy and cultural identity (*medium confidence*). For example, by 2100, 18.8% ± 19.0% to 38.9% ± 9.4% of the ocean will *very likely* undergo a change of more than 20 days (advances and delays) in the start of the phytoplankton growth period under SSP1-2.6 and SSP5-8.5 respectively (*low confidence*). This altered timing increases the risk of temporal mismatches between plankton

blooms and fish spawning seasons (*medium to high confidence*) and increases the risk of fish recruitment failure for species with restricted spawning locations, especially in mid- to high latitudes of the northern hemisphere (*low confidence*) but provide short-term opportunities to countries benefiting from shifting fish stocks (*medium confidence*). {3.4.2, 3.4.3, 3.5.6, 5.8.3, 5.9.3, 11.3.1, 13.4.1, 13.5.1, 14.5.2, CCP6.3, CCB MOVING SPECIES}

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

Food systems and food security

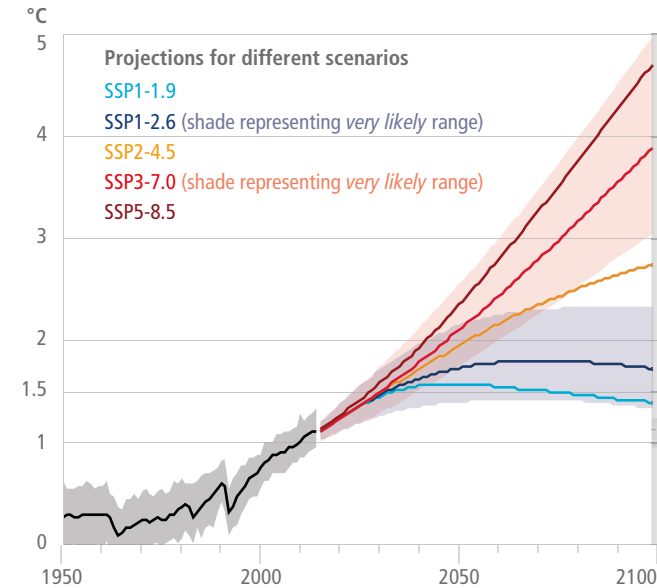
TS.C.3 Climate change will increasingly add pressure on food production systems, undermining food security (*high confidence*). With every increment of warming, exposure to climate hazards will grow substantially (*high confidence*), and adverse impacts on all food sectors will become prevalent, further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

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

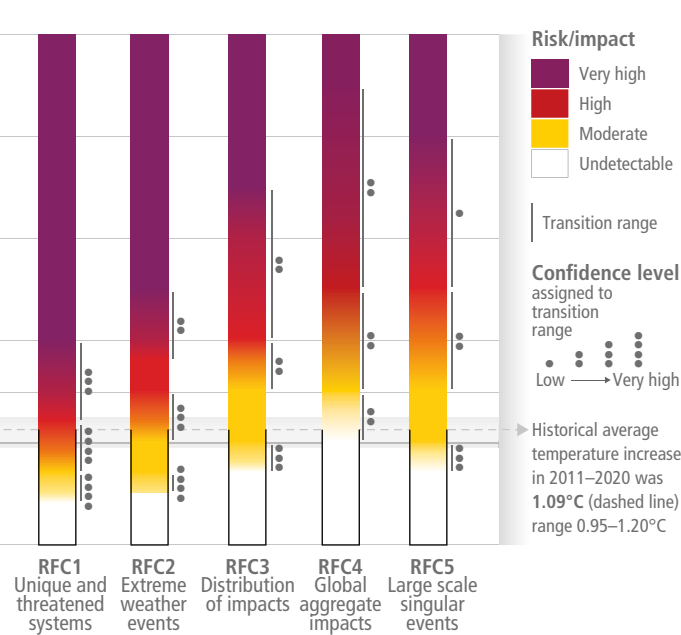
TS.C.3.2 Climate change will significantly alter aquatic food provisioning services, with direct impacts on food-insecure people (*high confidence*). Global ocean animal biomass will

Global and regional risks for increasing levels of global warming

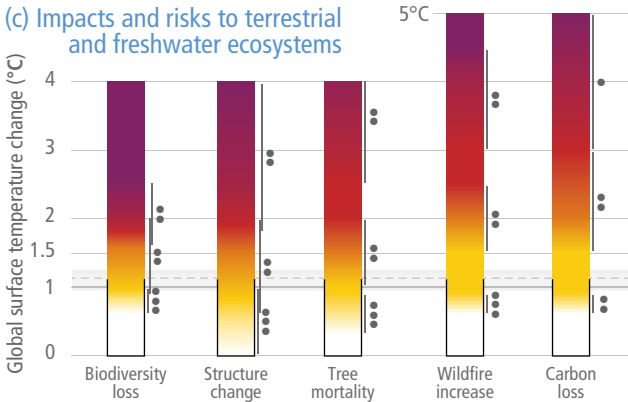
(a) Global surface temperature change
Increase relative to the period 1850–1900



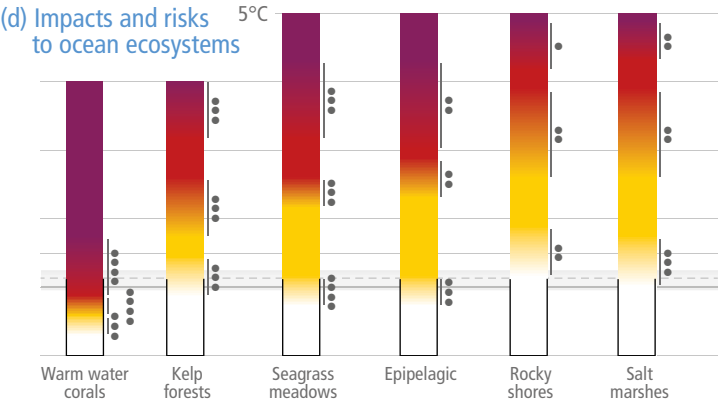
(b) Reasons for Concern (RFC)
Impact and risk assessments assuming low to no adaptation



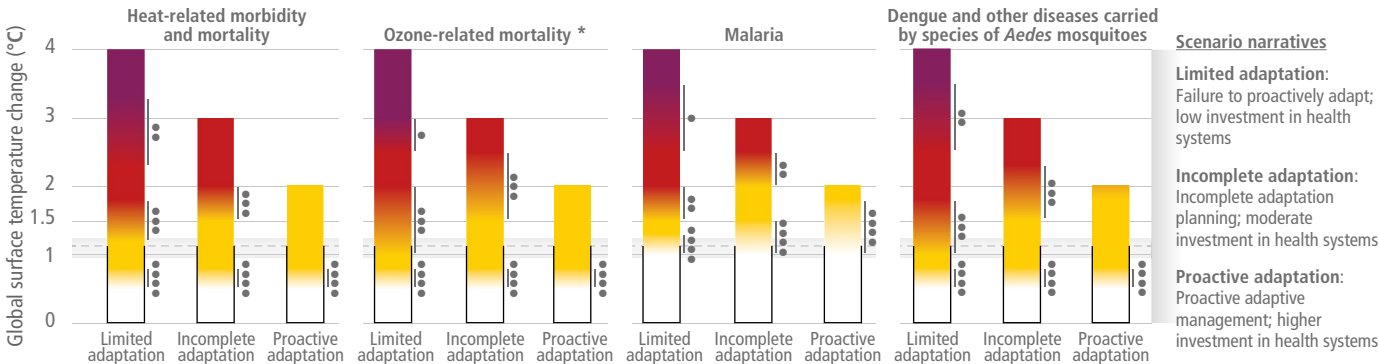
(c) Impacts and risks to terrestrial and freshwater ecosystems



(d) Impacts and risks to ocean ecosystems



(e) Climate sensitive health outcomes under three adaptation scenarios



* 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

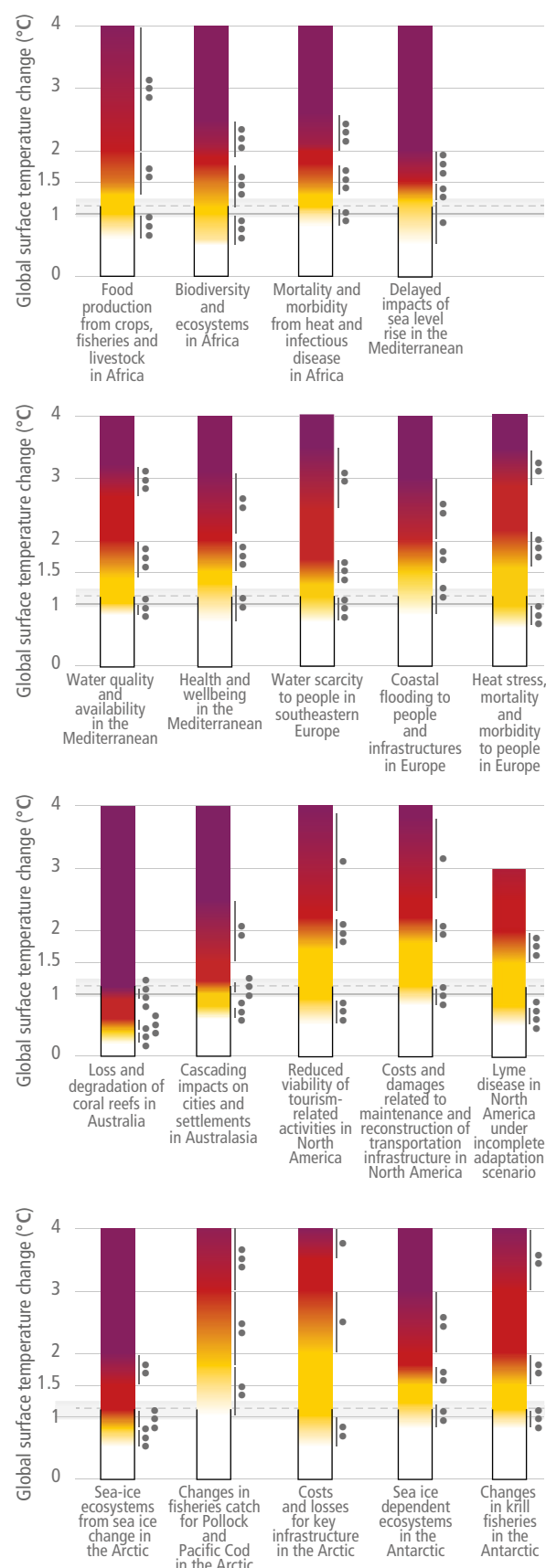


Figure TS.4 | Synthetic diagrams of global and sectoral assessments and examples of regional key risks. Diagrams show the change in the levels of impacts and risks assessed for global warming of 0–5°C global surface temperature change relative to pre-industrial period (1850–1900) over the range.

(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, 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 $5.7\% \pm 4.1\%$ and $15.5\% \pm 8.5\%$ 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 CO₂ 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, SRCLL}

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,

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, CCP6.2.4, 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.All) {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-CO₂ scenario. SRM would not stop CO₂ 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 CO₂ 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 (<i>very high confidence</i>)
	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 (<i>high confidence</i>)

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 (<i>high confidence</i>)
	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 (<i>medium confidence</i>)
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 (<i>high confidence</i>)
	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 (<i>medium confidence</i>)
	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 (<i>medium confidence</i>)
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 (<i>medium confidence</i>)
	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 (<i>medium confidence</i>)
	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 (<i>low confidence</i>)
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 (<i>high confidence</i>)
	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 (<i>medium confidence</i>)
	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 (<i>low confidence</i>)

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}

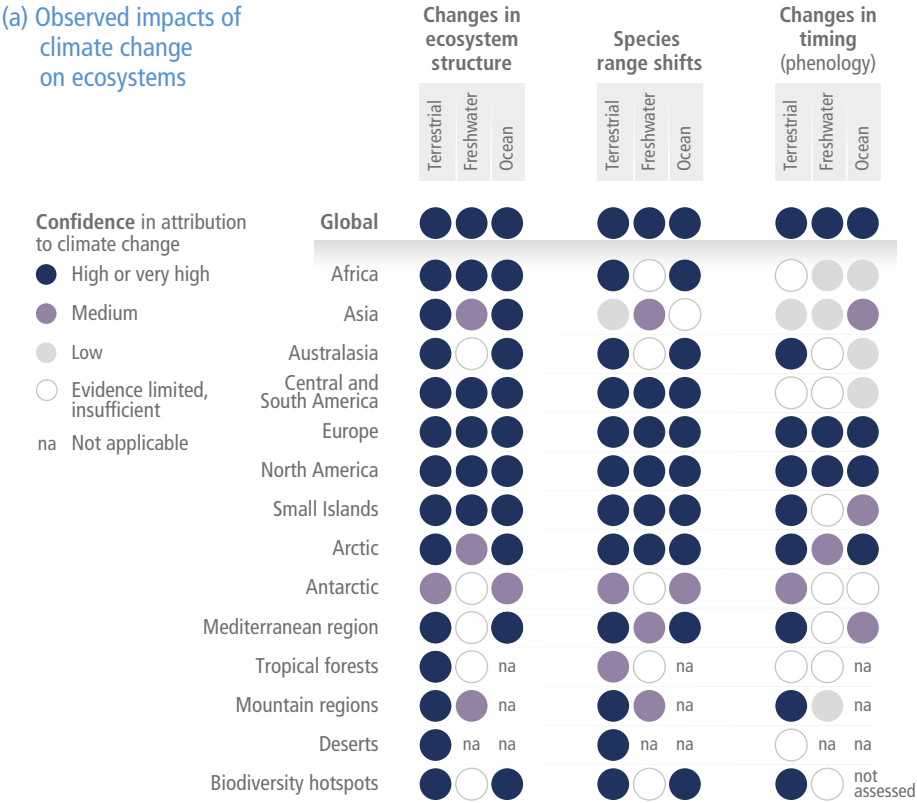
TS.D.1.2 Current adaptation in natural and managed ecosystems includes earlier planting and changes in crop varieties, soil improvement and water management for livestock and crops, aquaculture, restoration of coastal and hydrological processes, introduction of heat- and drought-adapted genotypes into 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}

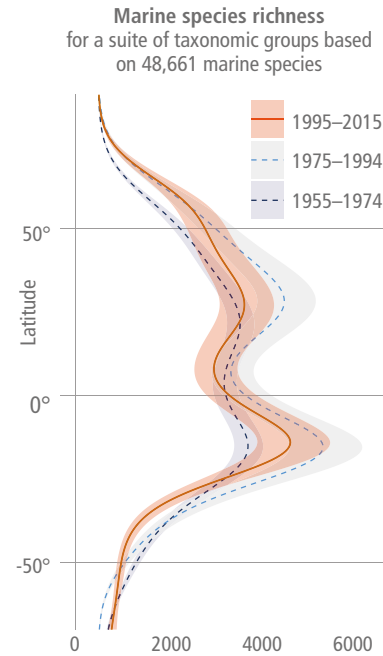
TS.D.1.4 Many cities and settlements have developed adaptation plans since AR5, but a limited number of these have been implemented so that urban adaptation gaps exist in all world regions and for all hazard types (*high confidence*). Many plans focus on climate risk reduction, missing opportunities 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

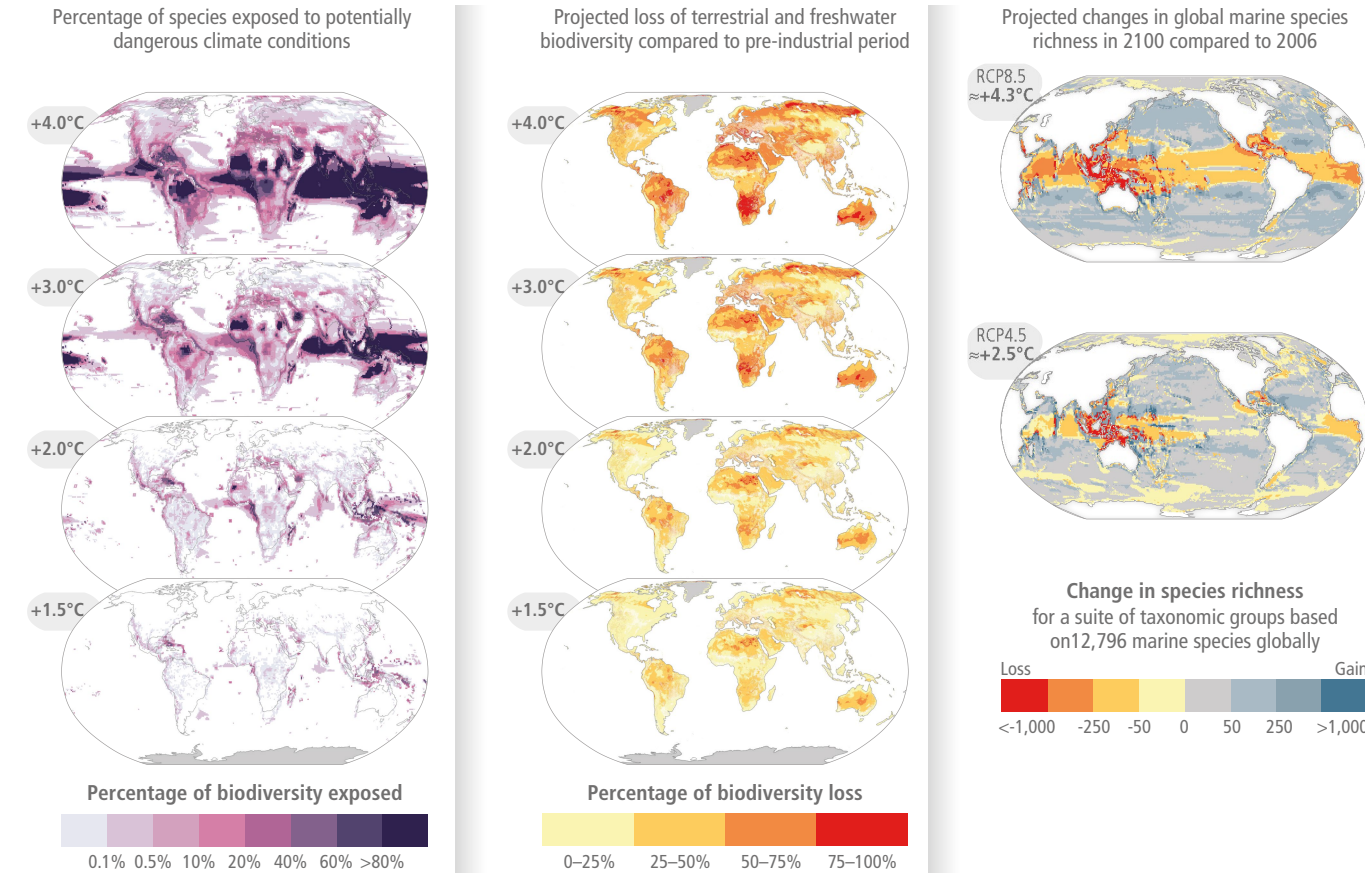
(a) Observed impacts of climate change on ecosystems



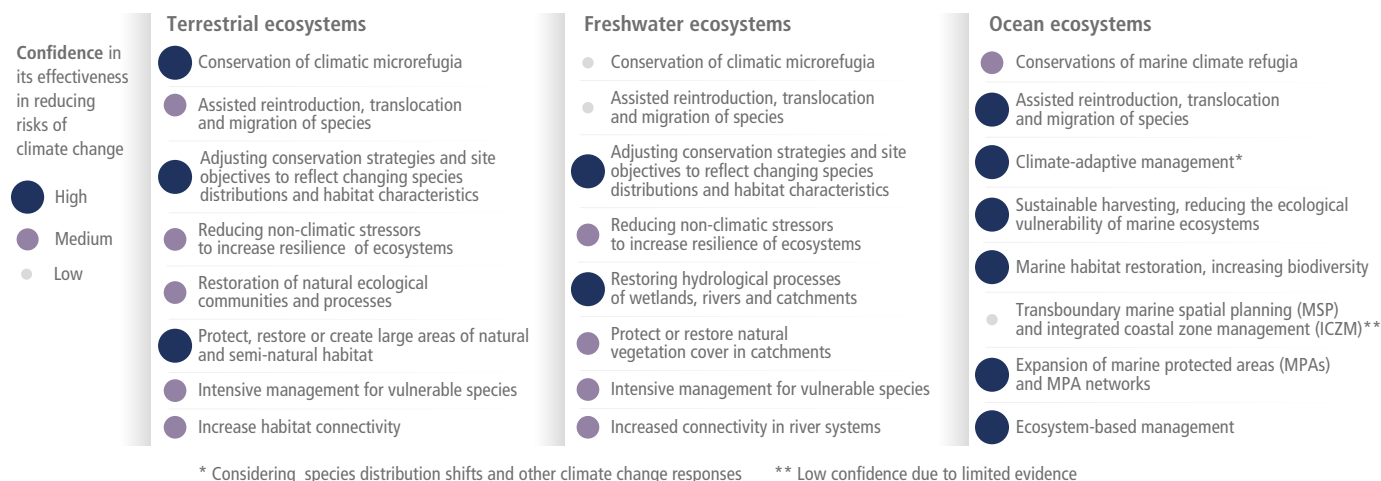
Marine species richness has been declining in equatorial and increasing in higher latitudes since the 1950s due to global warming



(b) With every additional increment of global warming more species will be exposed to potentially dangerous climate conditions and more biodiversity will be lost.



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



(d) Adaptation pathways for ecosystems.

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

Strategies

- Protect (Green line)
- Restore/migrate (Blue line)
- Sustainable use (Orange line)
- Uncertainty in effectiveness with increasing pressures (Dotted line)

Examples for actions

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

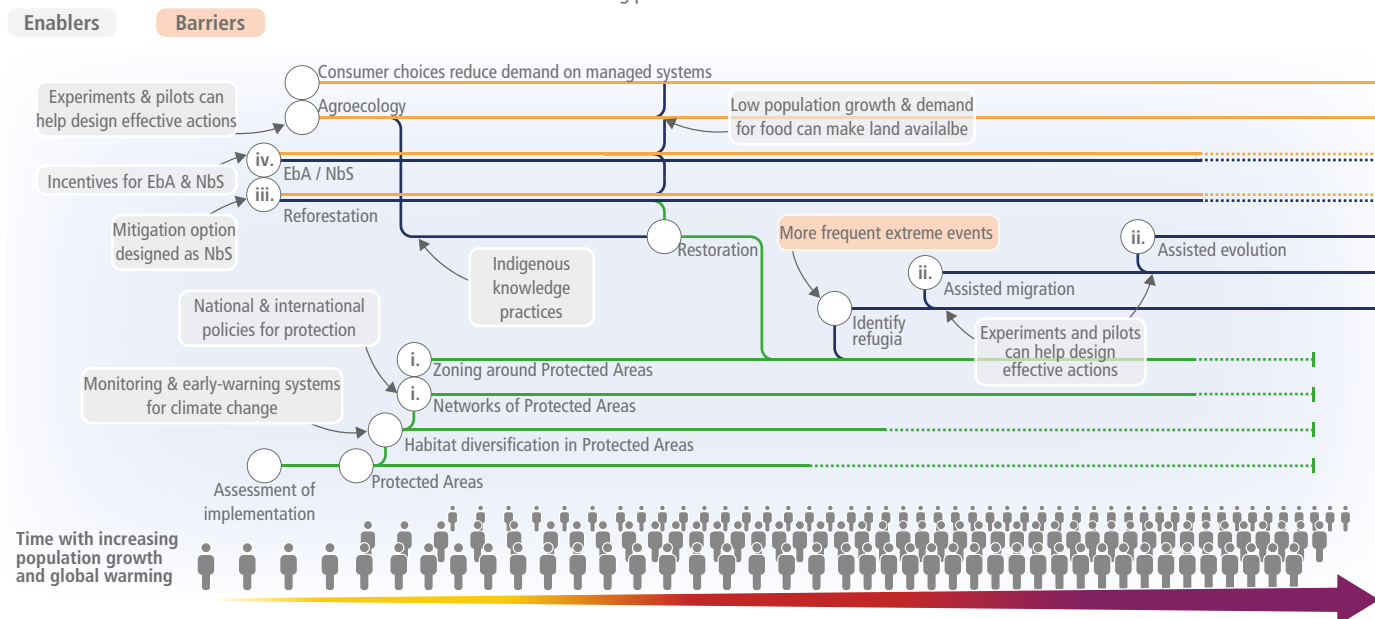
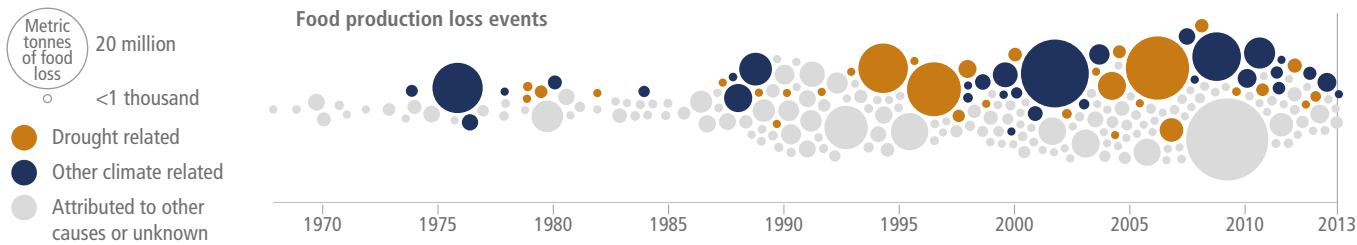


Figure TS.5 ECOSYSTEMS | (a) **Left:** Observed global and regional impacts on ecosystems and human systems attributed to climate change. Confidence levels reflect uncertainty in attribution of the observed impact to climate change. For more details and line of sight to chapters and cross-chapter papers see Figure TS.3a, SMTS.1 and Table SMTS.1. **Right:** Observed species richness across latitude for three historical periods. [3.4.3, Figure 3.18]. (b) **Left:** Global warming levels (GMST) modelled across the ranges of more than 30,000 marine and terrestrial species. **Middle:** Global warming levels (GSAT); change indicated by the proportion of species (modelled n=119,813 species globally) for which the climate is projected to become unsuitable across their current distributions. **Right:** Modelled 12,796 marine species globally. [2.5.1, Figure 2.6, 3.4.3, Figure 3.18, Figure 3.20a, CCP1.2.4, Figures AI.6, AI.15, AI.16]. (c) [2.6.2, Table 2.6, 3.6.2, Figure 3.24]. (d) Some actions facilitate sustainable use but also increase space for nature. [2.4.2, 2.6.2, 2.6.3, 2.6.5, 2.6.7, 2.6.8, 3.6.2, 3.6.5, Table 3.30, 5.6.3, Box 5.11, 9.3.1, 9.3.2, 9.6.3, 9.6.4, 9.12.3, 10.4.2, 10.4.3, 11.3.1, 11.3.2, 11.7.3, 12.5.1, 12.5.2, 12.5.9, 12.6.1, 13.3.2, 13.4.2, 13.5.2, 13.10.2, 14.5.1, 14.5.2, Box 14.2, Box 14.7, 15.5.4, 15.3.3, Table 15.6, 16.5.2, 16.6.3, CCP1.3, CCP3.2.2, CCP4.4.1, CCP5.2.5, CCP5.4.1, CCP6.3.2, CCP7.5, CCP7.5.1, CCPBox7.1, Table CCP7.3, CCB EXTREMES, CCB NATURAL]

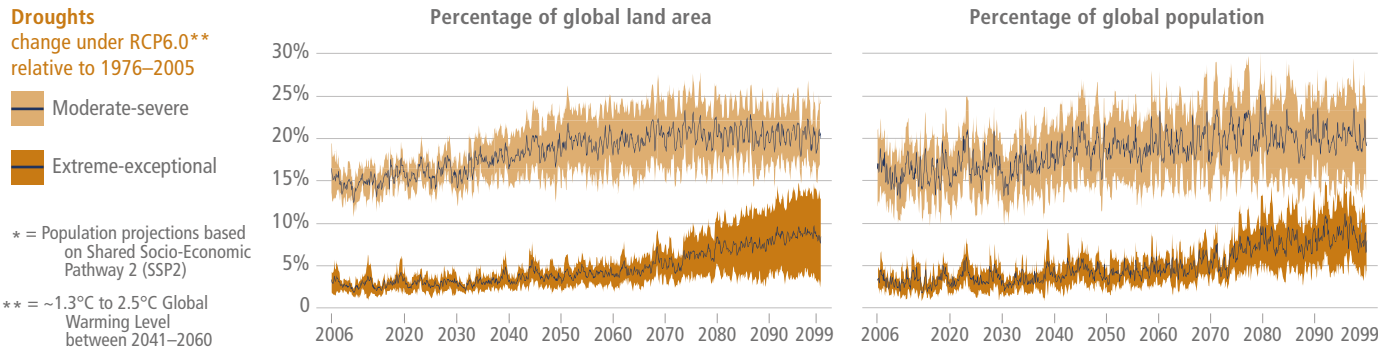
Climate change is affecting food security through pervasive water impacts

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 climate-related food production losses in crops, livestock, fisheries and aquacultures has been increasing over the last decades.

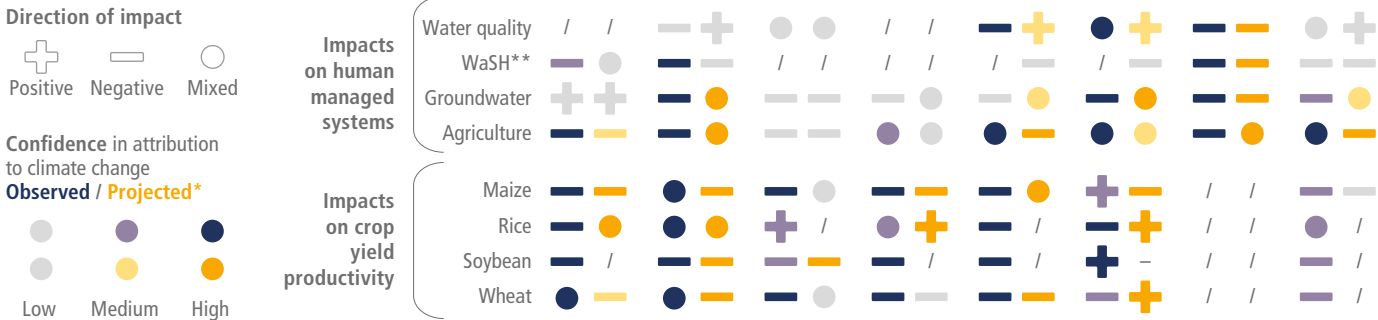


(b) By the late 21st century the share of the global land area and population* affected by combinations of agricultural, ecological and hydrological droughts is projected to increase substantially.



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

Most regions have already experienced negative impacts on the water cycle and agricultural productivity.

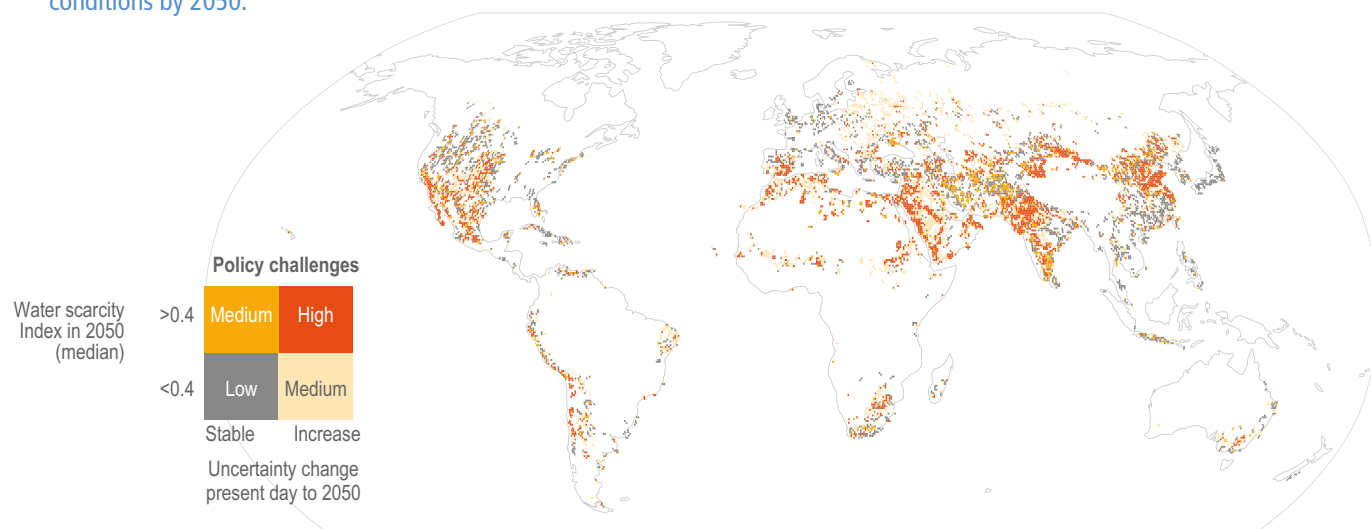


*Mid-century at RCP4.5 (~2°C Global Warming Level)

** = 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.

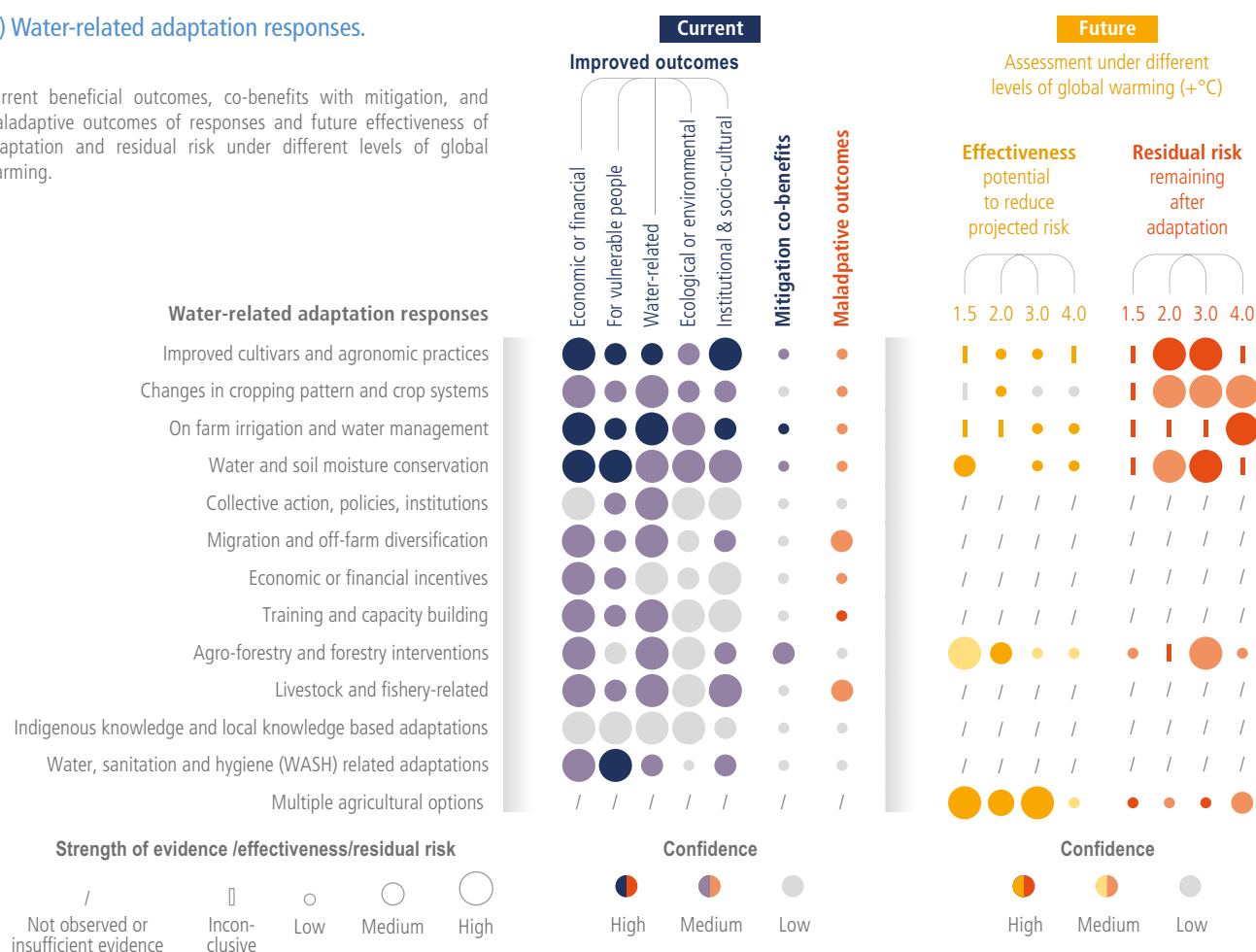
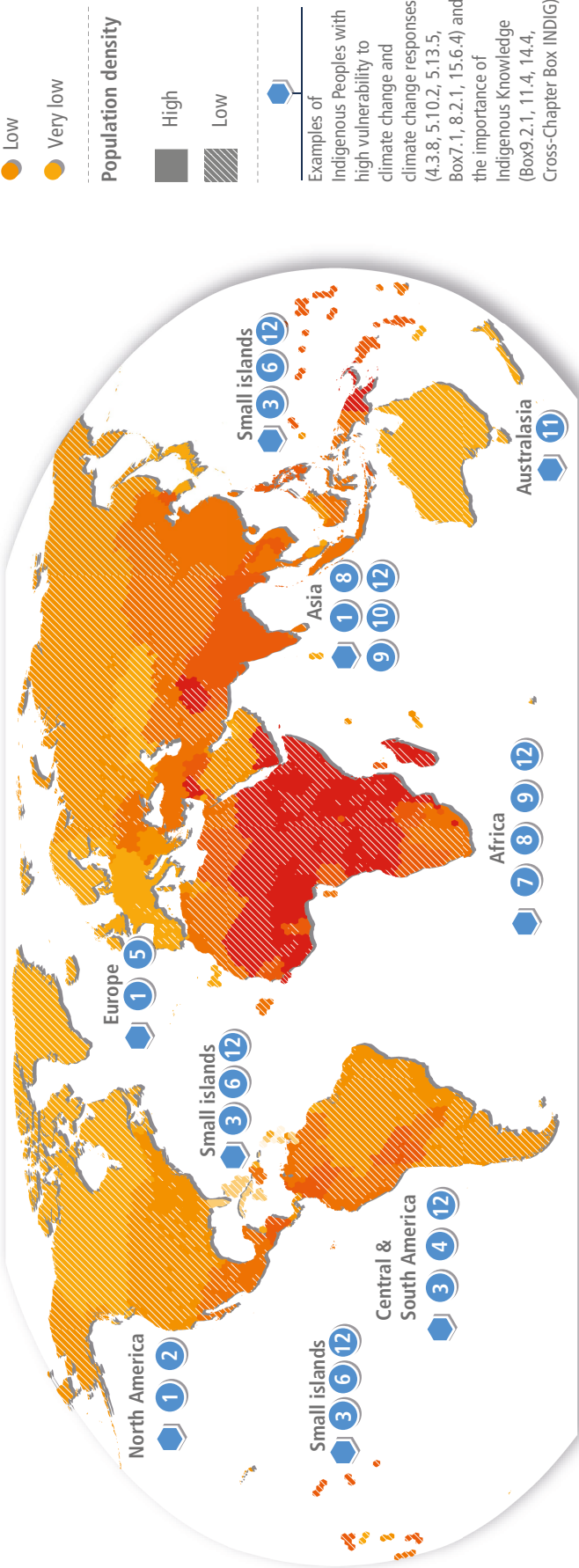


Figure TS.6 FOOD-WATER | (a) [5.4.1.1, Box 5.1, FAQ 5.1, SM5.1, Figure AI.20]. (b) Projected increase in the global share of area and population impacted from droughts. Changes are calculated based on the RCP6.0 concentration pathway for Terrestrial Water Storage (TWS) droughts, which can be considered 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 CO₂ 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 | 7 Children in rural low-income communities food insecurity, sensitivity to undernutrition and disease 5.12.3 |
| 2 Urban ethnic minorities structural inequality, marginalisation, exclusion from planning processes 14.5.9, 14.5.5, 6.3.6 | 8 People uprooted by conflict in the Near East and Sahel prolonged temporary status, limited mobility Box 8.1, Box 8.4 |
| 3 Smallholder coffee producers limited market access & stability, single crop dependency, limited institutional support 5.4.2 | 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 |
| 4 Indigenous Peoples in the Amazon land degradation, deforestation, poverty, lack of support 8.2.1, Box 8.6 | 10 Migrants informal status, limited access to health services & shelter, exclusion from decision-making processes 6.3.6, Box 10.2 |
| 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 | 11 Aboriginal and Torres Strait Islander Peoples poverty, food & housing insecurity, dislocation from community 11.4.1 |
| 6 Island communities limited land, population growth and coastal ecosystem degradation 15.3.2 | 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)



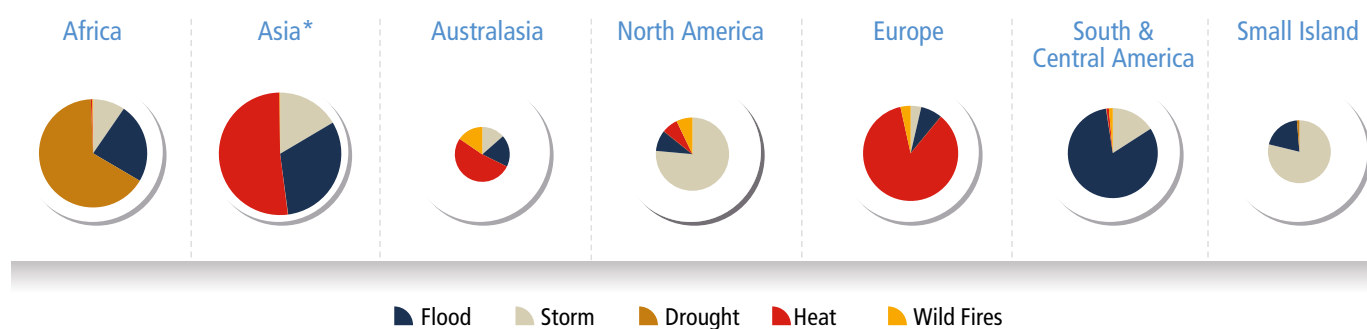
- Relatively severe challenges
- Relatively moderate challenges
- Relatively mild challenges

- 👤 Extreme poverty
- ⛑ Access to health care
- 👤 Dependency ratio

- 🚰 Access to basic infrastructure
- ⚖ Gender inequality
- 🍷 Food security

- 📖 Adult literacy rate
- 🏛 Governance
- 🏥 Health status

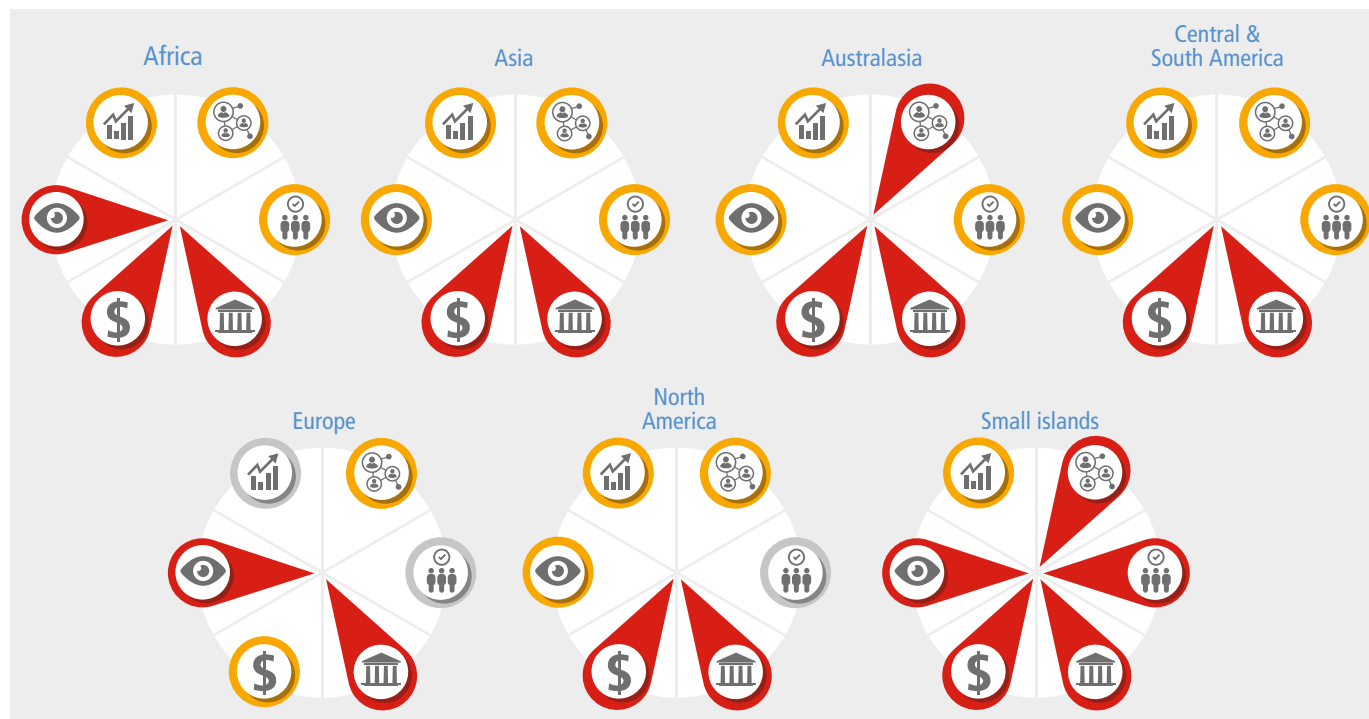
(c) Average mortality per hazard event per region between 2010 and 2020:



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

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

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



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

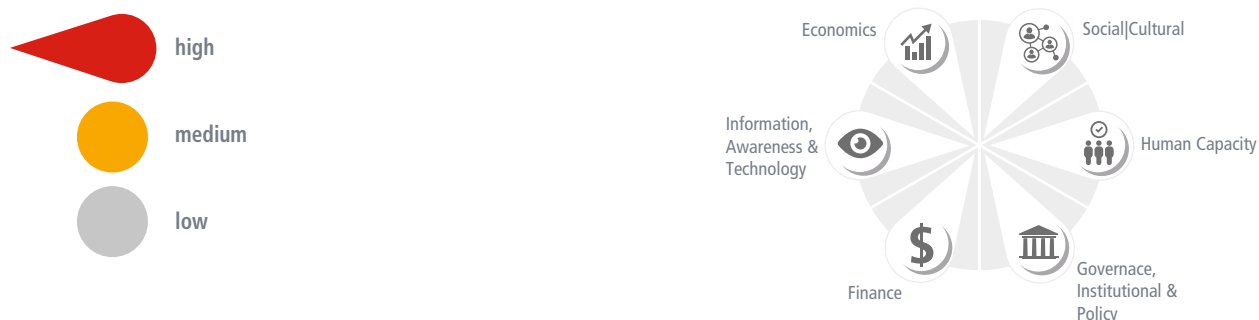


Figure TS.7 VULNERABILITY | (a) The global map of vulnerability is based on two comprehensive global indicator systems, namely INFORM Risk Index and WorldRiskIndex (2019). Climate change hazards and exposure levels are not included in this figure. The relative level of average national vulnerability is shown by the colours. Vulnerability values are based on the average of the two indices, classified into 5 classes using the quantile method. A hexagon binning method was used to simplify the global map and enlarge small states. The map combines information about the level of vulnerability (independent of the population size) with two classes of population density (high density ≥ 20 people/km² and low density < 20 people/km²). 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: $20\text{--}40\%$ of assessed literature identifies this constraint; High: $>40\%$ of assessed literature identifies this constraint. [9.3, 16.4.3, Figure 16.8]

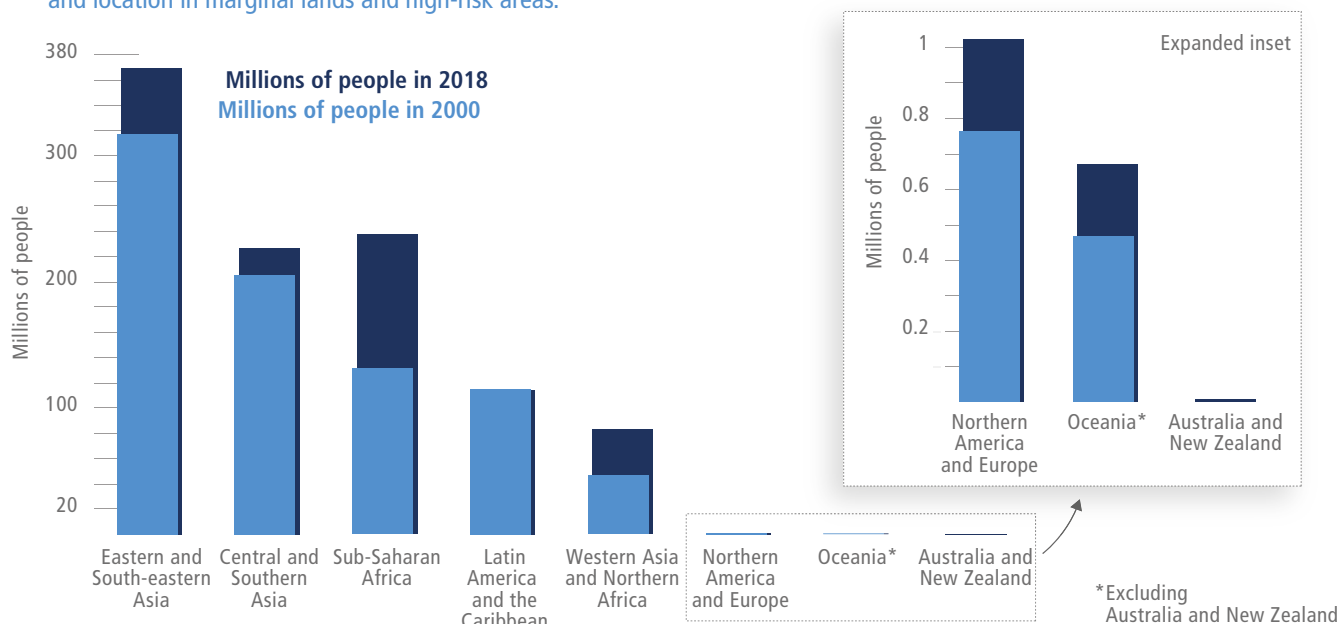
Climate change and human health and wellbeing: Risks and responses

CLIMATE HAZARDS, VULNERABILITY AND EXPOSURE		IMPACT AND RISKS		SOLUTIONS SPACE AND CLIMATE RESILIENT DEVELOPMENT PATHWAYS	
Vulnerability and upstream determinants of health outcomes	Exposure pathway	Example health outcomes		Health System Solution Space	Climate Resilient Development Pathways
Environmental factors Air pollution Biodiversity loss Deforestation Desertification Land degradation Land-use change Water pollution	Social factors 	Physical and mental health risks, displacement, forced migration, other context-specific risks		Environmentally sustainable and resilient technologies and infrastructure	Fully implementing climate-resilient health systems Achieving universal healthcare coverage Achieving net zero Greenhouse Gas Emissions from healthcare systems and services Achieving the Sustainable Development Goals Adopting mitigation policies and technologies with significant health co-benefits
	Vector distribution and ecology 	Chikungunya, dengue, hantavirus, Lyme disease, malaria, Rift Valley, West Nile, Zika		Health information systems (includes integrated risk monitoring and early warning and response systems, vulnerability, capacity, and adaptation assessments, health component of national adaptation plans, health and climate research)	
	Nutrient dense diets and food safety 	Malnutrition, salmonella, foodborne diseases		Service delivery (includes climate-smart health programs, management of environmental determinants of health, disaster risk reduction)	
Socioeconomic factors Growing inequity Demographic change Economic growth Migration and (im)mobility Urbanization Science and tech investment	Water quality and quantity 	Diarrheal diseases, campylobacteria infections, cholera, cryptosporidiosis, algal blooms		Collaborations with other sectors, agencies, and civil society	Achieving the Sustainable Development Goals Adopting mitigation policies and technologies with significant health co-benefits
	Air quality 	Exacerbated respiratory diseases, allergies, cardiovascular disease		Leadership and governance Coherent policies and strategies Sufficient health workforce	
	Heat stress 	Heat-related illness and death, adverse pregnancy outcomes, lost worker productivity		Health authorities Strengthening health delivery and system resilience Leveraging climate change specific funding streams	
Susceptibility Political commitment Social infrastructure Socioeconomic conditions Population health status Individual factors	Extreme weather events 	Injuries, fatalities, mental health effects			

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, 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.

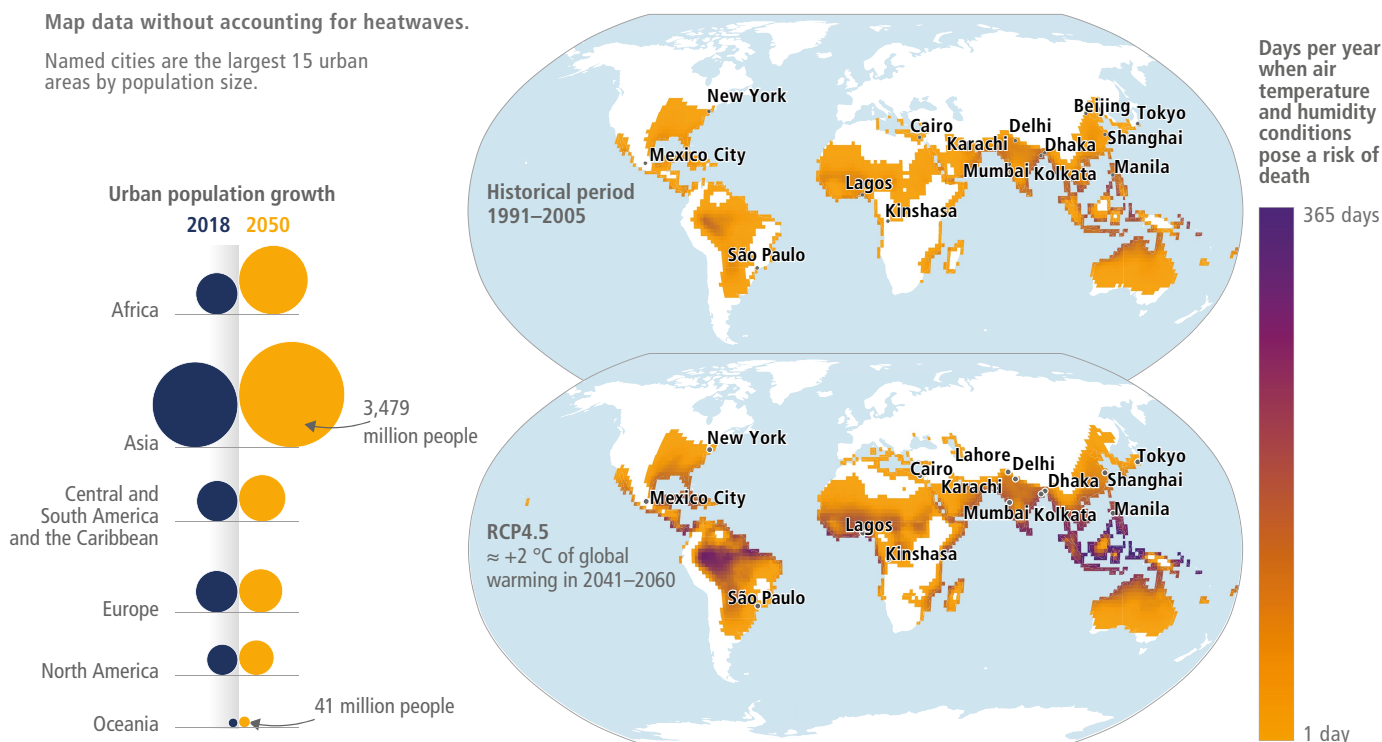
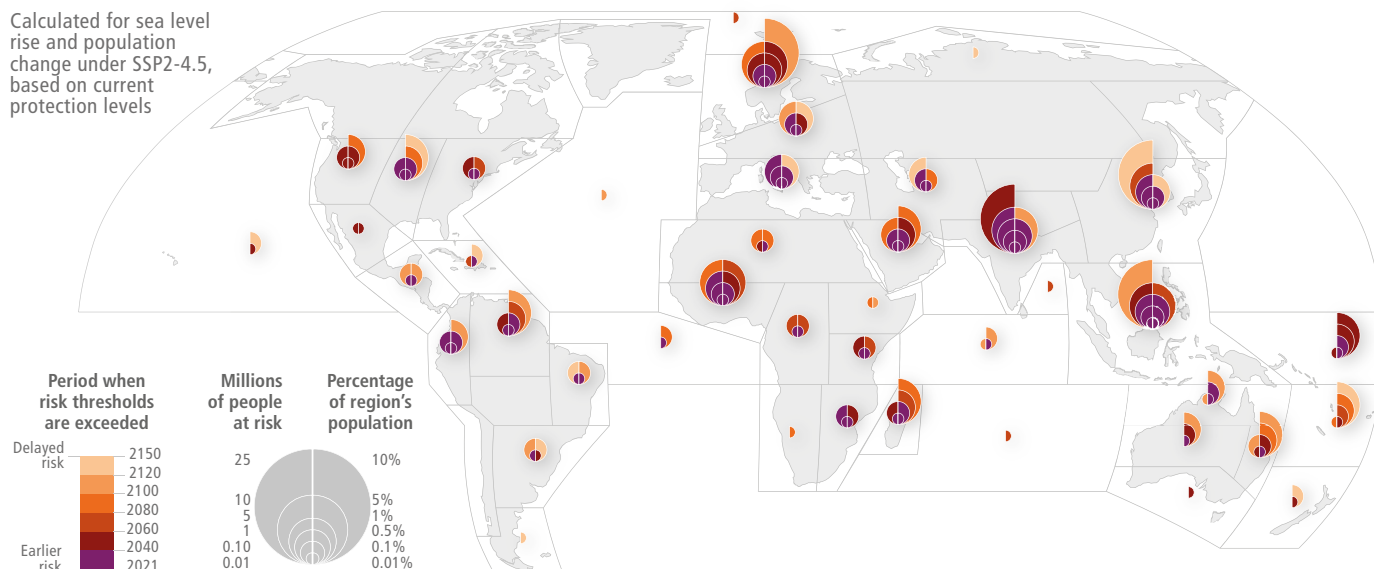


Figure TS.9 URBAN | (a) The regions shown are reflecting the original dataset from UN Habitat and vary from IPCC regions. {6.1.4, 9.9.3, 10.4.6, 12.5.5} **(b)** Heat is a growing health risk due to increasing urbanization and rising temperature extremes. Within cities the urban heat island effect elevates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

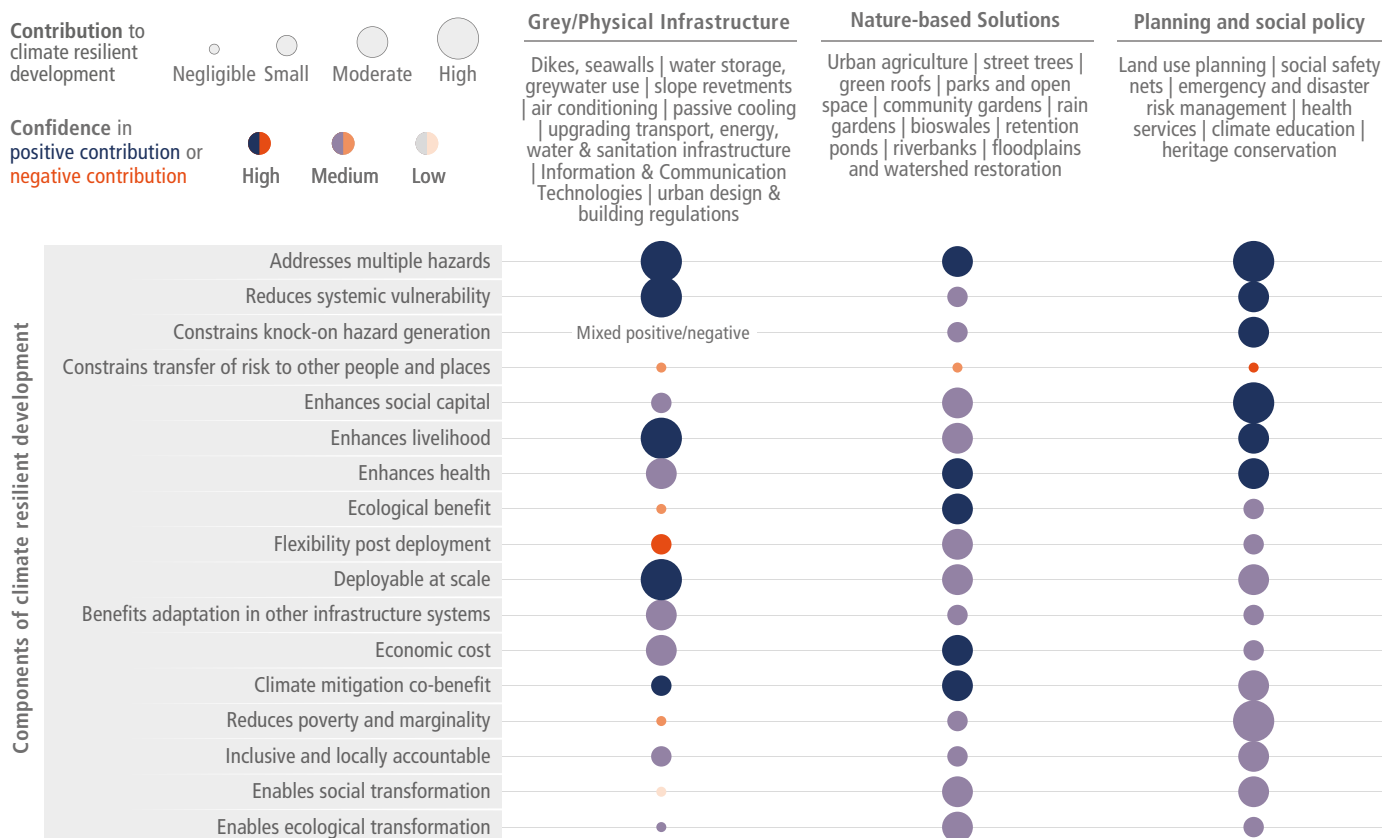
(c) Projected number of people at risk of a 100-year coastal flood.

Calculated for sea level rise and population change under SSP2-4.5, based on current protection levels



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

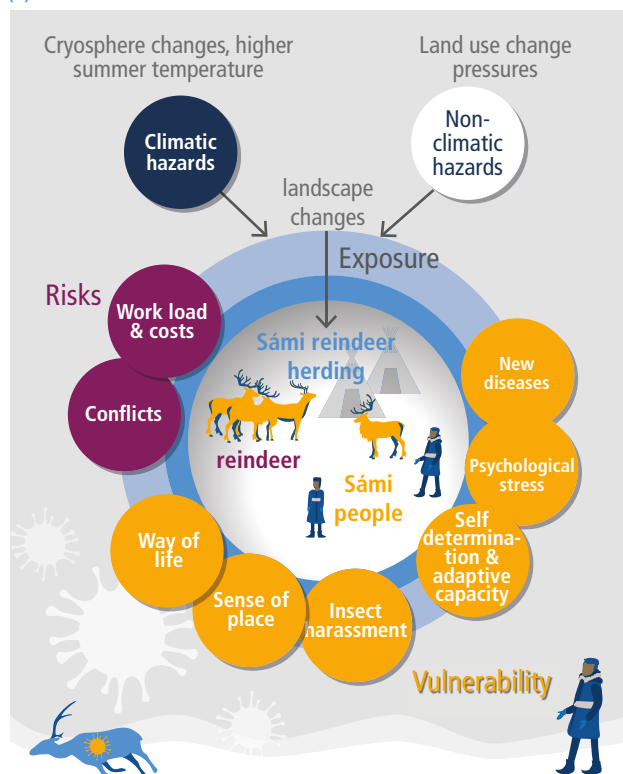
Nature-based solutions and social policy as innovative domains of adaptation show how some of the limitations of grey infrastructure can be mediated. A mixture of the three categories has considerable future scope in adaptation strategies and building climate resilience in cities and settlements.



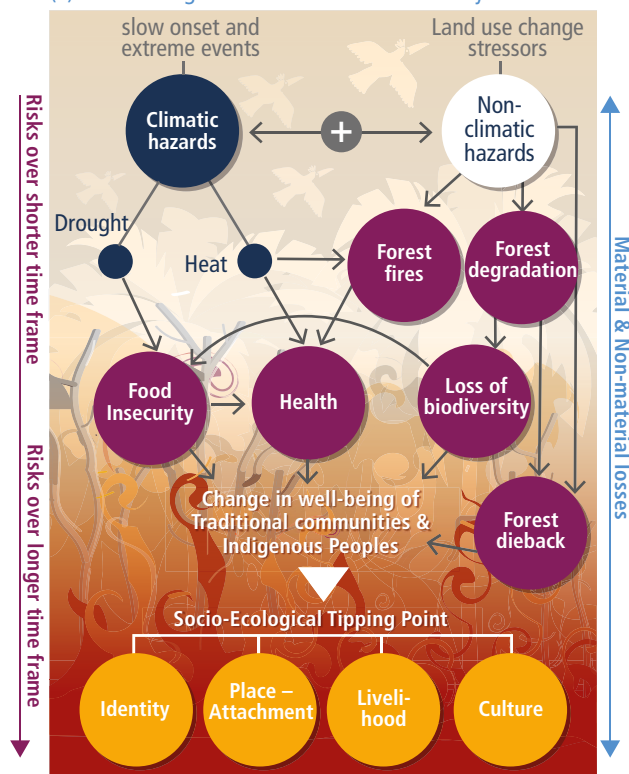
(c) The size of the circle represents the number of people at risk per IPCC region and the colours show the timing of risk based on projected population change and sea level rise under SSP2-4.5. Darker colours indicate earlier in setting risks. The left side of the circles shows absolute projected population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

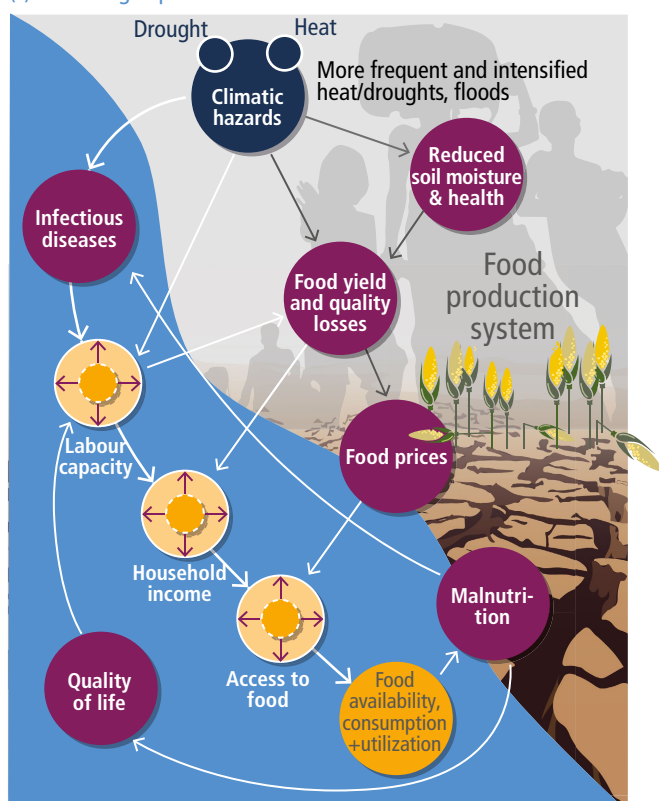
(a) Risks to livelihoods of Sámi Reindeer Herders in the Arctic



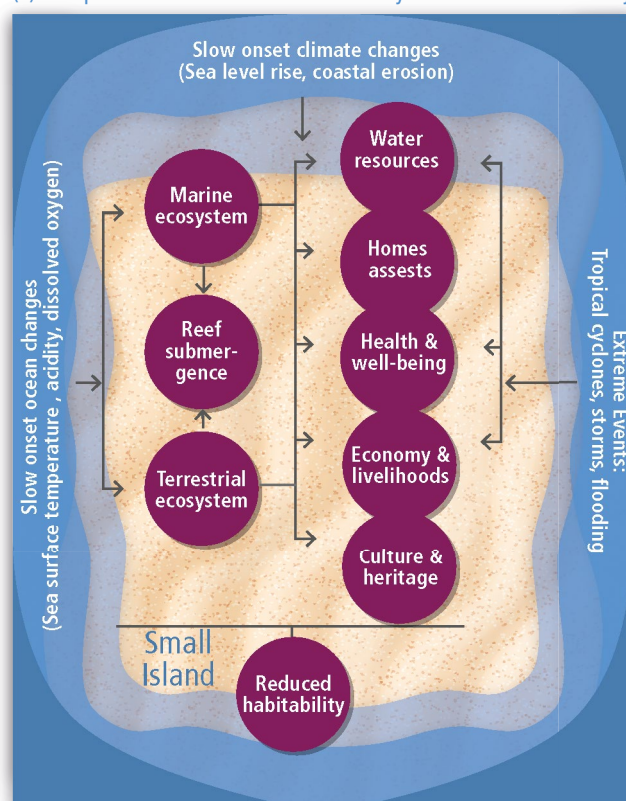
(b) Socio-ecological risks to the Amazonia ecosystem



(c) Cascading impacts of climate hazards on food and nutrition



(d) Compound risks in coastal and island systems reduce habitability



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



Compound risks

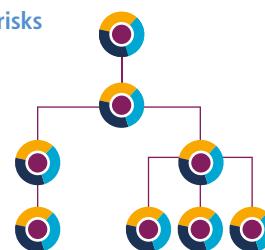
undirectional



bidirectional



Cascading risks



- Vulnerability
- Exposure
- Hazard
- Risk

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

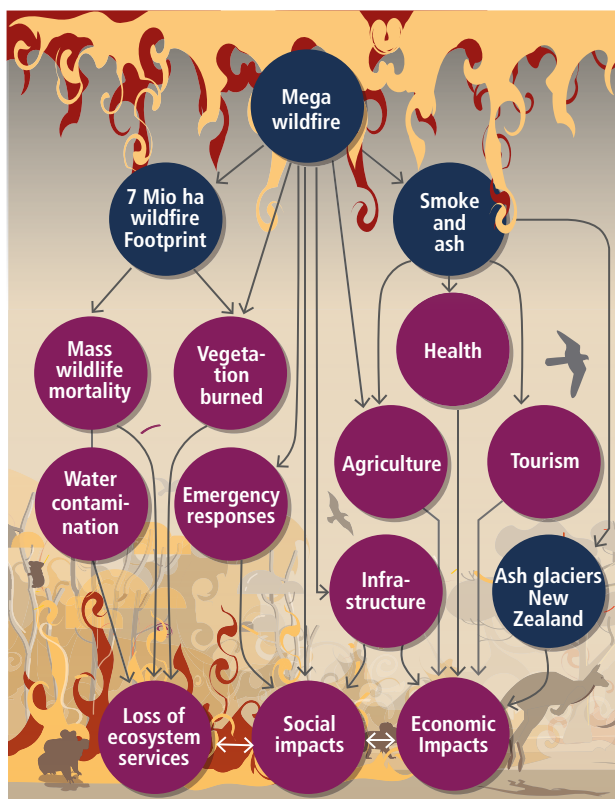


Figure TS.10 COMPLEX RISK | Compound, cascading and transboundary impacts for humans and ecosystems result from exposure to the complex interactions of (1) multiple climatic hazards, including with non-climatic stressors (as seen in panels a, b, c, d), (2) multiple vulnerabilities compounding the effect 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 solutions⁸ are themselves vulnerable to climate change impacts (*very high confidence*). Under higher emissions scenarios they will increasingly be under threat. Nature-based solutions cannot deliver the full range of benefits, unless they are based on functioning, resilient ecosystems and developed taking account of adaptation principles. There is a serious risk that high-carbon ecosystems will become sources of greenhouse gas emissions, which makes it increasingly difficult to halt anthropogenic climate change without prompt protection, restoration, adaptation and mitigation at a global scale. {2.5.2, 2.5.3, 2.5.4, 2.6.3, 2.6.5, 2.6.6, 2.6.7, 3.6.2, 3.6.3, 3.6.5, Box 4.6, 13.4.2, 15.3.3, 15.5.4, CCB NATURAL, CCB SLR}

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

Water and food sectors

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

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

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Index

Index

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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

Abrupt change*, 442–445, 445, 2416, 2457, 2661
responses to, 438

Abrupt ecosystem shifts, 442–445, 445

Acacia trees, 301

Acclimatisation*, 381, 407–409

Accumulation (bioaccumulation)*, 49, 64, 382, 462, 789

Action. See Climate action

Active ownership, 2710

Adaptation*, 134, 2428–2441, 2600–2614

about, 8–9, 22, 43

about: definition, 136

about: summary, 22–30, 71–99

acclimatisation* and, 407–409

adaptation-maladaptation continuum, 2600–2602, 2603

adaptation-related responses, 71, 2415, 2420, 2428–2441

adaptation-related responses: not all reducing risk, 2431, 2440–2441

adaptation-related responses: responses vs. impacts, 2431, 2441

adequacy of, 2431, 2434–2436

autonomous*, 284–285

barriers to, 84, 970, 978–980, 978, 1193, 2444

behavioural aspects, 1460, 1516–1519, 1517, 2433–2434, 2434

benefits of, 22, 2552–2553, 2553

bioeconomy and, 828–831

climate resilience, 1295

community-based*, 26, 91, 666–667, 808, 1246–1247

complexity of, 1228

context-sensitive, 23

contextual nature of, 2600

continuum of, 2600–2602, 2603

costs, 652–653, 1183, 1289

Cross-Chapter Box: ADAPT, 168–171

Cross-Chapter Box: PALEO, 154–157

current adaptation, 22–23, 71–84

decision making framework for, 22

decision-making framework for, 176–177, 307

definition of, 43

delay, consequences of, 1585, 1586, 1587, 1634, 1643, 1651, 1652, 1931, 1982

ecosystem-based (EbA)* (See Ecosystem-based adaptation)

effective, characteristics of, 162–163

effectiveness of, 558, 635–654, 2415, 2432, 2434–2435

effectiveness of, temperature and, 35, 87

enabling and catalysing conditions, 29–30, 97–98

enabling conditions, 29–30, 95, 126, 163–168, 484, 963–982, 1228–1238, 1231, 2546–2547, 2580–2600

ethics and, 162–163, 656–657

evolutionary*, 386, 407–409, 408

facilitating, 173–178

feasibility, 23–28, 24–26, 312–317, 313, 2733, 2769–2807

flexibility and, 29

gender and SDG5, 1174, 2703–2704

goals of, 41–43, 162, 179

governance and, 35, 71, 126, 166–168, 2581–2584, 2583

implementation (See Adaptation implementation)

importance of, 125, 129–132

incremental (See Incremental adaptation)

Indigenous knowledge in, 157–158

individuals and households, 2433, 2433

inequalities potentially worsened by, 2657

innovations in, 93, 101, 820–821

integrated, 23, 99, 106, 108, 2577

inter-regional climate risks, 2443–2444

interconnections, 41

justice and, 162–163, 1175, 2604–2605, 2606

knowledge gaps, 2437–2441

limits to (See Adaptation limits)

linkages, 134, 2658

local government and, 910, 991, 1232, 2433

low regrets options, 33, 94, 98

mainstreaming, 30, 93–94, 167, 909

metrics, 168–171

missed opportunities, 34, 93

mitigation and (See Adaptation and mitigation inter-relationships)

National Adaptation Plans, 911, 2444, 2544

National Adaptation Programmes of Action (NAPAs), 1192

Nationally Determined Contributions (NDCs), 659, 911, 920, 1229, 1246

natural, 386

natural, human, and physical capital for, 1233–1235

near-term, 15, 16, 23

not a substitute for emissions reductions, 15, 55, 87

past climate changes (PALEO) and, 154–157

planned adaptation, 84, 2561, 2562

political commitment and follow-through, 29, 98

priorities in, 29, 90, 94, 100

process and actions, 163–166

progress on, 2428–2441, 2605–2614, 2610–2613, 2620–2621

rate of climate change and, 154–155, 2431

right place and time for, 203, 290, 312

scale of, 22

social policy-based, 909–910, 996

socio-cultural factors, 1235–1238

socio-institutional, 468, 472, 473, 482

solution space, 126, 1127–1128

spectrum of, 2557–2558, 2561, 2619

successful, 180–181, 2548, 2600–2605, 2620–2621

sustainable, 1240

sustainable development and, 25, 132, 2681–2683

synergies, 24–26, 108, 910, 2687–2689

transformational (See Transformational adaptation)

triple-wins, 1240, 1528

types of, 2434

uncertainties, accounting for, 29

urgency of need for, 127, 128–133, 180, 204, 1651, 2045, 2048, 2596–2597, 2597, 2657

water security and, 558–565

youth innovation and, 820–821

See also Maladaptation; specific regions and sectors

Adaptation and mitigation inter-relationships, 308–309, 558, 653–654, 910, 2687, 2785–2787

co-benefits, 34, 108, 308–309, 960–961, 1238

synergies and trade-offs, 24–26, 108, 308–309, 1239–1245, 2687–2689, 2785–2787

Adaptation assessment, 22, 71–84, 72–83,

126–127, 136, 167, 168–171, 2600–2614

FAQ, 2620–2621

feasibility assessment, 2769–2807

monitoring and evaluation (M&E)*, 30

monitoring and evaluation (M&E), 126–127, 167, 168–171, 2547

PROGRESS (Cross-Chapter Box), 2610–2613

Adaptation constraints*. See Adaptation limits

Adaptation costs, 22, 94

projected, 66

reducing, 26

Adaptation deficit*, 1103

Adaptation finance, 30, 656, 719, 823–825, 824, 825, 826, 975–980, 996, 1230, 1247–1249, 2448–2450, 2542–2543

about: summary, 22, 28

access to, 98

adaptation limits and, 28, 84, 649

coverage of, 1247

as enabling condition, 30, 1115, 2584–2585, 2679

enabling conditions for, 1248–1249

FAQ, 2617–2618

future, 1247–1249

gap in, 55, 84, 2542–2543

health sector, 95–96

in Indonesia, 1248

needs for, 26, 93

Rio Markers, 2613

tracking, 2609–2614, 2613

See also Finance

Adaptation Fund*, 1115

Adaptation gaps*, 71, 91, 93, 132, 910, 941–942, 941, 989, 1050, 1194, 1239, 2679–2680

about: summaries, 22, 71–84, 72–73

finance and, 55, 84, 2542–2543

reducing, 84, 85, 1240

Adaptation implementation, 22, 29–30, 2542, 2680

Asia, 1510–1526, 1536–1537

Australasia, 1584–1585, 1635, 1647–1652

cities, 909–910

constraints on, 78

early warning systems, 944–946

enabling conditions, 29–30, 95, 97–99

Europe, 1820

- examples, 296–301, 638, 639–640, 642–643, 644
 FAQs, 666–667, 1998–1999
 food and fibre systems, 811–832
 governance and, 29, 1510–1514
 inclusivity in, 31, 86, 909, 911
 Indigenous knowledge and (See Indigenous knowledge)
 insurance, 2589–2590
 key risks and, 2431, 2444–2450, 2449, 2451–2452
 monitoring and evaluation, 30
 North America, 1932, 1933, 1991, 1998–1999
 ocean and coastal ecosystems, 475–489, 485
 Small Islands, 2081–2086
 urban areas, 909–910
- Adaptation limits***, 31, 78, 127, 132, 171–173, 1174, 1250, 2414, 2444–2450, 2445, 2448–2449, 2558–2562
 about: summary, 28, 84–85
 already reached, 28, 84–85
 biophysical, 650
 cities/urban areas, 26, 910
 compounding conditions, 67–68, 94, 1250
 decision making and, 2544
 definition of, 171, 2444
 determinants of, 85
 economic/finance, 649
 ecosystems, 55, 63, 84
 emissions pathways and, 85
 examples, 2445–2447
 exceedence of, 55, 1046
 finance, 28, 84, 649
 food production, 2449
 hard and soft limits, 28, 84, 127, 171, 649–650, 1224–1225, 1250, 1947, 2415, 2444, 2445, 2560
 linkages, 134
 mitigation and, 85
 ocean systems, 383
 projected, 84–85, 1217, 1222–1225, 2544
 rapid climate change and, 154–155
 RFCs and, 59–60
 risk and, 2504
 sectoral and regional synthesis, 2444–2450, 2448–2449
 on small islands, 2046, 2047, 2049, 2050, 2077
 soft limits already reached, 28, 84–85
 synthesis of, 2444–2450
 temperature and, 28
 transformational adaptation and, 910, 2558–2562, 2559–2560
 uneven distribution of, 93
 urgency for action and, 31
 water-related adaptation, 649–652, 650
- Adaptation options***, 23–28, 1227–1238, 2542–2544, 2548–2562, 2621, 2785–2787
 about: options by sectors, 23–28
 about: summary, 23–28
 24 adaptation options, 2557–2562, 2559–2560, 2604
 behavioral measures, 1460, 1516–1519, 1517, 2433–2434, 2434
 benefits of, 2552–2553, 2553
- climate resilient development (CRD) and, 2676–2689
 for climate risk management, 2548–2562
 co-production of strategies, 30, 971–973, 1942
 combinations of, 2553–2562, 2689
 context-sensitive, 23
 cross-cutting, 27–28, 99, 2781–2785
 decision making and, 2542
 ecosystem-based (See Ecosystem-based adaptation)
 enabling conditions, 29–30, 95, 163–168
 equity and, 23, 25
 FAQs, 994, 2621
 feasibility of, 23, 24–26, 312–317, 313, 2724–2733, 2769–2807
 finance and, 824–825
 future, 23–28
 hard and soft limits for, 84–85
 for key risks, 24–26, 88–90, 2551, 2604, 2621
 limits on (See Adaptation limits)
 low regrets, 33, 94, 98, 652–653, 2165, 2543
 maladaptive potential, 68, 2543–2544, 2548
 meta-analysis of, 564
 migration as an option, 476, 633, 930, 1469–1470
 multiple options available, 23
 nature-based (See Nature-based solutions)
 portfolio of, 2542, 2553–2562, 2577–2580, 2614–2615
 private sector engagement, 2552
 rapid climate change and, 154–155
 for Representative Key Risks, 24–26, 88–90
 SDGs and, 814, 2681–2683
 success of, 180–181, 2548, 2600–2605, 2620–2621
 trade-offs, 1239–1245, 2687–2689
 transformational (See Transformational adaptation)
 See also Transformational adaptation; and specific regions and sectors
- Adaptation pathways***. See Pathways
- Adaptation planning**, 22, 84, 98, 161, 2619
 inclusive, 29, 31, 86
- Adaptation progress**, 22, 71–84, 72–83
 storyline figures, 72–83
- Adaptive capacity***, 27, 68, 93
 assessment of, 1194
 building, 27, 35, 68, 97
 cities/urban areas, 26, 53, 937–940, 975
 compound risks and, 67–68
 exceedence of, 47, 55
 fisheries, 767, 772
 food systems, 767
 indicators of, 1194
 limits to, 975
 ocean systems, 456
 social capital and, 767
 social tipping points and, 1215–1216, 1216
 temperature and, 2666
 See also specific systems and regions
- Adaptive management**, 110
- Adaptive social protection (ASP)**, 943–944, 944
- Addis Ababa Action Agenda**, 40, 920
- Aeroallergens**, 52, 1071, 1095–1096
- Afforestation***, 34, 56, 68, 305, 314, 2374–2375, 2439, 2769, 2776–2777
 water and, 91, 557, 559, 654
- Aflatoxins**, 789, 798, 1072, 1098
- Africa, 1285–1455**
 about, 1289–1299
 about: regions, 1294
 about: Central Africa, 1294, 1326–1327
 about: East Africa, 1294, 1327–1328
 about: North Africa, 1294, 1322–1325
 about: Southern Africa, 1294, 1328–1329
 about: West Africa, 1294, 1325–1326
 adaptation, 1289, 1292–1293, 1339–1342, 1368–1371, 2432, 2436
 adaptation challenges in cities, 979
 adaptation co-benefits and trade-offs, 1289, 1304, 1401
 adaptation costs, 1289
 adaptation, ecosystem-based (EbA), 299–300, 1290, 1339–1342, 1340, 1368–1369, 1369
 adaptation feasibility and effectiveness, 1289, 1301–1304, 1303
 adaptation finance, 1305–1309, 1306–1307
 adaptation for threatened species (penguins), 298–299
 adaptation, in Durban, South Africa, 299–300
 adaptation law, 1312–1313, 1312
 adaptation limits, 1401
 adaptation options, 1289, 1301–1304, 1303
 adaptation planning, 1402
 adaptation trade-offs, 2658
 adaptation, vulnerability reduction and, 1388–1393
 agriculture, 1302–1303, 1304, 1350–1357, 1352, 1401
 agriculture: adaptation, 1356–1357, 1402, 2658
 air quality, 1371, 1379–1380
 aquaculture, 1357
 architecture, 1395
 biodiversity, 59, 1292, 1295, 1299, 1301, 1334–1338, 1337–1338, 2136, 2137, 2141
 biome changes, 1334, 1335
 burned area, 244
 cascading risks, 1302
 cash crops, 1351, 1353
 cities, 66, 979, 1291–1292, 1360–1371, 1362
 cities: adaptation, 1368–1371, 1369
 cities: water scarcity, 1343–1344
 climate change impacts (generally), 1298, 1298, 1361
 climate change literacy, 1314, 1316–1320
 climate data, 1298–1299, 1321, 1323
 climate hazards, 1320–1321, 1321, 1324–1325, 1361, 1395–1396, 1396, 1399–1400
 climate insurance, 1389–1390, 1390
 climate research funding, 1296–1297
 climate resilience, 1295
 climate resilient development, 1289–1290, 1304–1320, 2725
 climate-resilient pathways, 987–988
 climate security, 1292
 climate services (CS), 1290, 1313–1314, 1314, 1315, 1317, 1357

- climate variability, 1291, 1311, 1316, 1329, 1342–1344
- co-production, 1314–1316, 1317
- coastal heritage sites, 1396
- coastal zones, 1291–1292, 1302, 1360, 1364, 1364–1366
- coastal zones: adaptation, 1368
- coffee, 1336, 1353
- community engagement, 1382
- compound risks, 1290
- coral reefs, 1333
- COVID-19 and, 1375, 1390–1393
- crop yields, 1291, 1294, 1350–1353, 1352
- desert locusts, 795
- deserts, 1318, 2197, 2202–2203, 2205, 2206
- diseases, 292, 1294, 1299, 1302, 1371–1385, 1371
- diseases: adaptation, 1383–1385
- droughts, 579, 580–581, 1212–1213, 1290, 1342–1344, 1354, 1361, 1362, 1367
- droughts: Cape Town, 1343
- droughts: projected, 1324–1325
- early warning systems, 1293, 1357, 1382
- economy, 1291, 1300, 1302, 1385–1391, 1386, 1399–1400
- ecosystem services, 1302, 1338
- ecosystems, 1300, 1332–1342
- education, 1291, 1387
- energy insecurity, 1302
- energy systems, 1294, 1363, 1367, 1369–1371
- equity/inequity, 1293, 1387–1390
- extinctions, 1302, 1334–1336, 1336
- extreme events, 1345, 1350, 1377–1378
- FAQs, 1399–1402
- fisheries, 1291, 1357–1360, 1358, 1359
- fisheries: Ghana, 769
- floods, 1344, 1361, 1362–1367, 1362
- food production, 59, 1291, 1299, 1302, 1349–1360, 1352, 1401
- food security, 1294, 1401
- food systems, 1349–1360
- forests, 1294, 1341
- freshwater ecosystems, 1333, 1334, 1336, 1340–1342
- gender in, 1293, 1318, 1346, 1349, 1389
- glaciers, 1290, 1329
- governance, 1289, 1309–1310, 1310
- green buildings, 1395
- greenhouse gas emissions, 1289, 1295
- groundwater, 1342, 1343–1344, 1345
- groundwater: in Dodoma, Tanzania, 1343–1344
- health, 1291, 1300, 1371–1385, 1399–1400
- health: adaptation, 1379–1385, 1384, 1385
- health-climate change nexus, 1380–1381
- heat extremes, 57, 1367
- heat stress and mortality, 1371, 1375–1377, 1378, 1387
- heatwaves, 1290, 1329, 1345, 1361
- heritage, 1292, 1300, 1393–1398, 1396–1398
- HIV, 1371, 1375
- human population, 65, 1291–1292, 1294, 1360, 1361
- human settlements, 1291–1292, 1300, 1360–1371
- human–wildlife conflicts, 1054, 1339, 1481
- hydropower, 1347, 1348–1349, 1367, 1370–1371, 2658
- Indigenous knowledge and local knowledge, 1293, 1313, 1330–1332, 1393, 1396–1398, 1402, 2716
- indigenous foods and nutrition, 1056
- informal employment, 1387–1388
- informal settlements, 987–988, 1360, 1370
- infrastructure, 1292, 1294, 1302, 1302, 1360–1371
- infrastructure adaptation, 1368–1371, 2669–2670
- infrastructure corridor, 2669–2670
- infrastructure deficit, 1360
- insurance, 1293, 1357, 1389–1390, 1390
- interlinkages, 1381
- invasive species, 1338
- Kenya: Vision 2030 (LAPSSET) program, 2669–2670
- key risks, 1299–1301, 1299, 1302
- lake heatwaves, 1290, 1345, 1345
- land, 1294
- land-use change, 66
- landslides, 1362
- languages, 1331
- legislative framework/laws, 1289–1290, 1312–1313, 1312
- Limpopo River, 1345
- livelihoods, 1291, 1293, 1300, 1350, 1356, 1387–1389, 1399
- livelihoods: adaptation limits, 2447
- livelihoods: informal, 1387–1388
- livestock, 1350, 1354, 1355
- losses and damages, 1299, 1300
- malaria, 64, 1371, 1372–1373, 1383
- marine ecosystems, 1302, 1334, 1336, 1342
- marine heatwaves, 1329, 1333
- meningitis, 1375
- mental health, 1378, 1379
- migration (of humans), 1292, 1293, 1303–1304, 1350, 1360
- mitigation, 1304
- mixed crop and livestock farming, 785, 1302, 1350, 1356
- monsoon, 1325–1326
- nature-based tourism, 1338–1339
- nexus approach, 1311, 1346, 1347, 1380–1381
- nutrition/malnutrition, 1046, 1294, 1379
- observed changes, 1320–1329, 1321
- pandemic risks, 1375
- pastoralism, 1208–1209, 1218, 1350, 1354
- perceptions of climate change, 1316
- poverty, 1294, 1302, 1388–1390
- precipitation, 1290
- precipitation: projected, 1324–1325, 2723
- projected changes, 1320–1329, 1324–1325
- projected changes: confidence levels, 1322
- projected risks, 19, 59, 1334–1338
- protected areas, 1339, 1340, 1342
- Rift Valley fever, 51, 747, 750, 1063, 1354
- risk assessment, 1382
- river flow, 1342–1345
- road infrastructure, 1368, 1368
- sea level rise, 1362, 1364, 1364–1366, 1395–1396, 1396
- social protection, 1389–1393
- South African Karoo, 1336
- species range shifts, 1332
- sustainable development, 1304
- teleconnections, 1329
- temperature, 1290, 1294, 1299, 1320–1321, 1321, 1378, 2723
- temperature: projected, 1324–1325, 1378, 2723
- terrestrial ecosystems, 1332–1336, 1334, 1335, 1340
- trade, 1388
- traditional earthen ‘green energy’ buildings, 1395
- transboundary issues, 1289, 1310–1312
- transport systems, 1369, 1370
- tree mortality, 201
- tree planting, 1341
- tropical cyclones, 1290, 1329, 1333, 1361, 1362, 1363–1364, 1377–1378
- urbanisation, 979, 1360
- vaccination, 1375
- vector-borne diseases, 1372–1373
- vegetation, 1333, 1334, 1368
- violence and conflict, 1394–1395
- vulnerability, 1294, 1318–1320, 1363
- vulnerability reduction, 1388–1393
- water, 1290–1291, 1300, 1342–1349, 2658
- water adaptation, 1293
- water-energy-food nexus, 1346, 1347
- water insecurity, 1302
- water-related adaptation, 1346–1349
- water scarcity, 1343–1344
- West Africa, 1325–1326
- Western Cape Region, South Africa, 1212–1213, 1362
- wild-harvested food, 1353–1354
- Agency**, 101, 2659, 2705–2721
- Agenda for Sustainable Development (2030)***, 40, 93–94, 128–129, 911, 912, 919, 920, 2545, 2598, 2657, 2671, 2705
- Aggregated risk assessments**, 113–114, 115–118
- Agreement***, 159–160, 159, 920
- Agricultural drought***, 578–579, 609
- Agricultural intensity**, 90–91, 807, 830, 1697
- Agricultural land deals**, 91, 802–803, 803–804
- Agricultural productivity**. *See* Crop yields; Food production
- Agriculture**, 48–49, 57, 90–91
- adaptation feasibility, 2770, 2778
- adaptation limits, 85, 2449
- adaptation options, 23, 71, 90–91, 1240
- adaptation options, ecosystem-based, 309, 718
- adaptation options, FAQ, 664–666
- adaptation options, on-farm, 718
- adaptation options, water-related, 23, 622–625, 645–647, 646, 664–666
- as adaptation response, 626–627
- agro-ecological farming (AF), 71, 306–307, 309
- buffering capacity, 782–783
- climate resilient development (CRD), 1242–1243
- climate-smart (CSA)*, 108, 624, 819, 829–830, 1186, 1242, 1304
- competition issues, 805–806, 835–836
- compound risks, 67–68

- conservation agriculture*, 624, 1242–1243, 1356
cropping systems, 643, 738, 2778
Cross-Working Group Box (BIOECONOMY), 828–831
in deltas, 2470–2471
digital, 808
diversification, 624–625, 718, 722, 745
drought-resistant crops, 643
droughts and, 555, 578–579, 584–585, 613
emergence of, and past climate, 155–156
equity considerations, 734
expansion of, 14, 1695, 1697, 1713
extreme events and, 717
farmworkers, 734, 795
financial actors/investment, 810–811, 823–825, 824
flooding and, 585, 613, 805–806
gender and, 1468
genetics and, 743–744, 745
government policies and, 806
insurance and, 814–817
integrated systems, 91, 787
irrigation, 16, 556, 564, 584, 613–614, 626–627
irrigation-related adaptation, 645
livelihood shifts, 1174
maladaptation, 806, 2437, 2439
mixed systems, 782–787, 785, 1302
no-till, 1240
observed impacts, 12, 48–49, 555, 584–585, 717
outdoor workers, 60, 717–718, 734, 796–797, 797
projected risks, 57, 612–614
rainfed, 733
salinity and, 461–462, 585
smallholder, 585, 734, 806, 823, 1052, 1240, 1243, 1293
soil conservation, 624, 645
trade-offs, 804–805, 805
transformations, 822–823
urban and peri-urban*, 799, 800
water for, 16, 74–75, 613, 805–806
water management, 655
water sources, 624–625
water use, FAQ, 664–666
See also Crop yields; Food production
- Agro-ecological farming (AF)**, 306–307, 309
Agroecology, 71, 90, 718, 722, 745, 746, 815–817, 830
Agroeconomy*. See Bioeconomies
Agroforestry*, 640, 643, 647, 718, 722, 783, 1242–1243
adaptation, 71, 786–787, 786
cocoa and coffee, 784–785, 788, 825–827
enabling conditions, 1243
feasibility, 2769, 2775–2776
maladaptation, 2439
- Aichi targets**, 40
Air pollution*, 1095–1096
adaptation options, 1109–1110, 1110
Africa, 1371
cities and, 928, 939
feedbacks, 275–276
fires and, 1045, 1054, 1071, 1095
human health and, 939, 1095–1096
ozone, 52, 1096
respiratory diseases, 1045
Air quality, 457, 458, 461, 468
human health and, 1045, 1095–1096
interconnections, 910
ozone and, 1095–1096
in urban areas, 910, 949
Airports, 934
Albedo*, 206, 267, 275, 276
Algae, 401
coralline, 401, 407, 413, 415
macroalgae, 401, 404
as protein source, 753
See also Kelp
Algal blooms, 592, 1098, 1603
harmful (HABs), 20, 404, 463, 469, 789, 1076, 1098, 1840–1841, 1840, 1951
North America, 1946, 1947, 1951
Alien species. See Invasive species
Allergens, 1863
Allergic disease, 1071
Alpine Convention, 2298
Alpine ecosystems, 202
phenology, 225
Amazon region/forest, 82, 1220–1221, 1704–1706, 1754, 1757–1758
anthropogenic soils, 1757–1758
biomass, 202
biome shifts, 202
carbon cycle, 50, 1691, 1693, 1705, 1706, 1757–1758, 2499
carbon emissions (2003–2008), 250–251
as carbon source, net, 50
cascading risks and impacts, 21, 68, 82
deforestation, 244–245, 251, 1220, 1693, 1705, 1707, 2380
deforestation: climate impacts of, 2380
dieback, 207, 265, 272
droughts, 50, 82
ecological transformation, 56, 82
fires, 244–245, 271–272, 1220–1221
irreversible and severe losses, 21
land use change, 21, 272
projected changes, 56, 1219, 2500
tipping point, 82, 272, 1707, 2380
tree mortality, 272–273
See also Tropical forests
Amphibians, 200, 1703
chytrid fungus (Bd) and, 200, 201, 231–232
extinction risk, 202, 231
golden toad (extinction), 201, 2132
Andes region, 1691, 1697, 1701–1703, 1712–1715, 1717, 1723, 1727, 1734
pastoralists, 298, 1703
See also Central and South America
Animals
animal-sourced foods, 799
biomass, 57–60
body size, 225–226, 230
diseases (zoonoses), 13, 51–52, 57
diseases (zoonoses) and, 232–233, 233–235, 789–790
feral animals, 1598, 1636
human–animal conflicts, 1054–1055
marine, 406–407
multiple drivers, responses to, 406–407
Antarctica. See Polar Regions
Anthrax, 232–233, 2340
Anthropogenic* climate change, 125, 130, 555
attribution of, 152
DAI (dangerous anthropogenic interference), 69, 2415, 2420, 2450–2453
See also Detection and attribution
Anthropogenic forcing, 152
Aquaculture, 11, 57–60, 456, 459–460, 763, 773–782
adaptation, 309, 476–480, 722, 779–782, 781
adaptation feasibility, 2770
Africa, 1357
aquatic plants, 779
Asia, 1467, 1482, 1491, 1492, 1495
Central and South America, 1710, 1715, 1716, 1730
Europe, 1840–1841, 1844–1846, 1845, 1849, 1866
gender and, 775
inland systems, 773–774, 775–776, 776, 778–779
maladaptation, 808
marine, 776–779, 777–779
North America, 1957–1962, 1958, 1960–1961, 1997
observed impacts, 11, 614, 717, 724, 773–774, 774
ocean acidification and, 459–460
pearls, 461
polar regions, 2332
projected impacts, 57–60, 718, 775–779, 776–779
selective breeding, 780
shellfish, 463, 779
Small Islands, 2065–2067, 2070, 2099–2100
sustainable, 2774–2775
vulnerabilities, 774–775, 776
Aquifers. See Groundwater
Aragonite, 396, 412, 1951, 2329
Arctic Ocean, 431–433, 432
acidification, 2324, 2329
primary productivity, 2328–2329
sea ice, 391, 395, 399, 1936, 1938, 2321, 2324, 2325, 2332, 2336–2339, 2338–2339
upwelling, 2329
Arctic region, 68, 2319–2368
about (See also Polar Regions)
adaptation, 1988, 2321–2322, 2344–2351, 2346–2349, 2350
anthrax, 232–233, 2340
cascading risks and impacts, 2321, 2325, 2333, 2347–2349
climate change, pace and magnitude of, 68, 2321–2322, 2323, 2333, 2351, 2354
cryosphere changes, 50
culture and heritage sites, 2321, 2331, 2339–2340
diseases, 45, 51–52, 200, 232–233
economies, 2321, 2335–2336
ecosystems, 11, 45, 1932, 2323, 2324–2325, 2325–2331, 2333, 2348–2349, 2350
FAQs, 2333, 2336–2337, 2339, 2351
fire/wildfires, 245, 272, 2324, 2330–2331

- fish/fisheries, 59, 2321, 2328, 2329–2330, 2333–2335, 2333, 2334, 2348
- food webs, 1950, 2321, 2329–2330, 2332
- human health and wellness, 2340, 2341, 2347
- impacts: pace and magnitude of, 2321–2322, 2323, 2333, 2351, 2354
- impacts: severe disruption projected, 62–63
- Indigenous Peoples, 50, 68, 2321, 2322, 2323, 2325, 2352
- Indigenous Peoples: adaptation, 2339, 2343–2344
- Indigenous Peoples: Inuit knowledge, 2343–2344
- Indigenous Peoples: self-determination, 2322, 2342–2344, 2353–2354
- infrastructure, 59, 66, 933, 2321, 2334–2335, 2339, 2347
- key risks, 2344, 2346–2349
- lakes, 210
- livelihoods, 63, 1218, 1224, 2321, 2339–2340, 2342, 2345
- marine ecosystems, 1950
- marine heatwaves, 215
- marine mammals and seabirds, 215, 441
- maritime trade routes, 2338–2339
- mercury contamination, 1076
- nomadic lifestyles, 2342
- observed impacts, 11
- permafrost, carbon stocks, 201, 250
- permafrost thaw, 11, 251, 272, 279, 2321, 2325, 2331, 2332, 2339
- projected impacts, 62–63
- sea ice, 391, 395, 399, 1936, 1938, 2321, 2324, 2325, 2332, 2336–2339
- sea ice loss, 2321, 2338–2339
- sea ice projections, 59
- settlements and communities, 2336–2340
- shipping, 2321, 2332, 2334–2335, 2336–2339, 2347
- temperature, 215, 391, 1053, 2324, 2325, 2326, 2332
- tourism, 481, 1973, 2321, 2325, 2335, 2348
- trade and trade routes, 2335, 2338–2339
- vector-borne diseases in, 45
- water resources, 50
- zoonoses, 51–52
- See also* Polar Regions
- Arid zones***. *See* Deserts and semiarid areas
- Aridity***, 569, 570, 2197
- Aridity Index (AI), 2197, 2199–2200, 2200, 2211
- See also* Deserts and semiarid areas
- Arsenic**, 798
- Artificial intelligence (AI)**, 655, 2585–2593
- Asia, 1457–1580**
- about, 1459–1468
- about: countries and regions, 1462, 1463–1468, 1463, 1467
- adaptation, 1461–1462, 2432, 2436
- adaptation barriers, 1507, 1513–1514
- adaptation, behavioural aspects, 1460, 1516–1519, 1517
- adaptation, climate-change (CCA), 1472, 1511–1514
- adaptation, cross-boundary, 1489
- adaptation, ecosystem-based (EbA), 1461, 1504–1505, 1505
- adaptation finance, 1507, 1519–1522
- adaptation, food production, 1495–1497, 1496
- adaptation implementation, 1510–1526, 1536–1537
- adaptation interactions, 1488–1490
- adaptation limits, 2446–2447, 2449
- adaptation options, 1461, 1471–1472, 1483, 1501, 1528, 1534–1535, 1537
- adaptation, triple wins, 1528
- adaptation, urban areas, 1502–1506, 1503, 1505
- agriculture, 1464, 1468, 1490–1497, 1492, 1511–1512, 1515, 1533
- agriculture: adaptation limits, 2446–2447
- agriculture: irrigation, 2658
- agriculture: women in, 1468
- air quality, 1460, 1507
- bamboo, 2279
- Bangladesh Delta Plan, 1503, 1513
- biodiversity, 1466, 1473–1474, 1475–1477, 1533, 2136, 2137
- biome changes, 1472–1473, 1475, 1532
- capacity development, 1525–1526, 1527
- Circulating and Ecological Sphere (CES), 1462, 1515
- cities, 66, 1460, 1468, 1497–1506
- cities: megacities, 1499, 1503
- cities: urban agglomerations, 1498
- climate, generally, 1463–1466
- climate change hotspots, 1466
- climate resilient development (CRD), 1461, 1526–1532, 2725
- climate variability, 1460
- coal power plants, 615
- coastal areas, 1459, 1478–1483
- coastal flooding, 1499–1500
- coastal habitats, 1459
- conflicts and peace in, 1102
- coral reefs, 1478–1479, 1482–1483
- crop areas, 1493–1494
- crop production, 1491–1493, 1492
- deforestation, 251
- deltas, 1462, 1487, 1503, 1513
- deserts, 2204–2205, 2206, 2218
- detection and attribution, 1464
- disaster risk reduction (DRR), 1460, 1506, 1514, 1528, 1529–1530
- diseases, 292, 1460, 1507–1508, 1509
- droughts, 1464, 1498–1499
- dust storms, 1459, 1464, 1478, 1533
- economy, 1468
- ecoregions, 1467
- ecosystems, 1466, 1467
- ecosystems: adaptation options, 1477–1478
- ecosystems: ocean and coastal, 1478–1483
- education, 1525–1526, 1527
- El Niño Southern Oscillation events, 1494
- energy, 1468–1472
- energy demand, 1459, 1468, 1470
- energy infrastructure, 1470, 1472
- extirpation/extinction risk, 1476, 1476, 1477
- extreme weather events, 1459, 1460, 1464, 1506
- FAQs, 1532–1537
- fisheries and aquaculture, 1467, 1482, 1491, 1492, 1495
- floods, 1464, 1499–1500, 1533
- food production, 1459–1460, 1490–1497, 1492, 1496
- food security, 1462, 1494
- food–water–energy nexus, 1530–1531
- forests and forestry, 1466, 1512, 1515–1516
- freshwater resources, 1483–1490, 1485
- Ganges-Brahmaputra region, 1485–1488, 1489–1490
- gender, 1467–1468
- glaciers, 1459, 1463, 1465, 1485, 1532
- governance, 1510–1514
- groundwater, 1484, 1488–1489
- hazards, 1460
- health and well-being, 1468, 1506–1510, 1509
- Heat Action Plan, 1503
- heat-related deaths, 1507, 1508
- heat stress, 1468
- heatwaves, 1460, 1464, 1464, 1533
- heatwaves: marine, 1483, 1491
- Himalayas/Hindu Kush, 983–984, 983, 1462, 1485–1486, 1485, 1488, 1489–1490, 2280
- human population, 65, 1462, 1468
- human settlements, 1460, 1468, 1497–1506
- income inequality, 1497
- Indigenous knowledge and local knowledge, 1463, 1525–1526, 1535–1536
- Indigenous Peoples, 1525–1526
- infrastructure, 1460, 1497–1506, 1503
- infrastructure: impacts, 1501–1502
- infrastructure: technology and, 1503–1504, 1507
- invasive species, 1476–1477
- key risks, 1501, 1532–1533
- key systems, 1468–1510
- lakes, 1487
- land subsidence, 1499
- land tenure, 1504
- land-use change, 66, 1460, 1473
- land-use, sustainable, 1504
- livestock, 1492, 1493, 1511
- losses and damages, 1460–1461, 1520, 1521
- malaria, 1507–1508, 1509
- malnutrition, 1462
- mangroves, 1480, 1482, 1483, 1516
- marine ecosystems, 1467, 1478–1483
- medicinal plants, 1476
- mental health, 1460, 1508
- migration, 1460, 1469–1470, 1505–1506
- monsoon, 1459, 1463, 1466
- multiple stressors, 1462
- nutrition, 1046, 1462, 1508
- observed climate change, 1463–1465
- ocean acidification, 1465, 1466
- oceans, 1465
- ozone, 1507, 1508
- Pearl River Estuary, 462
- peatlands, 301
- permafrost, 1459, 1464, 1465, 1485, 1500
- phenology, 1474–1475
- poverty, 1468
- power disruptions, 1501–1502

- precipitation, 1459, 1464–1466, 1498–1499, 1532–1533, 2723
- production: oceans, 1464, 1481
- production: terrestrial, 1474–1475
- projected changes, 1465–1466
- projected changes and risks, 19, 59
- protected areas, 1483
- renewable energy, 1471
- risk insurance, 1522–1523
- riverine floods, 1500
- rivers, 1485–1490, 1498
- sea level rise, 1462, 1465, 1466, 1478, 1499–1500, 1532–1533
- sea walls and dikes, 1503
- seagrass meadows, 1480
- snow mass, 1486
- social justice and equity, 1531–1532
- social protection, 1523–1525
- species ranges and biodiversity, 1473–1474, 1475–1477
- Sponge City Programme, 1503, 1504–1505
- streamflow, 1485–1486
- Sundarbans, 462, 611, 1480, 1516
- Sustainable Development Goals, 1461, 1536–1537
- technology uses, 1503–1504, 1507, 1514–1516
- temperature, 1459, 1498, 1507, 2723
- temperature extremes, 57, 1498, 2723
- terrestrial and freshwater ecosystems, 1459, 1472–1478
- tigers (Bengal), 1476, 1516
- transboundary adaptation, 1489
- transboundary aspects, 1485, 1488
- transportation disruption, 1502
- treeline, 1472–1473, 1475
- tropical cyclones, 1463, 1465, 1500
- urban adaptation, 1502–1506, 1503, 1505
- urban agglomerations, 1498
- urban areas, 1460, 1468, 1497–1506
- urban heat islands, 1498, 1533
- urban resilience (Xi'an, China), 985
- urban vulnerabilities, 1497
- urbanisation, 1460, 1468, 1498
- vulnerabilities, 1466–1468, 1481, 1488–1490, 1495, 1497
- vulnerable populations, 65, 1468
- water resources, 1459, 1483–1490, 1485, 2658
- water scarcity, 1498–1499, 1532–1533
- water stress, 1459, 1485, 1515
- water supply and disposal disruption, 1502
- wildfires, 201, 245, 1464, 1474, 1477, 1533
- wind speeds, 1465, 1471
- See also specific countries*
- Aspergillus**, 789
- Assessment**, 149–158
- of adaptation (See Adaptation assessment)
- of impacts (See Impact assessment)
- IPCC Assessment Reports (See IPCC Assessment Reports)
- of vulnerabilities (See Vulnerability assessment)
- See also* Decision making; IPCC Assessment Reports
- Atlantic meridional overturning circulation (AMOC)**, 391, 395
- Atmospheric river events**, 1953, 1962
- Atolls**. *See* Small Islands
- Attribution***, 151–154
- assessment/methods, 151–152
- Cross-Working Group Box (ATTRIBUTION), 151–154
- See also* Detection and attribution
- Australasia, 1581–1688**
- about, 1583–1586, 1587
- adaptation, 1584–1585, 1587, 1639, 1641–1642, 1650–1651, 2432, 2436
- adaptation, governance and policies, 1584–1585, 1632–1633, 1635, 1640–1642, 1641–1642, 1643–1644
- adaptation, inaction/delay, 1585, 1586, 1587, 1634, 1643, 1651, 1652
- adaptation, Indigenous Peoples and, 1585, 1629–1632, 1631, 1642, 1650, 1652, 2716
- adaptation, proactive, 1585, 1586, 1640, 1645–1647
- adaptation, transformative, 1585
- adaptation barriers, 1584–1585, 1635, 1643–1644, 1644
- adaptation decision making, 1621, 1622, 1633, 1640–1647, 1641–1642
- adaptation enablers, 1585, 1587, 1644–1647, 1645
- adaptation implementation, 1584–1585, 1635, 1647–1652
- adaptation limits, 1584–1585, 1635, 1643–1644, 1652
- adaptation monitoring and evaluation, 1585, 1645, 1646
- adaptation trade-offs, 2658
- adaptation, underinvestment in, 2657
- adaptive capacity, 1584–1585
- agriculture, 1584, 1613–1614, 1635, 1637–1638
- alpine systems, 1584, 1594, 1595, 1597, 1635, 1636, 1638
- beaches, 1625
- biodiversity, 1584, 1591, 1635, 1636, 2136, 2137–2138, 2139
- birds, 1595–1596, 1596, 1598, 1603, 1605, 1628
- Bramble Cay melomys, 200, 221, 1583, 1591, 1595
- cascading impacts, 1583, 1584, 1591–1594, 1635, 1637–1638
- cascading impacts: wildfires, 83, 1600–1601
- cities and settlements, 59, 1584, 1616–1623, 1620
- cities and settlements: adaptation, 1619–1623
- climate action, urgency for, 1583, 1587, 1647, 1651, 1652
- climate change, 1586–1591
- climate resilient development (CRD), 1585, 1647–1652, 2726
- climate trends, 1583, 1586–1591, 1588–1594
- climate uncertainties, 1585, 1591
- coastal adaptation, 1621–1622
- coastal areas, 1584, 1594–1596, 1635, 1636, 1638
- coastal areas: sea level rise and, 1583, 1584, 1594, 1639
- coastal ecosystems, 1596, 1599–1607
- compound impacts, 1583, 1584, 1635, 1637–1638
- coral reefs, 1583, 1584, 1602–1607, 1635, 1636, 1638
- coral reefs: Great Barrier Reef, 57, 301, 1584, 1602, 1605–1607
- coral reefs: observed changes, 1583, 1602, 1604, 1636
- coral reefs: projected impacts, 59, 1584, 1587, 1602–1607, 1636
- costs of impacts, 1583, 1585, 1599, 1618, 1632–1634, 1634
- COVID-19, 1624
- cross-sectoral and -regional issues, 1632–1633
- deserts, 2205, 2206
- detection and attribution, 1587–1590, 1628, 1629
- disaster risk reduction, 1584, 1619, 1633, 1634
- diseases, 292–293, 1602, 1603, 1615, 1623
- disproportionate impacts, 1587
- drought, 579, 580, 1209, 1608, 1610–1611
- drought: observed, 1583, 1589–1590, 1608, 1610–1611
- drought: projected, 1589, 1591, 1592–1593
- dugongs, 1604
- economy, 1583, 1586, 1602, 1613, 1632, 1633–1634, 1634, 2657
- emission pathways/scenarios, 1583, 1585, 1587, 1590–1591, 1651, 1652
- energy sector, 1627–1629, 1628
- ENSO, SAM, IOD and IPO, 1591
- estuaries, 1583, 1602–1603, 1603, 1621
- eucalyptus, 208, 1594, 1599, 1615–1616
- extinction, 1583, 1591–1594, 1597, 2132
- FAQs, 1648–1651
- feral animals, 1598, 1636
- finance, 1626–1627
- fires/wildfires, 201, 1583, 1599–1601, 1623, 2658
- fires/wildfires: 2019–2020, 83, 245, 589–590, 591, 1583, 1599–1601
- fires/wildfires: area burned, 201, 244–245
- fires/wildfires: cascading impacts, 83, 1600–1601
- fires/wildfires: dangerous fire weather, 1583, 1589, 1591, 1599–1600
- fires/wildfires: observed, 201, 1583, 1589–1590, 1599–1601
- fires/wildfires: projected, 272, 1592, 1594, 1594
- fisheries, 1602, 1607, 1616, 1631
- floods, 1583, 1612–1613, 1618
- flying foxes, 216–217, 1595, 1637
- food, fibre, ecosystem products, 1613–1616
- forestry, 1616
- forests, 1584, 1591, 1594, 1595, 1597–1598, 1635, 1636, 1638
- freshwater resources, 1608–1613
- fruit bats, 215
- glaciers, 1583, 1625
- Gondwana refugia, 300, 1599
- governance, 1584, 1587, 1633, 1635, 1637–1638, 1640–1642, 1641–1642
- groundwater, 1591, 1608, 1630
- health and well-being, 1623–1625, 1624
- heat-related mortality, 1584, 1618, 1635, 1637–1639, 1648
- heatwaves, 1618, 1624–1625, 1639, 1648
- heatwaves: marine, 1583, 1584, 1589, 1590, 1602, 1603–1605
- human population, 1586

human systems/society, 1583, 1594, 1635, 1636, 1648–1649

Indian Ocean Dipole (IOD), 1591

Indigenous knowledge (IK), 1585, 1650, 2716

Indigenous Peoples, 1583, 1585, 1586, 1602, 1629–1632

Indigenous Peoples: Aboriginal and Torres Strait Islander Peoples (Australia), 1585, 1629–1630, 1630, 1650

Indigenous Peoples: Tangata Whenua Māori (New Zealand), 1585, 1617, 1630–1632, 1631, 1650, 2716

Indigenous Peoples: Uluru Statement from the Heart, 1630

Indigenous Peoples, social justice issues, 1609, 1617, 1630

Indigenous Peoples, UN Declaration of Rights, 1585, 1630

inequalities, 1583, 1586, 1624, 1629, 1631, 1635

inequalities: intergenerational, 1586

infrastructure, 1584, 1616–1623, 1620

insurance, 1626–1627

invasive species, 1594, 1598

Kakadu National Park, 1596, 1625

kelp forests, 1584, 1635, 1636, 1638

key risks, 1584, 1587, 1634–1640, 1636–1639, 1648–1649

koalas, 1595

land use, 1584, 1587, 1591, 1608, 1611, 1613, 1617

livestock, 1615–1616

losses and damages, 1583, 1618

losses and damages: from wildfires, 83, 245, 1583

Macquarie Island, 1595, 1603

mangroves, 1602, 1604

mass mortality events, 215–217, 1595, 1606, 1648

migrants to, 1586

mining, 1627

Murray-Darling Basin, 1597, 1610–1611

New Zealand, 1583, 1617

observed changes: Australia, 1586–1590, 1588–1589, 1648

observed changes: New Zealand, 1586–1590, 1588, 1590, 1648

observed climate change, 1583, 1586–1590, 1588–1590

observed impacts, 1583, 1591–1629

ocean acidification, 1587, 1589–1590, 1593–1594, 1607

ocean ecosystems, 1599–1607, 1603–1605

phenology, 1591, 1595–1596

poverty, 1629

precipitation: observed, 1583, 1588–1590

precipitation: projected, 1584, 1591, 1592–1593, 1612, 2723

precipitation extremes, 1589–1590, 1592–1593, 1612

projected changes: Australia, 1590–1591, 1592–1593

projected changes: New Zealand, 1590–1591, 1593–1594

projected climate change, 1590–1591, 1592–1594

projected impacts, 19, 59, 1583–1584, 1591–1629

rainforests, 1591, 1599

risk/vulnerability assessment, 1584, 1646

rivers, 1597–1598, 1610–1611

roads, 1620, 1620, 1632

runoff, 1608, 1609, 1610

rural areas, 1583, 1584, 1586, 1610, 1618, 1620, 1635, 1637

sea level rise, 1584, 1618, 1621–1622, 1636

sea level rise: observed, 1583, 1589–1590, 1621–1622, 1636

sea level rise: projected, 1584, 1587, 1592–1593, 1594, 1618, 1621–1622, 1636

snow, 1583, 1587, 1589–1590, 1593–1594, 1625–1626

social inequities, 1583

socioeconomic inequalities, 1586

species distribution, range, and viability, 1583, 1587, 1602, 1603–1604, 1616

storm surges, 1583, 1604, 1619, 1621, 1626

streamflow, 1608

Tasmanian Wilderness World Heritage Area, 300

temperature: observed, 1583, 1588–1590, 1603

temperature: projected, 1584, 1591, 1592–1593, 2723

temperature extremes, 1587, 1589–1590, 1592–1593, 1618, 1625, 2723

terrestrial and freshwater ecosystems, 1591–1598, 1595–1598, 1608–1613

tourism, 1583, 1605, 1607, 1617, 1625–1626

tropical cyclones and storms, 1583, 1589–1590, 1592, 1594, 1623

tuatara, 1598

turtles, reptiles and frogs, 1597–1598

water contamination, 1623

water resources, 1608–1613, 1617

weeds, 1594, 1598, 1616, 1636, 1637

wetlands, 1596, 1598

wildlife species, 1584, 1595–1598, 1602, 1637

wind speed, 1589, 1590, 1592, 1593

World Heritage Areas, 1595, 1625

Autonomous adaptation*, 284–285

B

Bangladesh

adaptation and disaster risk reduction, 657

adaptation limits, 2446

Bangladesh Delta Plan, 1503, 1513

Cyclone Aila (2009), 1209, 1236–1237

Cyclone Amphan (2020), 588–589, 590

Cyclone Sidr, 1209

human–tiger conflicts, 1055

maladaptation, 1222

sea level rise and, 611

Sundarbans, 462, 611, 1480

See also Asia

Baobab tree, 270–271, 760

Bark beetles, 248–249, 273

Baseline*. See Reference periods

Batrachochytrium dendrobatidis (Bd), 200, 231–232, 1703

Beaches, 424–426, 424

beach nourishment, 1368, 2077, 2172

erosion, 414–415

fauna, 425–426

observed impacts, 388

projections, 425

rocky shores, 414–418, 418

sandy, 424–426, 424

See also Coastal areas and ecosystems

Beaver, 592

Bees, 740

Behavioural change, 1460, 1516–1519, 1517, 2175–2176, 2433–2434, 2434

Behavioural plasticity, 225

Benthic* habitats and ecosystems, 47, 431–432, 454–455, 2328

Bering Sea

Blob and, 416

shelf seas, 427

Bhojtal Lake, India, 300–301

Bhutan, 1222

Bioaccumulation, 49, 64, 382, 462, 789

Biodiversity*, 280, 468, 2661

about, 16, 45–48, 55–57

about: storyline figure, 72–73

about: synthesis, 280–281

adaptation, biodiversity conservation, 55, 285–287, 2148, 2149–2150

adaptation, case studies, 296–297, 300–301

adaptation feasibility, 2769, 2777–2778

adaptation limits, 45

Africa, 1292, 1295, 1299, 1301, 1334–1338, 1337–1338

Asia, 1466, 1473–1474, 1475–1477, 1533

assisted colonisation, 296–297

assisted migration, 221–222, 287

Australasia, 1584, 1591, 1635, 1636

bioenergy crops and, 204

Central and South America, 1695, 1696, 1700, 1709, 1711, 1712, 1725–1726

climate resilient development and, 34–35

connectivity/ corridors, 285–287, 286

Convention on Biological Diversity (CBD), 40, 129, 158, 911

coral reefs, 415, 2147

disease links to, 233

diseases and, 291–295

ecosystem connectivity, 279, 285–287, 286, 2777–2778

ecosystem integrity and, 202

endemic species, 2046, 2125, 2126, 2132, 2135

Europe, 1834–1835, 1836, 1838, 1840

global, 280

hotspots (See Biodiversity hotspots)

human health and, 253

interconnections, 8, 42, 55

key risks, 280, 281, 2456–2457

land area needed to maintain, 109, 203–204

managed relocation, 296–297

models, 253–256

North America, 1939, 1958, 1984

observed impacts, 45–48, 46, 458

ocean and coastal systems, 16, 72, 382, 438–446, 441, 456, 458

peatlands, 301

planetary boundaries for, 2661

- projections, 55–57, 1224
 projections: ocean systems, 440–441, 441, 458
 projections: terrestrial and freshwater, 257–258, 258, 260
 refugia and, 203, 271, 285, 286
 resilience, 87
 risks, 204, 280–281, 2456–2457
 Small Islands, 2046, 2062–2063, 2074, 2081–2083
 species responses, 45
 temperature and, 16
 terrestrial and freshwater ecosystems, 72, 203–204, 253–258, 280–281, 285–287
 timeline to preserve, 204
 trends, 2421
 tropical, 382
 tropicalisation, 438–440
See also Extinction; Range shifts
- Biodiversity hotspots***, 2123–2161
 adaptation, 2125, 2148, 2149–2150
 climate policies and, 2152
 climate velocity, 2125, 2126–2131, 2129
 climatically suitable area, 2133
 compounding and cascading effects, 2134–2136
 definition of, 2126
 endemic species, 2125, 2126, 2132, 2135
 extinction risk, 16, 2125, 2132–2133, 2135
 FAQs, 2151–2152
 freshwater, 2128, 2134, 2138–2143, 2138, 2144
 global perspective, 2126–2136
 human impacts, 2125
 human impacts: recent (map), 2127, 2128
 importance of, 2151
 island, 2136–2137, 2142, 2147, 2150–2151
 list of, 2130–2131
 marine, 2128, 2131, 2134, 2138, 2143–2148
 marine: high latitude, 2146
 mitigation and, 2135, 2149
 observed impacts, global, 2126–2132, 2127–2129
 polar regions, 2140, 2145, 2148
 projected impacts, global, 2132–2136, 2134–2135
 projected warming, 2134
 range shifts and replacement, 2131–2132
 species responses, 2125
 terrestrial, 2127, 2136–2138, 2138, 2139–2142
- Bioeconomies**, 718, 829–831
 maladaptive potential, 313
- BIOECONOMY (Cross-Working Group Box)**, 828–831
- Bioenergy***, 1244–1245, 2421
 crops, 34, 204, 653–654
 water requirements, 557
- Bioenergy with carbon capture and storage (BECCS)**, 204, 313, 653–654
 water footprint, 559, 653–654
- Biofuels***, 1245
 deforestation and, 1697
 water for, 653–654
- Biomass***, 67, 828–831
 animal, 57–60, 67
 demand for, 828–829
 marine organisms, 16, 67, 382, 436, 446–451, 450, 452
 observed changes, 446
- phytoplankton, 382
 projections, 16, 436, 446–451, 452, 2678
- Biomes***
 guidelines for planting semi-natural vegetation, 316
 terrestrial and freshwater ecosystems, 201, 237–243
See also Ecosystems
- Biome shifts**, 56, 200, 202, 237–238
 land use change and, 238
 ocean and coastal ecosystems, 432, 441
 regional, 1334, 1335, 1472–1473, 1475, 1723, 1754
 terrestrial and freshwater ecosystems, 201, 202, 237–238, 252, 262, 269
- Biophysical feedbacks**, 275–276, 277
- Biosphere***, 86–87, 156, 202, 274
 carbon balance in, 202, 279
 climate-biosphere feedbacks, 274
 responses and impacts, 71, 156
 strengthening, 86–87
- Birds**
 mass mortality events, 216
 seabirds, 215, 439, 443–445, 2328
 tree mortality and, 249
- Black Sea**, 427
- Blob, northwest Pacific**, 215, 417
- Blue carbon***, 47, 56, 305, 308–309, 383, 464–466, 468
- Blue carbon ecosystems**, 47, 56, 305, 421–424, 422, 464–466, 1841, 2692
 benefits and trade-offs, 308–309
- Blue-green economies**, 488
- Blue-green infrastructure**, 910, 935, 1461
- Blue infrastructure***, 910, 935, 2692, 2780–2781
- Body size**, 225–226, 230
- Boreal ecosystems**, 200–202, 2323
 biodiversity hotspots, 2140
See also Polar Regions
- Boreal forests**, 201, 237–238, 241
 adaptation, 308
 browning, 2321
 feedbacks, 276
 projected risks, 265–266, 269, 272
 wildfires, 245, 272
- Boundaries**. *See* Planetary boundaries
- Bramble Cay melomys**, 200, 221, 1583, 1591, 1595
- Brazil**. *See* Central and South America
- Browning**, 200, 243, 2321, 2379
- Bryozoans**, 414
- Building design**, 953–954, 989, 1047
- Built environment***, 953–954, 2691
 maladaptation, 2438
 retrofitting, 34, 946, 953, 989
- Built infrastructure**, 472, 474, 474, 476, 482
See also Dams
- Burning ember diagrams**, 114, 258, 281, 2482–2483, 2486, 2507–2508
- Business-As-Usual (BAU)**, 1753, 2328, 2692
- Butterflies**, 296–297
- C**
- C₃ plants**, 264, 614, 748
- C₄ plants**, 264, 734–735, 748
- Califiers**, 396, 400–401, 412–413, 1481, 2329
See also Ocean acidification
- Calification***, 396, 412, 2329
- Campylobacter**, 51, 64, 1045, 1066, 1095, 1623, 1970
- Canada**. *See* North America
- Cancer**, 1071–1072
- Capacity building***, 26, 95, 97, 640, 2657
See also Adaptive capacity
- Capital**
 human, 1234–1235, 1387
 natural, 1233–1234
 physical, 1235
 social, 767, 1237–1238, 2047
- Carbon**
 carbon dependency, 911
 carbon pricing, 2719
 carbon taxes, 2719
 decarbonisation*, 2658, 2690, 2693, 2705, 2708
 low-carbon development, 911, 2660
 social cost of, 2420, 2495, 2498
 storage (*See* carbon sequestration; carbon sinks)
See also Blue carbon
- Carbon balance**, 22, 47, 56, 202–203, 274–277, 275, 276, 281
- Carbon capture and storage (CCS)**, 653
 water requirements, 557, 653
- Carbon cycle**, 56, 274–276, 463, 1836–1837, 2499
 feedbacks, 274–277, 276
- Carbon dioxide (CO₂)***
 direct air capture (DAC), 653
 effects on ecosystems, 1335
 effects on plant growth, 736, 749, 754, 1046
 net zero emissions*, 1121–1122, 2658
 plant productivity and, 749
- Carbon dioxide fertilisation***, 724, 736, 754
- Carbon funds**, 2710
- Carbon sequestration**, 23, 47, 56, 57, 204, 2692, 2769
 climate change effects on, 273–274
 feedbacks and, 274–277, 276
 forests, 240, 250, 272
 mangroves, 459, 464, 2692
 ocean and coastal systems, 440–441, 458–459, 463, 464–466, 468, 1602, 2769
 phytoplankton, 440–441
 seagrasses, 1480
 terrestrial and freshwater ecosystems, 200–202, 204, 243, 249, 273–274, 2692
See also Carbon capture and storage; Carbon sinks
- Carbon sinks**, 22, 56, 57, 249–251
 Amazon forest, 50, 1691, 1693, 1705, 1706, 1757–1758, 2499
 ocean and coastal, 440–441, 458–459, 463, 1602
 peatlands, 241–242, 266, 273, 315
 potential reversal to sources, 22, 47, 50, 56, 69, 201–203, 241–242, 250–251, 253, 273–274, 279, 281, 2499
 terrestrial ecosystems, 47, 201–202, 243, 249–251, 253, 273–274

- Carbon stocks***, 56, 69, 249–251
high-carbon ecosystems, 22, 201–203, 249–251, 273
- Carbonate chemistry**, 401, 413
- Cardiovascular diseases**, 13, 64, 1070, 1096–1097
- Caribbean Region, 2071–2072**
See also Small Islands
- Caribou**, 1945
- Carpathian Convention**, 2298
- Cascading impacts***, 20–21, 67–68, 724, 724, 909
about: storyline figure, 82–83
food production, 724, 724
food webs, 67
health, 1050–1051
infrastructure, 916, 935–936
linkages, 82–83, 134
mega-disturbances, 1946
polar regions, 2321, 2325, 2333, 2347–2349
small islands, 2045, 2071–2072, 2073
urban areas, 909, 916
wildfires, 83, 1600–1601
- Cascading risks**, 20–21, 66, 67–68, 82–83, 147, 912, 935–936, 1065
compound risk vs., 83
- Catalysing conditions**, 98, 2596–2600
climate litigation, 2598, 2599
social movements and, 101, 2598–2600, 2736
urgency, 2596–2597, 2597
- Catalysts**, 98, 126, 164–165, 2543, 2598
- Cattle**. See Livestock
- Central and South America, 1689–1816**
about, 1691–1698, 1695, 1696, 1763–1764
about: subregions, 1695, 1695–1696, 1724–1726
about: Central America (CA), 1695, 1698–1700, 1724–1726
about: Northeastern South America (NES), 1695, 1709–1710, 1724–1726
about: Northern South America (NSA), 1695, 1703–1706, 1724–1726
about: Northwestern South America (NWS), 1695, 1700–1703, 1724–1726
about: South American Monsoon (SAM), 1695, 1706–1709, 1724–1726
about: Southeastern South America (SES), 1695, 1711–1713, 1724–1726
about: Southern South America (SSA), 1695, 1717–1719, 1724–1726
about: Southwestern South America (SWS), 1695, 1713–1717, 1724–1726
adaptation, 1692, 1693–1694, 1697, 1725–1760, 1763–1764, 2432, 2436
adaptation barriers, 1692, 1731–1732
adaptation, case studies, 1756–1760
adaptation, ecosystem-based, 1692, 1727–1728, 1729, 1756–1758, 1763
adaptation, engagement in, 1693
adaptation feasibility, 1755–1756, 1755
adaptation governance and finance, 1692, 1693, 1694, 1727, 1740, 1745, 1752–1753, 1758–1760
adaptation, IKLK and, 1693, 1733–1734, 1749, 1770
- adaptation limits, 1731–1732, 1748, 1765–1767, 2449
adaptation, maladaptation, 1222
adaptation, national plans, 1730, 1731, 1745–1746, 1763
adaptation options, 1727–1728, 1737–1739, 1748–1749, 1753–1754
agriculture, 1697, 1707, 1710, 1715, 1736, 1763, 1768–1769
agriculture: adaptation, 1692, 1693, 1736–1739, 1738–1739, 1764, 1768–1769
agriculture: climate-smart, 1693
agriculture: expansion of, 1695, 1697, 1713
agriculture: growth duration, 1716
agriculture: intensification of, 1697
agriculture: productivity, 1691, 1692, 1693, 1697, 1707, 1708
agriculture: suitable area for, 1692, 1699–1700, 1736
agroforestry, 1739, 1769
air quality, 1705, 1714, 1717
alpaca and vicuña, 1703
alpine systems, 1703
Amazon forest, 1693, 1697, 1705–1707
Amazon forest: carbon cycle, 1691, 1693, 1705, 1706, 1757–1758
Amazon forest: deforestation, 244–245, 251, 1220, 1693, 1705, 1707, 2380
Amazon forest: tipping point, 272, 1707, 2380
Amazon region, 1704–1706, 1754
Amazon region: anthropogenic soils, 1757–1758
Amazon region: drought, 1704, 1706–1707
amphibians, 1703
andean pastoralists, 298, 1703
Andes region, 1691, 1697, 1701–1703, 1712–1715, 1717, 1723, 1727, 1734
aquaculture, 1710, 1715, 1716, 1730
biodiversity, 1695, 1696, 1700, 1709, 1711, 1712, 1725–1726
biodiversity hotspots, 1693, 1712, 1715, 2136, 2137, 2139
biofuel production, 1697
biomes, 1697
biomes: biome shifts, 1723, 1754
carbon cycle, 1691, 1693, 1705, 1706, 1757–1758
case studies, 1756–1760
Cerrado biome, 1706, 1707, 1712, 1763
chikungunya, 51, 1702, 1710
cities, 1698, 1711, 1716–1717, 1739–1742, 1746, 1761
cities: adaptation, 1692, 1693, 1753, 1764, 1766–1767
cities: impact synthesis, 1725
cities: informal settlements, 1692, 1693, 1701, 1739, 1740–1741, 1746
cities: megacities, 1739
cities: population, 1698, 1707, 1709, 1711, 1739
cities: São Paulo, Rio de Janeiro, Belo Horizonte, Buenos Aires, 1711, 1712
cities: urban heat islands, 1711, 1712
climate change finance, 1752–1753
climate change perceptions, 1693, 1750
climate justice, 1693
- climate refugia, 1706, 1715
climate resilient development (CRD), 2726
climate services, 1737, 1742–1743
climate variability, 1697, 1698
coastal areas, 1701, 1704, 1716, 1723, 1754
coastal ecosystems, 1691, 1697, 1714, 1716, 1728–1732
coffee, 1700, 1736
conflicts, 1735, 1750
coral bleaching, 1723, 1754
coral reefs, 1691, 1693, 1709, 1710, 1723, 1729, 1754
COVID-19, 1708, 1723, 1752
cross-cutting issues, 1749–1753, 1762–1763
cyclones, extratropical, 1711, 1712
deforestation, 1691, 1693, 1697, 1703, 1736
dengue, 51, 1691, 1699, 1702, 1705, 1710, 1712, 1713
desertification, 1697, 1709, 1710, 1722
deserts, 1697, 1709, 1710, 1722, 2204, 2206
dew water, animals dependent on, 1707
disaster management plans, 1745–1746
diseases, 293, 1691, 1693, 1699, 1702, 1708, 1710, 1712, 1715, 1722, 1762
diseases: forecasting/warnings, 1743, 1755
diseases: vector-borne, 293, 1691, 1692, 1699, 1702, 1702, 1705, 1722
disproportionate impacts, 1692
droughts, 581, 1699, 1704, 1706–1709, 1716, 1753
droughts: extreme, 1709, 1718
Dry Corridor, 49, 1698, 1700, 1763
early warning systems (EWSs), 1692, 1743, 1745, 1755
economic exclusion zones (EEZs), 1701, 1721
economy, 1695, 1712, 1715, 1728, 1746, 1763
education, 1692, 1696, 1704, 1715, 1729, 1737, 1745
El Niño Southern Oscillation (ENSO), 1700–1702
exotic species, 1714, 1715
exposure, 1691, 1698–1721
extreme events, 1691, 1697, 1699, 1704, 1711, 1763
FAQs, 1765–1770
fires, 1695, 1704, 1705, 1706, 1713–1714, 1715, 1717, 1718–1719, 1718
fires: area burned, 245–246
fires: mega-fires (Chile, 2017), 589, 591
fisheries, 1705, 1715, 1716, 1730
floods, 1691, 1692–1693, 1701, 1703, 1708–1709, 1722–1723, 1753, 1763
floods: extreme, 1704, 1708, 1751, 1763
food availability, 1736
food, fibre and ecosystem products, 1736–1739, 1755, 1761
food imports/exports, 1695, 1699, 1736
food production, 1695, 1736, 1764, 1768–1769
food security/insecurity, 1691, 1692, 1699, 1705, 1722, 1753
forests, 1693, 1700, 1703, 1715, 1717–1718, 1739
forests: carbon sink or source, 1691, 1693
forests: tree mortality, 1691, 1706
frogs, 1703
Galapagos and Malpelo islands, 1701

- gender aspects, 1692, 1750–1751
 glaciers, 1691, 1701, 1702–1703, 1714, 1717, 1718
 glaciers: glacier lakes, 1715
 glaciers: lake outburst floods, 1715
 glaciers: regional overview, 1734
 governance, 1692, 1693, 1727, 1746–1747
 grasslands, 1696, 1700, 1717, 1724, 1768
 greenhouse gas emissions, 1697
 gross national income, 1696
 groundwater, 1716
 Guatemala, water governance, 1759–1760
 hazards, 1698–1721, 1719, 1744
 health, 1691, 1699, 1710, 1714, 1722, 1742–1746, 1761–1762, 1764
 health : adaptation, 1692, 1742–1746, 1753, 1755
 health : climate hazards, 1744
 health : impact synthesis, 1725
 health : national health plans, 1745
 heat stress, 1699, 1712
 heatwaves, 1697, 1698, 1704, 1708, 1713
 housing, 1692, 1701, 1740–1741
 Human Development Index, 1696
 human population, 1695, 1696, 1698, 1709
 hurricanes, 1699
 hydropower, 1701, 1708, 1710, 1718
 impacts, 1698–1721, 1763
 impacts: key impacts, 1721–1725
 impacts: regional synthesis, 1724–1725
 Indigenous knowledge and local knowledge, 1692, 1693, 1705, 1733–1734, 1749, 1770
 Indigenous Peoples, 1692, 1695, 1704, 1705, 1716, 1770
 Indigenous Peoples: adaptation, 1704–1705, 1733–1734, 1749, 1770, 2716
 Indigenous Peoples: agriculture, 1699
 inequalities, 1693, 1707, 1714, 1715, 1739–1740, 1746, 1765–1766
 infrastructure, 1691, 1714, 1716, 1722, 1739–1742, 1761
 infrastructure: adaptation, 1692, 1741–1742, 1753, 1754
 infrastructure: green and grey, 1741–1742
 infrastructure: impacts (synthesis), 1725, 1754
 insurance, 1693, 1731, 1737, 1738, 1748
 invasive species, 1712
 key risks, 1692–1693, 1721–1725, 1722–1723, 1726
 key risks: adaptation options, 1753–1756, 1753–1754
 knowledge gaps, 1760–1763
 land cover, 1696
 land use, 1691, 1736, 1747
 land use change, 1693, 1695, 1697, 1714, 1739, 1763
 landslides, 1691, 1692, 1701, 1711, 1715, 1722
 leishmaniasis, 1699, 1705
 leptospirosis, 1702
 life expectancy, 1696
 Lima, Peru: water governance, 1758–1759
 livelihoods, 1691, 1701, 1705, 1715, 1746–1749, 1762
 livelihoods: rural, 1692, 1699, 1704
 livestock/cattle, 1697, 1699, 1718, 1737–1739
 losses and damages, 1699, 1712, 1733
 maize, 1699–1700, 1708, 1710, 1716
 malaria, 64, 1699, 1702, 1702, 1705
 mangroves, 1691, 1710, 1713, 1729–1730
 marine protected areas, 1730
 Mesoamerica, 1695
 Mexico (See North America)
 migration and displacement, 1226, 1691–1692, 1703, 1704, 1710, 1751–1752, 1767–1768
 migration and displacement: by subregion, 1725
 mining, 1714–1715
 observed changes and impacts, 1691–1692, 1697, 1698–1721
 ocean and coastal ecosystems, 1691, 1693, 1697, 1714, 1716, 1728–1732, 1761
 ocean and coastal systems: adaptation, 1692, 1729–1730, 1730
 ocean and coastal systems: impacts, 1706, 1725
 ocean and coastal systems: sensitivity of, 1721
 Pantanal, 1706, 1707
 pastoralism, 1717
 Patagonia, 1717, 1718
 payment for ecosystem services (PES), 1692
 penguins, 1718
 permafrost, 1702, 1715
 pine (*Pinus*), 1714, 1715, 1719
 plants/vegetation, 1707
 poverty, 1693, 1695, 1697, 1698–1699, 1710, 1712, 1727, 1746–1749, 1762, 1765–1766
 poverty: by subregion, 1725
 precipitation, 1691, 1703–1704, 1708, 1709, 1713, 1714, 1717, 2723
 precipitation extremes, 1692–1693, 1698, 1702, 1709
 projected changes and impacts, 19, 59, 1692–1693, 1697, 1698–1721
 protected areas, 1692, 1727, 1730
 Quito, Ecuador, 1756–1757
 regional impacts, 1724–1725
 rice, 1716
 rivers, 1692, 1707–1708, 1711–1712, 1718
 runoff, 1701, 1708, 1718
 rural areas, 1695, 1698, 1710, 1728
 rural livelihoods, 1692, 1712
 rural poor, 1698–1699
 sea level rise, 1704, 1709, 1712, 1714, 1723, 1754
 slums, 1701, 1712, 1746
 snow, 1702, 1714, 1717, 1718
 social movements, 1693, 1749–1750
 soil (anthropogenic soils), 1757–1758
 soybeans, 1697, 1708, 1716
 species range and distributions, 1691, 1712
 storm surges, 1712
 streamflows, 1697, 1708, 1715–1716
 sugarcane, 1697, 1699, 1736
 sustainable development, 1746–1749, 1766–1767
 temperature, 1704, 1714, 1715, 1717, 2723
 temperature extremes, 1691, 1698, 1703, 1706, 1717, 1763, 2723
 Terras Pretas de Índio, 1757–1758
 terrestrial and freshwater ecosystems, 1691, 1725–1729, 1725, 1760–1761
 terrestrial and freshwater systems: adaptation, 1692, 1755–1756
 terrestrial and freshwater systems: impacts, 1706
 tourism, 1709, 1710, 1714
 transport systems, 1742
 undernutrition, 1697
 vulnerabilities, 1691–1692, 1698–1721, 1720
 vulnerable groups, 1695, 1750
 water, 1725, 1732–1736, 1755, 1764
 water availability, 1692, 1697, 1699, 1700, 1714
 water governance, 1758–1760
 water insecurity, 1722, 1753
 water management, 1692
 water quality, 1732–1733
 water-related conflicts, 1735
 water resources, 1691, 1702–1703, 1712, 1714, 1763
 water scarcity, 1693, 1710, 1716, 1717, 1732–1733
 water supply, 1692
 wetlands, 1691, 1692, 1713, 1718
 wheat, 1716
 Zika, 1691, 1710
Certainty, 159–160, 159
 See also Uncertainty
Certainty language, 40, 41
Chagas disease, 1969
Change
 abrupt change, 442–445, 445, 2416, 2457, 2661
 irreversible (See Tipping points)
 land use (See Land-use change)
Chikungunya, 51, 1063, 1093–1094, 1702, 1710, 1969, 2427
 in Europe, 1862
Children
 differential impacts, 17, 1197, 1218–1219
 diseases and, 1089, 1097
 future of, 162, 1860
 health, 1045, 1053, 1219, 1221
 mental health, 1046, 1076
 mortality (deaths), 1046, 1094, 1192, 1207
 nutrition, 1046, 1049, 1089, 1097, 1209, 1219
 stunted growth, 51, 1089
 vulnerabilities, 49, 65, 1052, 1053, 1185, 1198, 1206, 1217
Chile: mega-fires (2017), 589, 591
China
 Pearl River Estuary, 462
 urban resilience (Xi'Xian), 985
 See also Asia
Choices. See Societal choices
Cholera, 13, 64, 292–294, 1064, 1371
Chytrid fungus, 200, 201, 231–232
Ciguatera fish poisoning, 2064–2065
Circular bioeconomies, 718, 829–831
Circular economies, 631, 718
Circulating and Ecological Sphere (CES), 1462, 1515
Circulation
 atmospheric, 1591
 oceanic, 391, 395
Cities and settlements*, 907–1040
 about, 912–916
 about: summaries, 17, 53–54, 65–66

- about: storyline figure, 80–81
- adaptation (See Urban adaptation)
- adaptive capacity, 26, 53, 909, 937–940, 975
- air pollution, 928
- building design, 953–954, 989
- carbon dependency, 911
- case studies, 983–988
- climate resilient development, 33–34, 911, 989–990, 2730
- climate shocks, 976–977
- coastal (See Cities and settlements by the sea)
- compound events and impacts, 67–68, 909, 935–936
- COVID-19 and, 909, 959
- Cross-Working Group Box (URBAN), 988–991
- decision making in, 2601–2602
- definition of, 914, 915
- as drivers of climate change, 989
- economic impacts, 909
- exposure, 53–54
- FAQs, 992–996
- functional disruptions, 17
- global trends, 916–917
- governance, 91, 910, 913, 964, 973
- green spaces, 289, 309
- heat islands, 922–925, 952, 1711, 1712
- impacts and risks, 921–940
- informal settlements, 53, 909, 911, 912, 917
- information and communication technologies, 910, 931, 954
- infrastructure, 910, 914, 921–940
- infrastructure: adaptation, 942–947, 952–958
- interconnections, 34, 68, 91, 910, 916
- interdependence, 910, 912, 913, 988–989
- key risks, 938–939, 993
- low-carbon development, 911
- megacities*, 916–917, 1194, 1499, 1503, 2167, 2174, 2175
- metaregions, 912
- morphology and design, 26, 952–954, 974
- New Urban Agenda*, 911, 912, 920
- observed impacts, 12, 46, 53–54, 909
- planning (See Urban planning)
- policy context, 913
- population in, 17, 34, 53, 65, 80, 909, 912, 914
- population growth, 53, 65, 909, 916–917
- poverty and, 80, 921, 929, 943–944, 1701, 1712, 1746
- projected risks, 17, 65–66, 616–617
- risk creation, 66, 910, 921–922
- risks, 909, 910, 921–940, 938–939
- sanitation systems, 934–935, 949–950, 956–957
- SDGs, 910, 911, 912, 2730
- size class by population, 914
- slums, 1701, 1712, 1746
- sustainability, 2691–2692
- terminology, 914–916
- transitions (system transitions), 26–27, 2691–2692, 2699, 2779–2781
- unplanned settlements, 53, 909, 912
- urban agglomerations (Asia), 1498
- urban morphology, 26, 952–954, 974
- vulnerability, 53, 928–930, 992
- water deficits, 558
- women in governance, 973
- See also Informal settlements; Urban areas; Urbanisation
- Cities and settlements by the sea**, 33, 53–54, 66, 68, 2163–2194
 - about, 2167–2169
 - accommodation of built environment, 2173, 2174
 - adaptation, 2165–2166, 2172–2175, 2174, 2183
 - adaptation gap, 2166
 - adaptation pathways, 2175
 - advance, 2173–2174, 2174
 - archetypes, 2167–2169, 2168–2169, 2174
 - behavioural change, 2175–2176
 - choices and behaviour, 2166
 - climate change risks, 2169–2171, 2170
 - climate resilient development (CRD), 2165, 2166, 2181–2182, 2184
 - compound and cascading risks, 2165, 2171
 - defined, 2167
 - deltas, 2174
 - enabling conditions, 2175–2182
 - examples, 2168
 - exposure, 2167
 - FAQs, 2182–2184
 - finance, 2176–2177
 - flooding, 2169
 - governance, 2177–2181, 2178, 2184
 - habitability, 2165
 - hard protection, 2172, 2174, 2183
 - hazards and impacts, 2168–2169, 2169–2171
 - infrastructure, 2170, 2171
 - innovation and, 2165, 2166
 - institutions and regulations, 2166
 - interconnected challenges, 2184
 - interventions for, 2165–2166
 - lessons learned, 2179–2180
 - low-regret actions, 2165
 - megacities, 2167, 2174, 2175
 - nature-based measures, 2172–2173
 - population in, 34, 382, 2167, 2168
 - projections and scenarios, 2165
 - protection, 2172–2173, 2174
 - retreat, 2174–2175, 2174
 - risks, 2165, 2169–2171, 2170, 2171, 2182, 2183
 - sea level rise, 2165, 2171, 2171, 2173, 2174
 - sediment-based measures, 2172, 2174, 2183
 - soft engineering, 2172, 2174, 2183
 - submergence, 2165
 - types of settlements, 2167–2169, 2168
 - urbanisation, 2167–2169
- Citizen science**, 30
- Cleantech venture capital**, 2710
- Climate***, 44
 - common climate dimensions, 9–10, 44, 139
 - Cross-Chapter Box (CLIMATE), 137–145
 - feedbacks: ecosystem-climate, 274–277, 275, 276
 - human influence on, 125, 129, 130–131, 152, 1931, 1939, 2655, 2684
 - interactions of urban areas with, 922–928
 - past climate (PALEO), 154–157
 - weather and, 152, 587
- Climate action**, 42, 108, 125, 1238, 2419, 2664–2665, 2720–2721
 - actions and outcomes, 8, 2662
 - capacity for, 2657
 - climate resilient development and, 2660, 2661–2666, 2662–2665, 2720–2721
 - consensus building for, 1940
 - development pathways and, 2662–2663, 2670–2689, 2674
 - differing perspectives and priorities, 2673, 2733
 - fragmented, 2665
 - frontiers of, 2720–2721
 - health benefits, 1124–1125
 - litigation, 650, 2543, 2598, 2599
 - motivation and, 2595–2596
 - near-term, 15, 16
 - perceptions of climate change and, 1939–1942, 1941
 - policy context, 40, 2666–2667
 - scale of action needed, 108
 - SDG 13, 2666
 - sustainable development and, 2657, 2666, 2670
 - timeline for action, 55–56, 204, 2659
 - transformative, 2665, 2668–2669
 - transitions enabling, 2660, 2665, 2736
 - urgency for, 31, 42, 55–56, 127, 128–133, 146, 204, 1203, 1985, 2045, 2047, 2048, 2596–2597
 - urgency levels, 2596–2597, 2597
 - window of opportunity for, 31, 32–33, 35, 102–107, 204, 2658, 2662–2663
 - youth and social movements, 911, 912, 946–947, 963, 2418, 2720–2721, 2736
- See also Urgency
- Climate change***, 42, 2662–2663
 - additional deaths attributable to, 1089
 - anxiety about, 1078
 - assessment of, 130–132, 133
 - attribution of, 151–154
 - communication about, 126, 159–160, 159, 1931, 1940
 - consensus building, 1940
 - current severe risks from, 2657
 - ecosystem health and, 92
 - education about, 946–947, 1525
 - evidence of worldwide impacts, 129
 - future outcomes, 2658, 2662
 - future response capacities, 1214–1215
 - human dimensions of, 1177
 - human influence as unequivocal and growing, 123, 125, 129, 130–131, 152, 1931, 1939, 2655, 2684
 - impacts (See Impacts)
 - inaction and, 1585, 1586, 2665
 - key concept linkages, 134
 - linkages, 8, 42, 82–83
 - mid to long-term risks, 16–17, 18–20
 - misinformation on, 1931, 1939–1940
 - near-term risks, 15
 - past and future, 2662
 - past (paleo-ecological evidence), 154–155
 - perceptions of, 1316, 1645–1646, 1931, 1939–1942, 1941, 2596

- projected time to reach 1.5°C, 10, 44, 144–145
 public awareness, 29
 public face of, 588–591
 rate of, 43
 reference periods and years, 10, 44
 regional projections, 2677–2678
 scientific consensus on, 35, 125, 129, 130–131, 152, 1931, 1939, 2655, 2684
 speed and magnitude of, 41–43, 2321, 2351, 2658, 2733
 as threat to human and planetary health, 35
 unprecedented nature of, 45, 55–56, 68
 urgency of current moment, 8, 31, 55–56, 127, 128–133, 146, 180, 1203, 1985, 2596–2597, 2597
 window of opportunity, 31, 32–33, 35, 102–107, 204, 2662
- Climate change literacy***, 96, 98, 1314, 1316–1320
- Climate change scenarios.** See Scenarios
- Climate-compatible development (CCD)**, 1238–1239, 1238
- Climate debt**, 236
- Climate extremes***. See Extreme weather events
- Climate finance***, 35, 2586–2593, 2708–2709, 2721
 See also Finance
- Climate governance***. See Governance
- Climate grief**, 467, 594, 1078, 1971
- Climate information.** See Climate services
- Climate justice***, 96–97, 126, 921, 1175, 1180, 2657
 gender and, 2700
 youth-led movements for, 911, 912, 946–947, 2720–2721
 See also Justice
- Climate literacy***, 96, 98, 1314, 1316–1320
- Climate litigation**, 650, 2598, 2599
- Climate models***, 9–10, 44, 138–143, 725–727, 726
 CMIP5 and CMIP6, 9, 44, 139–143, 1590
 Earth System Models (ESMs)*, 138, 143
 integrated SSP-RCP framework, 10, 44
- Climate policy.** See Governance; Policies
- Climate Policy Initiative (CPI)**, 2590
- Climate refugia***, 87, 203, 271, 285, 286, 414, 435, 475
 Gondwana refugia (Tasmania), 300, 1599
 Joshua Tree Park (USA), 299
 in mountain areas, 2276, 2277–2279
- Climate regulation**, 202, 457, 458–459, 461
- Climate resilient development (CRD)***, 127, 177–178, 2655–2807
 about, 8, 30, 42, 2657–2668, 2662–2665
 about: summary, 30–35, 100–112
 achieving, 35
 actors in, 2658, 2659–2660, 2661, 2666, 2667, 2705, 2736
 adaptation and, 2676–2689, 2734–2735
 adaptation needs, 2658
 adaptation options enabled by, 2657
 agency and, 101, 2659, 2705–2721
 Aichi 2020 Target, 40, 302
 analysis by sectors, 1241–1245
 arenas of engagement, 32, 2659, 2662, 2664, 2711–2720
 assessment of, 2667, 2721–2724, 2725–2731
 biodiversity and, 34–35
 capacity building, 27, 35, 68
 civic engagement, 33, 112, 2659
 climate action and, 2670–2689, 2720–2721
 climate change risk, regional, 2721–2722, 2723
 climate justice and, 1175, 1238, 2657
 co-benefits of, 34, 108, 109, 2657
 conclusions on, 2732–2733
 conditions for, 31
 constraints and limits, 2657
 coordinated adaptation and mitigation with, 2658, 2687
 current pathways, 100, 2657, 2660
 decision making and, 34, 1245–1247, 2614–2615, 2660, 2661
 decisions resolving divergent views, 33
 definition of, 177, 2657, 2734
 development patterns and, 31, 2658, 2659, 2670–2689, 2674
 development perspectives, 31, 2671–2673
 differential starting points for, 31, 1174, 2661
 differing capacities, 31, 35, 2659, 2661–2666
 differing opinions and priorities, 90, 2658, 2661, 2673
 differing perspectives, 2673, 2733
 economics and finance, 35, 2717–2718, 2718–2719, 2721
 ecosystem health and, 92, 310–311
 ecosystem-level, 302–317, 310–311, 2694–2697
 emissions pathways, and likelihood of being realized, 2658
 empowerment in, 2666, 2736
 enabling conditions, 31–33, 101, 108–109, 112, 2658, 2659–2660, 2667, 2706–2711
 equity and, 31, 2658, 2659, 2661, 2667, 2668, 2733
 ethical considerations, 2658, 2667
 European cities, 1883
 example: Vision 2030 in Kenya, 2669–2670
 FAQs, 2734–2737
 feasibility, 2724–2732, 2769–2807
 five pillars (people, planet, prosperity, peace, partnership), 2671
 framing and linkages, 8, 134, 177–178, 2660–2667
 gender and, 2700–2704
 goals and aims, 2660–2661
 goals and aims: prioritising, 101, 2658, 2659, 2661, 2689, 2733
 governance and, 35, 110–111, 2659–2660, 2706–2707, 2712–2717
 health and well-being, 1044–1047, 1119–1123, 1120
 human and ecological well-being, 35, 2658
 Indigenous knowledge and local knowledge and, 35, 2657, 2713–2715
 inequalities and, 2657, 2658
 interactions, 2662–2665
 just and equitable for all, 31, 33, 107, 2657, 2659, 2661, 2667, 2668, 2733
 knowledge gaps, 2732
 knowledge systems, 35, 2667, 2713–2715
 linkages, 8, 42, 134, 1238, 2658, 2660–2661, 2664, 2670–2689, 2735
 livelihoods and, 1238–1249, 1238
 local conditions and contexts, 101, 2657, 2665, 2667
 mitigation measures and, 105
 multiple pathways, 31, 100–101, 2657–2658
 need for, demonstrated, 31
 opportunities, varying by location, 2657
 pathways away from, 2664
 pathways to, 31, 35, 177–178, 2657–2658, 2661–2666, 2662–2665
 planning for, 34–35, 2658
 policy context, 101, 2666–2667
 political economy of, 2705–2706
 poverty and, 1238–1249, 1238, 2660
 priorities in, 31, 35, 100, 101, 2658, 2659, 2661, 2689, 2733
 regional and national differences in capacity, 2659, 2661–2666
 regional perspectives, 2722–2724
 regional synthesis, 2721–2724, 2725–2727
 research needs, 2732–2733
 risk management and, 2544, 2614–2615, 2676–2689
 scenarios/SSPs, 9–10, 2660, 2673–2675, 2674
 science-technology and, 2709, 2718–2720
 sectoral synthesis, 2724, 2728–2731
 societal choices and, 32, 35, 2658, 2659, 2661, 2664–2665, 2720
 solution space, 2659, 2666, 2690, 2705, 2706, 2736
 success in, 2667, 2737
 sustainable development and, 31, 100–101, 2659, 2674, 2681–2683
 synergies and trade-offs, 31, 108, 1239–1241, 2657–2658, 2687–2689
 system transitions and, 100, 177, 2658, 2665, 2690–2705, 2736
 temperature overshoot and, 35
 trade-offs, 31, 1239–1241, 2657–2658, 2668, 2687–2689, 2736
 triple-wins, 1240
 urgency about, 31, 35
 values and interests, 31, 35, 2657–2658
 vulnerabilities, effects on, 2658
 vulnerable populations and locations, 2657, 2665
 warming narrows options and choices, 31, 32, 35, 2657–2658
 water security and, 558–565
 window of opportunity for, 31, 32–33, 35, 102–107, 204, 2662
 See also Development; Transitions; specific regions and sectors
- Climate resilient development pathways (CRDPs)***, 31–35, 177–178, 2655–2807
 about, 2657–2668, 2662–2665
 action over the next decade, 2659
 actors in, 2658, 2661, 2666, 2667, 2736
 agency and, 101, 2659, 2705–2721
 aim of, 2661
 arenas of engagement, 32, 2659, 2662, 2664, 2711–2720

- climate action and, 2660, 2661–2666, 2662–2665, 2670–2689, 2720–2721
- climate justice and, 2659, 2700
- contending social interests, 2659
- context-specific, 101, 2667, 2668
- cooperation and working together, 23, 31–33, 34, 112, 2659
- definition of, 177, 2734
- development trajectories and, 2659, 2660–2661, 2673–2675, 2674
- differing capacities for, 2659, 2661–2666
- enabling conditions, 101, 108–109, 112, 178, 1120, 2658, 2659, 2667, 2706–2711
- equity and, 177, 2658, 2659, 2661, 2667, 2668, 2733
- FAQs, 2734–2737
- food-fibre systems, 825–827
- health sector, 1044, 1046–1047, 1119–1123, 1120
- illustrative pathways, 2662–2663
- inclusion in, 31, 2659
- justice and, 31, 33, 107, 2659, 2661, 2667, 2668, 2671, 2700, 2733
- knowledge systems and, 2659, 2713–2715
- linkages, 8, 42, 134, 2657–2668, 2662–2665, 2670–2689, 2735
- local and regional context, 101, 2659, 2667
- mitigation and, 105, 2660, 2683–2687, 2686
- multiple pathways, 100–101, 2657–2658, 2734
- participatory interactions, 31, 2659
- partnerships, 31, 34, 2659
- people as agents, 2659
- planetary and ecosystem health, 30, 35, 134, 2659
- priorities/prioritising of actions, 101, 2658, 2659, 2689, 2733
- regional and national differences in capacity, 2659, 2661–2666
- societal choices, 32, 35, 2659, 2661, 2662–2665, 2720
- solution space, 2659
- stakeholders, 2658, 2666, 2692
- Sustainable Development Goals (SDGs) and, 2662, 2674, 2681–2683, 2737
- synergies and trade-offs, 108, 2657–2658, 2659, 2687–2689
- system transitions and, 2658, 2660, 2665, 2690–2705, 2736
- transformations needed, 111–112, 1044–1045, 2658–2659, 2660, 2665, 2671, 2736
- transformations supporting, 111–112, 2668–2669, 2736
- urban areas, 961, 962–963, 989–990
- warming narrows options for, 31, 2657–2658
- window of opportunity, 32–33, 35, 102–107, 2662–2663
- Climate responses, 2785–2787**
- Climate risk management.** See Risk management
- Climate risks, 145–149, 146**
- aggregated assessments, 113–114, 115–118
- costs of, 2547
- perception of, 150, 1115, 1518, 1645, 1886–1887, 1886, 2596
- See also Risk; Temperature
- Climate scenarios*.** See Scenarios
- Climate services (CS)*, 28, 106, 2543, 2594–2595, 2782**
- Africa, 1290, 1313–1314, 1314, 1315, 1317, 1357
- Central and South America, 1737, 1742–1743
- feasibility assessment, 2771, 2782
- Climate shocks, 976–977, 1047, 2508, 2657, 2668**
- Climate-smart agriculture (CSA)*, 108, 624, 819, 829–830, 1186, 1242, 1304**
- Climate traps, 1183–1184**
- Climate variability*, 144, 147, 152, 728, 1045**
- regional, 155
- Climate velocity*, 208, 392, 392, 393**
- in biodiversity hotspots, 2125, 2126–2131, 2129
- Climatic drivers*, 410–411**
- Climatic impact drivers*, 391, 397–409, 794**
- biological responses to, 400–409
- ecological responses to, 409
- multiple-driver research, 410–411
- multiple drivers, responses to, 401–409, 402–403, 405
- primary production and, 404–406
- single drivers, responses to, 400–401, 403
- CMIP5 and CMIP6*, 9, 44, 139–143, 1590**
- Co-learning, 30**
- Co-production, 30, 97, 971–973, 1942, 2594**
- Coastal areas and ecosystems, 379–550**
- about, 82, 381–391, 389, 391
- about: concept map, 389
- adaptation and mitigation, 94, 310, 475–489
- adaptation feasibility, 2769, 2774
- adaptation limits, 84–85, 2415, 2449
- biodiversity, 16, 47, 458
- blue carbon ecosystems, 47, 421–424, 422, 464–466, 468, 2692
- cities in (See Cities and settlements by the sea)
- climate resilient development, 33–34
- compound risks, 67, 82, 94–95
- deltas, 420–421, 421, 2470–2471
- development, 62, 68
- development decisions, 383, 386, 476, 478
- drivers of change, 386, 391, 400–409, 402–403, 412
- ecosystems and seas, 410–433
- education about environmental change, 383
- erosion, 382, 424–425, 935, 2055–2056
- estuaries and lagoons, 420–421, 421
- eutrophication, 401
- exposure, 53–54, 62–63, 382
- FAQ (sea level rise), 477–480
- flooding, 17, 63, 81, 382, 718, 950, 1964–1967
- food provisioning, 718
- groundwater, 21
- habitat destruction, 386
- hard protection, 86, 2075–2076, 2078–2079, 2081, 2084
- hazards (summary), 412
- human population in, 17, 34, 53, 65, 382
- infrastructure, 63, 807, 935, 958, 2456
- integrated coastal zone management (ICZM), 475, 2769, 2775
- inundation, 934
- kelp ecosystems, 418–420, 419, 2145
- key risks and vulnerabilities, 2454–2456, 2455, 2503
- livelihoods, 63, 2456
- loss and damage, 17, 63
- Low Elevation Coastal Zone, 34, 54, 925, 934
- migration and displacement, 1099–1100
- natural infrastructure, 935
- non-climate drivers, 386
- observed impacts, 53–54, 391
- ocean acidity and, 420
- projected risks, 15, 17, 21, 62–63
- protection services, 463, 468
- risks, 62, 66, 382, 477–478, 2425, 2454–2456, 2455
- rocky shores, 414–418, 418
- salinity, 382, 420, 461–462
- sandy beaches, 424–426, 424
- sea level extremes, 391
- sea level rise, 15, 27, 53, 62–63, 94, 382, 391, 393–395, 423, 423, 477–480, 909, 1100
- sediment, 62, 381, 385, 410, 420–423
- semi-enclosed seas, 426–427, 426
- shelf seas, 427–429, 428, 429
- storm surge, 420, 476, 909, 934, 950, 993
- subsidence, 66, 386, 393
- tourism and recreation, 383, 467, 935
- transitions (system transitions), 2692–2693, 2699, 2774
- upwelling zones, 391, 395, 429–431, 430
- vulnerability, 53–54, 2454–2456, 2455, 2503
- wastewater management, 463
- waves, 395, 463
- wetlands, 420–423, 423, 463
- See also Cities and settlements by the sea; Ocean and coastal ecosystems; Small Islands
- Coastal Niño (Peru, 2017), 589, 591**
- Coastal seas, 399**
- Coastal squeeze, 465, 476**
- Co-benefits*, 31, 109, 2657**
- of adaptation, 25, 108–109, 811–832, 1124–1125, 1238, 1887, 1888, 2436–2437, 2437–2440
- benefit-cost ratio, 1240–1241
- of climate resilient development, 34, 108, 2657
- human health, 1124–1125
- of mitigation, 308–309, 910, 960–961, 1123, 1238
- urban areas, 960–961
- water adaptation, 556, 557, 635–643
- Coccolithophores*, 404, 2328**
- See also Phytoplankton
- Cocoa, 784–785, 788, 1353**
- Cod, 1951**
- Coffee, 784–785, 788, 825–827, 1052, 1211, 1336, 1353, 1700, 1736**
- Cold-related health effects, 1060–1061, 1091**
- Cold spells, 927**
- Common but differentiated responsibilities (CBDR), 162, 1229**
- Communicable diseases*, 1045, 1062–1071**
- Communication about climate change, 126, 150, 159–160, 159, 1940**
- Community-based adaptation*, 26, 91, 808, 965, 967, 1246–1247**

- food and fibre sector, 817–818
 Small Islands, 2079
 tropical forests and, 2371, 2381, 2382
 urban areas, 965, 967
 for water security, 666–667
- Complex risk**, 10, 20–21, 67–68, 82–83
 compound vs. cascading risks, 83
- Compound risk***, 20–21, 66, 67–68, 935–936, 1070, 1201, 1225–1227, 1226, 2420
 about: storyline figure, 82–83
 adaptation and, 94–95
 cascading risk vs., 83
 sea level rise and, 62
- Compound weather/climate events***, 48, 49, 909
 examples, 2071–2072
- Confidence***, 40, 41, 159–160, 159
- Conflicts**, 53, 1052, 1086–1088, 1190, 2428, 2464–2466
 adaptation and, 937, 1101, 1119, 1394–1395
 Africa, 1394–1395
 armed conflict, 1045, 1086, 1102
 Asia, 1102
 Central and South America, 1735, 1750
 climate and, 53, 65, 1046, 1086–1088
 climate change and, 1102, 1128, 1190, 2428, 2429, 2673
 climate resilient development and, 1044, 1047
 climate–security nexus, 1190
 droughts and, 1087, 1190
 extreme weather events and, 53, 1087, 1190
 FAQ, 1128
 food-related, 718–719, 1087
 gendered dimensions, 1045, 1088
 geopolitics and, 1088
 health impacts, 1044, 1045
 human–animal, 1054–1055, 1481, 1945
 interpersonal violence, 1394, 1971
 intrastate, 65
 key risks, 2455, 2463–2464, 2503
 migration and, 17, 65, 1087–1088, 1395, 2465
 observed impacts, 48, 1086–1088, 2428
 peacebuilding, 95, 937, 1047, 1119, 1123
 poverty and, 95, 1178
 projections for, 15, 17, 1046, 1102
 reduction, 95, 96, 719, 1119
 risk management in conflict-affected areas, 2557
 Syrian Civil War, 2429
 violent, 15, 17, 65, 1048, 1086–1088, 1102, 1128, 1980–1982, 2428
 water-related, 53, 90, 593, 618, 622, 718, 1087, 1735
 water-related: adaptation, 629–632
- Conservation agriculture***, 624, 1242–1243, 1356
- Consumerism**, 14, 2664, 2693
- Convention on Biological Diversity (CBD)**, 40, 129, 158, 911
- Cooperation**, 23, 30, 31–33, 34, 112, 560, 2659
- Copepods**, 436, 440, 2329
- Coping***, 640, 657, 965, 1047
 with disasters, 1236–1237
- Coral bleaching***, 442, 1583, 1602, 1605–1607, 1723, 1754
 ENSO and, 2045
- global-scale event (GCBE), 1478
 Great Barrier Reef, 57, 442, 1602, 1605–1607
 observed impacts, 11, 412, 1478–1479
 projections: potential annual events, 2046
 tourism and, 1583
- Coral reefs**, 410–414, 2468
 about (summary), 413
 adaptation, 414, 1479–1480
 adaptation limits, 1224, 2448
 adaptation pathways, 485
 artificial reefs, 2077
 Asia, 1478–1479, 1482–1483
 Australasia, 1583, 1584, 1602–1607, 1605–1607, 1635, 1636, 1638
 biodiversity, 415, 2147
 Central and South America, 1691, 1693, 1709, 1710, 1723, 1729, 1754
 community composition, 47
 ecosystem integrity, 56–57
 ecosystem services, 2046
 emotional attachments, 467
 Great Barrier Reef, 57, 301, 442, 1584, 1602, 1605–1607
 habitat loss, 415
 heat stress, 412
 marine heatwaves, 416, 442–444, 1951, 2560–2562
 mitigation as essential for, 1479
 North America, 1950, 1971–1973
 observed impacts, 47, 388, 412, 413, 442–443
 ocean acidification and, 412–413
 paleo-ecological evidence, 414
 projected changes, 399, 413, 415, 1224, 2048
 projected impacts, 413, 414, 2145
 provisioning services, 2046
 reef grief, 467
 restoration, 414, 484, 485, 1952
 thermal refuges, 414
 thermal stress, 2048
 thermal tolerance, 407
 tourism, 1583, 1602, 1605, 1710
 vulnerability/risk, 1478–1479, 2455–2456
 warm-water, 410–414, 2455–2456
- Coralline algae**, 401, 407, 413, 415
- Corals**
 beneficial microorganisms of, 1479
 calcification of, 412–413
 jewellery, 461
 managed breeding, 484
 mass mortality events, 1602, 1604, 1605, 1606, 1648
 nutrient supply and, 404
 temperature and, 407
- Cost-benefit analysis***, 94, 1240–1241, 2576
- Costa Rica, toad extinction**, 201, 2132
- Costs**
 adaptation costs, 652–653, 1183, 1289
 of climate change, 909, 1205–1207, 1599, 1632–1634, 1634, 2417, 2547, 2661
 social cost of carbon, 2420, 2495, 2498
 See also Loss and Damage
- Cotton**, 741, 1353
- Coupled Model Intercomparison Project (CMIP)***, 9, 44, 139–143, 1590
- Covenant of Mayors**, 920–921
- COVID-19**, 558, 628, 912, 959, 1047, 1067–1070, 1188, 2657
 adaptation and, 1047, 1068, 1175, 1188
 Africa, 1375, 1390–1393
 air quality improvements, 928
 Australasia, 1624
 cascading impacts, 1047, 1068
 cities and, 909, 959
 Cyclone Amphan (2020) and, 588–589
 disproportionate impacts, 1252
 financial impacts, 1175
 food security and, 792
 hand washing and, 628
 impacts in cities and urban areas, 909
 impacts on adaptation, 909
 inequalities and, 1175, 1188
 informal settlements and, 917
 migration and, 1469
 poverty and, 909, 959, 1175, 1188, 1202, 2666
 priorities shifted by, 65
 recovery packages, uses of, 1390–1393, 2592–2593
 SARS-CoV-2 and, 290
 SDGs and, 2661
 Small Islands, 2050, 2070, 2093
 vulnerability and, 1047, 1175, 2418, 2657, 2661
- Crabs**, 1947
- Critical thresholds**, 1050, 2417
 exceedence of, 55, 1090–1091
 See also Tipping points
- Crop insurance**, 814–817
- Crop production**
 adaptation, 71, 719, 742–746
 carbon dioxide effects, 736, 1046
 climate variability and, 728
 crop failures, 731, 1250
 cropping systems, 738
 cultivar improvements, 743–746
 diversification, 745
 equity considerations, 734
 fibre crops, 729
 genetically modified (GM) crops, 71, 798–799, 799
 grains, 728–729, 732, 1492
 land for, 717, 802–803, 803–804
 major crops, 728–729, 732, 735–736, 737, 738, 742, 1046
 models, 725–728
 nutritional quality, 1046
 observed impacts, 46, 728–733, 729
 ozone effects, 736
 pests and, 16, 730–732, 1844
 plant breeding, 728, 743–744, 745, 1356
 projected impacts, 734–742
 risks and vulnerabilities, 719
 soil health, 741
 tree crops, 728–729
 vegetables, fruit, and nuts, 729, 742–743
 See also Food production
- Crop yields**, 48, 74, 728–733, 2425–2426
 adaptation potential, 743

crop failures, 731, 1250
 observed impacts, 48, 54, 555, 584–585, 717, 728–733
 projected impacts, 613, 718, 734–742, 1352
 salinity and, 461–462
 water scarcity and, 584–585
See also Agriculture; Crop production; *specific regions*

Cross-Chapter Boxes, 112, 178
 ADAPT, 168–171
 CLIMATE, 137–145
 DEEP, 2578–2580
 DISASTER, 588–591
 EXTREMES, 215–218
 FEASIB, 2769–2807
 FINANCE, 2586–2593
 GENDER, 2700–2704
 HEALTH, 1124–1125
 ILLNESS, 291–295
 INDIG, 2713–2715
 INTEREG, 2441–2444
 LOSS, 2563–2565
 MIGRATE, 1080–1083
 MOVING PLATE, 768–773
 NATURAL, 303–309
 PALEO, 154–157
 PROGRESS, 2610–2613
 SLR, 477–480

Cross-Chapter Papers
 Biodiversity Hotspots, 2123–2161
 Cities and Settlements by the Sea, 2163–2194
 Deserts, Semi-arid areas, and Desertification, 2195–2231
 Mediterranean Region, 2233–2272
 Mountains, 2273–2318
 Polar Regions, 2319–2368
 Tropical Forests, 2369–2410

Cross-Working Group Boxes
 ATTRIBUTION, 151–154
 BIOECONOMY, 828–831
 ECONOMIC, 2495–2499
 SRM (solar radiation modification), 2473–2478
 URBAN, 988–991

Crowdfunding, 2710

Cryosphere*, 50, 570–571
 dependent communities, 50, 82
 mountain areas, 2275, 2276, 2277, 2291
 observed changes, 50, 565, 570–571, 571, 592, 2275
 projected changes, 61, 602–603
 Special Report on (SROCC), 40, 130–131, 386–389, 563, 720, 913
 temperature impacts on, 565
See also Polar Regions

Ctenophores, 2330

Cultivar improvements, 743–746

Cultural ecosystem services (CES), 457, 459, 467, 468, 484–488, 740, 741–742, 2694

Cultural heritage, 65, 156, 947, 1393–1398
 Africa, 1292, 1300, 1393–1398, 1396–1398
 Europe, 1827, 1866, 1870, 1874, 1880
 Indigenous Peoples, 383, 1943
 Mediterranean Region, 2235, 2237, 2247, 2248

polar regions, 2321, 2331, 2339–2340, 2352

Cultural uses of water, 565, 572, 594–596, 595–596, 619, 620, 633–634, 636, 2464

Culture
 adaptation and, 633–634
 cultural identity, 53, 57, 634
 cultural practices, 45, 47, 52
 cultural services: ocean and coastal, 457, 459, 467, 468, 484–488
 cultural values, 2546, 2547, 2567, 2596
 losses of, 51
 mountain areas, 2276, 2295, 2298

Cumulative impacts, examples, 2071–2072

Cyanobacteria, 13, 252, 1953

Cyclones
 Cyclone Aila (2009), 1209, 1236–1237
 Cyclone Amphan (2020), 588–589, 590
 Cyclone Sidr, 1209
 Cyclones Idai and Kenneth (2019), 588, 590, 1208, 1362, 1377
See also Extratropical cyclones; Tropical cyclones

D

Dams, 564, 2283
 failures of, 615
 in Vietnam, 1209

Dangerous anthropogenic interference (DAI), 69, 2415, 2420, 2450–2453

Deaths. *See* Mortality

Debt, 826
 climate debt, 236

Decarbonisation*, 2658, 2690, 2693, 2705, 2708

Decision making, 101, 2539–2654
 about, 2542–2548, 2549
 action frameworks and, 307, 911, 2660
 adaptation and, 22, 98, 307, 911, 1253
 adaptation, enabling conditions, 2546–2547
 adaptation finance, 2542–2543
 adaptation limits, 2544
 adaptation-maladaptation continuum, 2600–2602, 2603
 adaptation options, 2548–2562, 2553
 adaptation options: 24 adaptation options, 2557–2562, 2559–2560, 2604
 adaptation options: combinations of, 2553–2562
 adaptation progress, 2546, 2605–2614, 2610–2613
 adaptation success, 2548, 2600–2605, 2620–2621
 benefit considerations, 2547
 catalysing conditions, 2543, 2596–2600
 climate impacts and, 1192–1193
 for climate resilient development, 34, 101, 1245–1247, 2544, 2614–2615, 2660, 2661
 for climate risk management, 2542–2548
 climate services and, 2543, 2594–2595
 Cynefin framework, 2567, 2569–2574, 2577
 decision-analytic methods, 98, 2543, 2565–2577, 2569–2574
 decision-analytic tools, 2565
 decision support tools, 2543, 2549, 2616
 deep uncertainty and, 2543, 2578–2580

drivers of, 2546
 dynamic (changing) nature of risk, 2544
 elicitation methods, 2568, 2576
 equity and justice, 23, 101, 2604–2605, 2605
 evaluation and learning, 2613–2614
 FAQs, 2616–2621
 feedback and, 2577
 frameworks for, 176–177, 307
 gender and, 97, 2701
 inclusive, 23, 31, 86
 informal, 2575
 integrated, 911
 interconnections, 41, 2545
 iterative, 2577
 key risks and, 2546
 knowledge systems, 2543, 2585–2596
 Loss and Damage (L&D), 2544, 2563–2565
 maladaptation, consideration of, 2548
 for managing climate risks, 2545
 mechanisms for, 2547
 monitoring and evaluation (M&E), 2544, 2547, 2605–2614, 2610–2613, 2620
 observed impacts, 1192–1193
 process of, 2562–2580, 2569–2574
 process of: cognitive phase, 2566–2567, 2569–2574
 process of: real world relationships, 31, 2566
 process of: schematic, 2549
 residual risk, 2544, 2619
 risk assessment, 2545–2546
 risk management, 2551, 2604
 risk management: in conflict-affected areas, 2557
 risks and trade-offs, evaluating, 2576–2577
 scenario analysis, 2576
 in settlements/cities, 2601–2602
 stakeholder engagement, 2543, 2547, 2557, 2567–2568, 2576, 2594–2595
 synergies, 2547, 2548, 2600, 2603
 trade-offs, evaluation of, 2547
 for transformational adaptation, 2601–2602
 uncertainty and, 2543, 2568, 2569–2574, 2616
 uncertainty, deep (Cross-Chapter Box), 2578–2580
 urban, 910, 911, 947
 urgency and, 55, 2543, 2596–2597, 2597
 values and, 2546, 2547, 2567, 2568, 2578–2579, 2596, 2609
 vulnerable groups and, 30, 1175, 2544, 2550, 2556, 2560
 windows of opportunity, 2543, 2597–2598

DEEP (Cross-Chapter Box), 2578–2580

Deep-sea ecosystems, 454–455

Deforestation*, 47, 56, 201, 249, 2371, 2374–2376, 2375
 Amazon region/forest, 244–245, 1220, 1693, 1705, 1707
 biofuels and, 1697
 drivers of, 2375–2376, 2376
 feedbacks, 275–276
 REDD+ and, 757, 757, 1512, 2384
 wildfires and, 201, 271–272
See also Tree mortality

Degrowth, 174–175, 2672, 2705

- Deltas**, 420–421, 421, 2174, 2470–2471
 agriculture and, 2470–2471
 in Asia, 1462, 1487, 1503, 1513
 Bangladesh Delta Plan, 1503, 1513
 exposure and vulnerability, 62–63, 2470–2471
 hazard trends, 2470
- Dematerialisation**, 2693
- Dengue fever**, 17, 1060, 1062, 1063, 2462
 Africa, 1371, 1373
 Asia, 1508, 1509
 Australasia, 1623
 Central and South America, 1691, 1699, 1702, 1705, 1710, 1712, 1713
 climate-related factors and, 1713, 2705
 El Niño and, 1063
 Europe, 1862, 1862
 North America, 1969–1970
 observed changes, 51, 292–293, 1045, 1063, 2427
 projected changes, 17, 58, 1089, 1090, 1094, 2462
 regional occurrence, 17, 292–293
 transmission, 51, 1063, 1713
- Deoxygenation***, 391, 394, 396–397, 401
- Desalination**, 624, 631, 653, 655, 1349
- Desertification***. See Deserts and semiarid areas
- Deserts and semiarid areas***, 2195–2231
 about, 2197–2200, 2200
 adaptation, 2197–2198, 2199, 2214–2217, 2215–2216, 2218
 adaptive capacity, 2197
 Africa, 1318, 2197, 2202–2203, 2205, 2206
 arid zones, 2199–2200, 2200, 2202–2205
 aridity*, 569, 570, 2197–2198, 2199, 2200
 aridity: hyper-arid areas, 2199, 2200, 2202
 aridity: projected, 2211
 Aridity Index (AI), 2197, 2199–2200, 2200, 2211
 Asia, 2204–2205, 2206, 2218
 Australasia, 2205, 2206
 biodiversity, 2197, 2217
 carbon cycle/balance, 2197, 2198
 Central and South America, 1697, 1709, 1710, 1722, 2204, 2206
 climate change impacts, 2197, 2200–2210, 2217–2218
 climate resilient development (CRD), 2198
 climate variability, 2198
 crop yields, 584–585
 definitions, 2199
 desert locusts, 795
 desertification*, 2199, 2207, 2208, 2213
 drivers of expansion, 2198
 droughts, 2211, 2214, 2215
 drylands, 2199–2200, 2200
 drylands: extent, 2200, 2212–2213
 dynamics of, 2199–2200, 2200
 ecosystem processes, 2201
 ecosystem services, 2197
 enabling conditions, 2198
 Europe, 1823
 evapotranspiration, 2212
 FAQs, 2217–2218
 finance, 2198
 food systems, 2209, 2213, 2217, 2218
 governance, 2198, 2199, 2218
 greening, 2198, 2200
 herbaceous cover, 2206–2207
 human health, 2197, 2208
 human population, 2199
 human systems, 2208–2210, 2213
 Indigenous knowledge (IK), 2198, 2199, 2210, 2217
 land degradation, 2199, 2207, 2215
 land tenure, 2198
 livelihoods, 2197, 2199, 2209, 2210
 local adaptation, 1219–1220
 megacities, 2199
 migration and conflict, 2209–2210
 mineral resources, 2213
 natural systems, 2200–2208
 natural systems, projections, 2211–2213
 North America, 2202, 2203–2204, 2205
 oases, 2199
 observed impacts, 47, 2197, 2200–2210
 pastoralism, 2198, 2210, 2215
 poverty, 2199
 productivity, 2197, 2199
 projections, 2197–2198, 2211–2213, 2217–2218
 regional assessments, 2202–2206
 resilience, 2198
 risks, 2197–2198
 sand and dust storms, 1478, 2207–2208, 2207, 2216
 savannas, 2205
 semi-arid zones*, 2200, 2205–2206
 sustainable development, 2198, 2214, 2218
 temperature and rainfall, 2200–2201, 2211, 2218
 tree death, 2201–2207
 vegetation, 2197, 2201–2207, 2215
 vulnerability, 2217
 warming pathways, 2197–2198
 water resources, 2197, 2217
 water scarcity, 2208, 2217
 wild foods, 760
 woody cover, 2201–2207, 2215
 See also Pastoralism; Savannas
- Detection and attribution***, 11, 150, 587, 1819, 2422–2423, 2505
 climate attribution, 2423
 Cross-Working Group Box (ATTRIBUTION), 151–154
 event attribution, 1938–1939
 extreme weather events, 587
 FAQ, 387–388
 food and fibre systems, 723–724
 impact attribution, 2422, 2423–2424
 ocean and coastal systems, 386, 387–388
 perceptions about climate change, 1939–1942, 1941
 uncertainties in, 254–256
 wildfires, 1948
- Developed/developing countries***
 adaptation finance, 2586–2593
 adaptation responses, 71, 556
 burden for residual risk, 2619
 carbon-intensity of energy systems, 2670–2671
 decisions resolving divergent views, 33
 economic context for decisions, 2670–2671
 fairness and, 162
 GDPs, 2661, 2717
 Least Developed Countries (LDCs)*, 1519
 risk from climate change, 2658
 Small Island Developing States (SIDS), 1218, 2048, 2073
- Development**, 14–15, 54–55, 108, 2657–2666, 2670–2689, 2722–2724
 adaptive capacity and, 1239
 assessment/measures, 2671–2672
 chronic and sudden-onset challenges, 1174
 cities/urban areas, 911
 climate action and, 2670–2689
 climate change and, 1238, 1239, 2670, 2675, 2677–2678
 climate change responses and, 71, 1215
 climate change risks, 2675, 2677–2678
 climate-compatible (CCD), 1238–1239, 1238
 climate-resilient (CRD) (See Climate resilient development)
 coastal areas, 62, 68, 383, 386, 476, 478
 current patterns, 54–55, 100, 2670–2671
 current patterns: as not advancing CRD, 100, 2658
 current patterns: risks of, 2657, 2660
 development deficits, 1174
 economic context, 67, 2670, 2672
 economic growth orientation, 67
 ecosystem risks and, 56
 equity issues, 1176, 2733
 five dimensions of, 2668
 Human Development Index (HDI), 2671, 2722
 improvement context, 2671–2672
 indicators/measures, 2722–2724, 2724
 inequity and injustices, 2657
 low-carbon, 911, 2660
 past development choices, 31, 32, 33, 35
 pathways, 2662–2663
 patterns driving climate risk, 2660–2661
 perspectives on, 2671–2673, 2733
 regional perspectives, 2722–2724
 risks, 55
 scenarios/SSPs, 9–10, 2660, 2673–2675, 2674
 SDGs and, 2657
 sudden-onset challenges, 1174
 trends, 15, 2657
 unsustainable, 14, 2661, 2671
 See also Climate resilient development; Sustainable development
- Development pathways***, 2662–2663
- Diabetes**, 1061, 1072
- Diarrhoeal diseases**, 13, 586, 616, 798, 1045, 1060, 1062, 1064, 2426
 adaptation to, 1383
 Africa, 1371, 1373, 1374, 1376
 Asia, 1508–1509, 1509
 projections, 64, 1089, 1095
- Diatoms***, 404, 408–409, 1951, 2329
- Diet***, 23, 799–802, 1097–1098
 alternate protein sources, 753
 changing, 1510, 1970–1971, 2692
 food quality and, 1046
 food sourcing (MOVING PLATE), 768–773
 healthy, 1510

- mortality, diet-related, 717
sustainable, 1970–1971
- Dinoflagellates**, 404, 2064–2065
- Direct air capture (DAC) of CO₂**, 653
- Disabilities, people with**, 1053
- Disaster risk***, 1212–1213
- Disaster risk management (DRM)***, 28, 135–136, 944–946
early warning systems, 944–946
feasibility, 2770–2771, 2781–2782
health-EDRM, 1114
Sendai Framework*, 93, 591, 911, 912, 919, 920, 2545, 2581–2582, 2598
See also Risk management
- Disaster risk reduction (DRR)***, 591, 1113–1114, 2658
Asia, 1460, 1506, 1514, 1528, 1529–1530
Australasia, 1584, 1619, 1633, 1634
Bangladesh, 657
- Disasters***
adaptation and coping, 1236–1237
compound, 48, 628
Cross-Chapter Box (DISASTER), 588–591
drought-related, 51, 555
flood-related, 555, 558, 577
as public face of climate change, 588–591
specific examples (2017–2021), 588–591
water-related, 555, 558, 662–663
See also Cyclones; Extreme weather events; *specific disasters*
- Discounting***, 2498
- Diseases**, 13, 51–52, 230–236, 1062–1072
adaptation, 27, 290–291, 294–295, 1047, 1107–1108, 1107
attribution of changes in, 2427
burden of, 63, 1046, 1060–1062, 1096
case studies, 231–233
cholera, 292–293, 1064, 1371
ciguatera fish poisoning, 2064–2065
climate change impacts, 200, 218–220, 233–235, 248–251, 291–295
communicable*, 1045, 1062–1071
COVID-19, 290, 558, 628, 792, 909, 1066–1069
Cross-Chapter Box (ILLNESS), 291–295
diarrhoeal (See Diarrhoeal diseases)
ENSO and, 2064
FAQ, 233–235
floods and, 586, 1064
food-borne, 1065–1066, 1095, 1107, 2064–2065
global distribution changes, 1045
infectious, 291–295, 462–463, 1063
key risks, 2462
livestock, 747, 750–751
Lyme disease, 64, 261, 1045, 1063–1064, 1090, 1094, 2427
marine heatwaves and, 415
mosquito-borne, 1063–1064, 1092–1094, 1373
non-communicable (NCDs)*, 52, 64, 1045, 1046, 1071–1072
nutrition and, 1045
observed climate impacts, 13, 51–52, 230–236, 1045
phenology and, 261
projections and risks, 57, 58, 63, 64, 261, 718, 1046
public health and, 269–270, 294–295
respiratory diseases, 52, 64, 1045, 1060, 1066–1067, 1071
skin diseases, 1071
thermal mismatch, 232
tick-borne, 200, 234, 1045, 1063–1064, 1094, 1862
vector-borne, 231–262, 291–295, 585, 1062–1064, 1092–1095, 1093, 2427
water events and, 558
waterborne, 462–463, 582–583, 586, 616, 1064, 1065, 1095, 2462
West Nile fever, 51, 261, 1063, 1090, 1862, 1969, 2427
wildlife diseases, 51–52, 200, 230–236, 261
zoonoses, 13, 51–52, 57, 232–233, 233–235, 789–790
See also Food-borne diseases; Vector-borne diseases; Waterborne diseases; *specific diseases and regions*
- Displacement (of humans)***, 13, 17, 52, 64–65, 929–930, 1080–1083
Cross-Chapter Box (MIGRATE), 1080–1083
humanitarian crises and, 13, 65
internally displaced people, 1082, 1183–1184, 2428
involuntary, 17, 52, 96, 1044, 1046, 1082, 1128, 2465
livelihood strategies (Yap), 1185–1186
numbers of people displaced, 1045, 1046, 1084
projections, 17, 64–65, 556, 1099–1102, 1100
reducing future risks, 1083
refugees, 1183–1184, 1249, 2428
water-related issues and, 593–594
See also Migration (of humans)
- Disproportionate impacts**, 11, 18, 41, 61, 76, 564, 928–930, 1178–1180, 1249, 2490–2492
compound risks and, 1225–1227, 1226
COVID-19, 1252
extreme events, 47, 1181, 1206
FAQ, 1251
key risks and, 2486, 2490–2492
losses and damages, 1205–1208
observed, 49, 1205–1208
poverty and, 2421–2422
Reasons for Concern (RFC3), 18, 2417, 2486, 2490–2492, 2501
See also Inequality; Vulnerability
- Distribution of impacts.** *See* Disproportionate impacts
- Distribution of species.** *See* Range shifts; Species distribution
- Distributive justice***, 126, 162, 924, 958–959
- Disturbance regimes***, 208, 237, 280, 314
abrupt changes and, 442–445, 445, 2416, 2457
See also Fires; Insect pests
- Drivers.** *See* Climatic drivers; Climatic impact drivers
- Drosophila melanogaster***, 236
- Droughts***, 50, 558, 578–579, 578
adaptation, 637, 802
agricultural*, 578–579, 609
attribution of, 579, 587
Cape Town, Africa (2015–2018), 1343
cascading effects, 578
compound risks, 67–68
conflicts and, 1087, 1190
ecological, 578–579
extreme, 556
extreme, return time of, 587
FAQ, 662–663
food security and, 802
global land area affected, 74
health and, 578
human migration and, 64, 578, 593–594, 1085
human mortality, 50–51
hydrological*, 74, 578–579
livelihoods and, 1209
meteorological*, 62, 555, 559, 578–579, 585
in North America, 580–581, 1936, 1953, 1954–1955, 1954, 1960, 1984
observed changes, 11, 50, 555, 578–579
observed impacts, 11, 50, 556, 558, 579
projected changes, 57, 61–62, 556, 608–610, 609, 610
resilience, IKLK and, 578–579
risk (current), 578
societal impacts, 579
specific examples, 580–581
tree mortality, 201
urban areas, 938
vulnerability/risk, 50, 578, 579, 1203
Western Cape Region, South Africa, 1212–1213, 1362
See also specific regions
- Durban, South Africa**, 299–300
- Dust storms**, 1459, 1464, 1478, 1533, 2207–2208, 2207
- E**
- E. coli***, 1970
- Early warning systems (EWS)***, 23, 383, 474, 782, 944–946, 1112
Africa, 1293, 1357, 1382
Central and South America, 1692, 1743, 1745, 1755
Europe, 1833
feasibility, 2782
Indigenous, 1330
mountains, 2276, 2288
Small Islands, 2050, 2064, 2080, 2088
transnational, 795
- Earth System Models (ESMs)***, 138, 143
- Eastern boundary upwelling system (EBUS)***, 391, 395, 429–431, 430
- Ecomodernism**, 174–175
- Economic costs of climate change**, 17, 54–55, 66–67, 68, 909, 1205–1207, 2417
adaptation costs, 66
as percent of GDP, 2661
regional variation in, 17
See also Loss and Damage
- Economic sectors**
losses and damages, 13, 17, 45, 54, 66–67
observed impacts, 13, 45, 54–55
projections, 66–67

Economics

adaptation enablers, 30
 circular economies, 631, 718, 829–831
 climate risk disclosure, 30
 Cross-Working Group Box (BIOECONOMY), 828–831
 Cross-Working Group Box (ECONOMIC), 2495–2499
 development and, 67, 2670, 2672
 economic growth, 54, 67, 2671–2672
 fiscal policy, 2719
 global economic damage, 66–67
 incentives, 2707
 macroeconomics, 2718–2719
 monetary policy, 2718
 political economy*, 2705–2706
 socioeconomic futures, 67
See also Finance; specific regions and sectors

Ecosystem-based adaptation (EbA)*, 90, 288–290, 475, 629, 718, 1247

about: summaries, 26, 87
 about: terminology, 283–284
 Africa, 1339–1342, 1340, 1368–1369, 1369
 agriculture, 309, 718
 Asia, 1461, 1504–1505, 1505
 case studies, 296–301
 co-benefits, 109, 1175, 1247, 2439
 definition on, 723
 Durban, South Africa, 299–300
 effectiveness of, 28, 35, 87
 Europe, 1838–1839, 1842
 FAQ, 310–312
 flood adaptation, 634–635, 950
 food and fibre systems, 718, 722
 maladaptation, 2439
 ocean and coastal systems, 475
 right place and time for, 203, 290
 Small Islands, 2050, 2077, 2078–2079, 2082, 2084, 2097
 temperature and, 28, 35
 terrestrial and freshwater ecosystems, 203, 283–284, 288–290, 288–289, 310–312
 as vulnerable to climate change, 87, 203
See also Nature-based solutions (NbS)

Ecosystem connectivity, 26, 67, 279, 285–287, 286, 2777–2778**Ecosystem health*, 42, 92, 109–110, 134, 310–311, 2659****Ecosystem services*, 56, 109, 2694–2697**

adaptation for, 23
 climate-induced impacts (summary), 468
 climate resilient development (CRD), 35, 2728–2729
 connections to climate change, 206, 207
 cultural (CES), 457, 459, 467, 468, 484–488, 740, 741–742, 2694
 ecosystem products (See Food, fibre, and ecosystem products)
 food provisioning, 61, 456–460, 457, 468, 2694
 human health, 282–283
 non-consumable goods, 461
 non-food consumable products, 460–461
 observed impacts, 47

ocean and coastal ecosystems, 383, 386, 456–467, 457, 458–459
 payment for ecosystem services (PES), 1692, 2384
 projected changes, 45–48, 46, 56, 458–459
 resilience, 87, 109–110
 species extinctions and, 279
 supporting and regulating, 457, 461–466, 468, 2694
 terrestrial and freshwater ecosystems, 201–202, 204, 243–279
See also specific systems and regions

Ecosystems*, 12, 42, 55–57

about: storyline figure, 72–73
 adaptation and, 23–26, 2695–2697, 2774–2779
 adaptation limits, 55, 63, 84
 adaptation limits: hard limits, 28
 adaptation pathways for, 73
 climate change impacts on, 16–17, 18–20, 2695
 climate resilient development, role in, 34, 2694–2697
 connectivity, 279, 285–287, 286
 degradation of, 16, 34, 56, 219, 283, 284, 304, 307, 2059
 health of, 42, 92, 109–110, 310–311
 healthy vs. degraded, 2059
 high-carbon, 22, 201–203, 249–251, 273
 integrity of, 16, 55, 56–57, 109, 201, 202, 205, 267, 276, 311
 irreversible losses, 11, 16–17, 55–56, 57, 69
 maladaptation examples, 29
 Mediterranean-type (MTEs), 239, 263–264, 269
 Millennium Ecosystem Assessment, 206, 2694
 observed changes, 11, 12, 45
 observed impacts, 45–48, 46, 72
 ocean and coastal, 379–550
 preserving, 109, 222
 projected risks, 14–22, 18–20, 55–57, 72–73
 protection of, 30, 55, 56, 86–87, 92, 203–204, 286, 310–312
 regional impacts, 12
 resilience, 45, 55–56, 86–87, 109–110
 restoration of, 26, 34, 109, 203–204, 313, 315–316, 465, 483–484, 485, 1340
 species as fundamental unit of, 202, 279
 structural changes, 12, 45–46, 46, 55, 201, 267, 280–281
 temperature overshoot and, 57, 69
 terrestrial and freshwater, 197–377
 tipping points, 16, 208
 transformation of, 55
 transitions (system transitions), 2692–2693, 2699, 2774–2779
 unprecedented conditions, 55–57, 68
 vulnerability and exposure, 14–22, 55–56
 wetlands*, 421–424
See also Biomes; Ecosystem services; specific ecosystems

Ecotourism, 480–481, 1714**Education, 99, 2596**

about environmental change, 383
 climate education, 96, 98, 946–947, 1525

Eelgrass, 404**Effectiveness (of solutions), 9, 160–164, 161, 163**

adaptation effectiveness, 558, 635–654, 2415, 2432, 2434–2435
 temperature and, 35, 87
 water and, 558

Egypt, sea level rise, 1362**El Niño Southern Oscillation (ENSO)***

Africa, 1329, 1373
 agriculture effects, 1494
 Asia, 1494
 Australasia, 1591
 Central and South America, 1700–1702
 Coastal Niño (2017), 589, 591
 coral bleaching and, 2045
 malaria and, 1373, 1702, 2064
 marine heatwave, 416
 Small Islands, 2053, 2054, 2071–2072, 2095
 vector-borne diseases and, 1373, 1702
 wildfires and, 201

Elderly populations

diseases, 1045, 1062, 1065
 disproportionate impacts, 1181, 1191
 health, 1045, 1053, 1079, 1089, 1226
 mental health, 1046
 mortality (deaths), 1089, 1091, 1181, 1225
 nutrition, 1061
 vulnerability, 49, 172, 1053, 1107, 1174, 1181, 1206, 1217

Electric power, 932–933, 1244

decarbonization of, 2658, 2690, 2693, 2705, 2708

Elicitation methods, 2482–2483, 2483, 2568, 2576**Ember diagrams, 18–20, 58–59, 114, 258, 281, 2482–2483, 2486, 2507–2508****Emergent risks*, 2484–2485****Emissions*, 44, 44**

ecosystem losses and, 34
 net zero CO₂, 1121–1122, 2658
 urgent need for action on, 31, 35, 55, 128–133, 180, 204

Emissions pathways*, 9–10, 15, 32, 44, 138, 1647, 2658, 2686

low-emissions, likelihood of being realized, 2658
 regional, 2685
See also Scenarios

Emissions reductions

adaptation not a substitute for, 15, 55, 87, 203
 aggressive, 55, 2683, 2685, 2733
 unprecedented reductions needed, 55, 2733
 window of opportunity for, 31, 32–33, 35, 102–107, 204, 2683, 2685, 2733

Enabling conditions*, 106, 126, 163–168, 818–825, 990–991, 1250, 2580–2600

about (summary), 29–30, 106
 for adaptation, 29–30, 95, 97–99, 126, 163–168, 484, 818–825, 990–991, 1228–1238, 1231, 2546–2547
 for adaptation and risk management, 30, 2580–2600
 for cities, 913, 963–982
 for climate resilient development, 31–33, 101, 108–109, 112, 178, 1120, 1175, 2658, 2706–2711
 decision making and, 30, 2546–2547
 finance, 30, 164, 2542–2543, 2584–2585

in food and fibre systems, 818–825
governance, 30, 106, 2542, 2581–2584, 2706–2707
for health adaptation, 1115–1116
knowledge, 30, 2585–2596
linkages, 134
poverty, equity, and livelihoods, 1175, 1228–1239
for societal resilience, 108–109
for transformation, 175–177, 981–982
for water security, 557

Endemic species*, 16, 47, 56

Endemic species, 2046, 2125, 2126, 2132, 2135

Energy
access, 2657
climate resilient development (CRD), 1244–1245
infrastructure, 931–933, 954–955
prices, 932
water-energy-food (WEF) nexus, 655, 811, 1246, 1347, 1530–1531, 2769

Energy production, 49, 50, 99, 585–586
adaptation, 27, 625–627, 640, 647
biofuels, 653–654, 1245, 1697
coal fuel, 615
diversification, 625
efficiency increase, 625
electric power, 932–933, 1244
extreme weather events and, 586
hydropower, 555, 585–586, 614–615, 625, 647
observed impacts, 49, 50, 555
oceans and coastal systems, 457
projected risks, 614–616
renewable energy (See Renewable energy)
solar power, 932–933, 1245
system transition, 27, 99, 2690–2691, 2699, 2769, 2773–2774
thermoelectric, 555, 585, 586, 615, 932
water requirements and sources, 99, 555, 625–627
wind power, 1245

ENSO. See El Niño Southern Oscillation (ENSO)

Equality*, 31, 86, 909
See also Equity; Inequality

Equity*, 41, 96–97, 126, 162–163, 656–657, 734, 958–960, 2668, 2733
adaptation options and, 23, 25
for all, 31, 33, 86, 2657, 2659, 2661, 2667, 2668, 2733
in climate finance, 2592
compound risks and, 1225–1227, 1226
demand for, 100
disproportionate impacts, 555, 564, 909
equitable development, 1176
fairness* and, 162
financial instruments and, 826, 2710
human rights-based approaches, 31, 101, 801
justice and, 30, 2604–2605, 2606, 2733
land acquisitions, large scale (LSLA), 719
leave no one behind, 2661, 2671
linkages, 53, 134
mainstreaming, 656
prioritising, 30
See also Gender; Inequality; Justice

Erosion
beaches, 424–425
coastal systems, 382, 424–425, 2055–2056
soil erosion*, 583–584, 612

Estuaries, 61, 420–421, 421, 1603
oxygen concentration and, 401

Ethics*, 162–163
adaptation and, 162–163, 656–657
See also Equity; Justice

Eucalyptus, 208, 1594, 1599, 1615–1616

Europe, 1817–1928
about, 1819–1827
about: geography and subdivisions, 1822–1823, 1822
adaptation, 1819–1821, 1881–1888, 2432
adaptation barriers, 1821
adaptation, behavioural, 1886–1887
adaptation, co-benefits of, 1887, 1888
adaptation, ecosystem-based (EbA), 1838–1839, 1842
adaptation effectiveness and feasibility, 1819, 1846, 1856, 1858, 1864
adaptation finance, 1884, 1885
adaptation governance, 1842, 1858
adaptation, implementation of, 1820
adaptation, inclusive and equitable, 1821, 1892
adaptation, incremental, 1819
adaptation limits, 1821, 1859, 1865, 1890, 2449
adaptation, mitigation links, 1819, 1857, 1858–1859
adaptation, national plans, 1831, 1882
adaptation, nature-based (NbS), 1819, 1830, 1842
adaptation, policies, 1882–1885, 1882
adaptation, private sector in, 1821, 1885–1886
adaptation, SDGs and, 1887, 1888
adaptation, societal adaptation, 1881–1888
adaptation, synergies and trade-offs, 1857, 1858–1859, 1887, 1888
adaptation, transformative, 1819, 1821, 1856–1858, 1887, 2436
adaptation, windows of opportunity, 1821
adaptive capacity, 1823, 1823
agriculture, 1843–1844, 1847–1849, 1848
agriculture: irrigation and, 1820, 1833, 1844, 1848
agriculture: production losses, 1819–1820, 1848, 1874, 1876, 1877
agriculture: trade and imports, 1871, 1871
agroclimatic zones, 1843, 1844
air quality, 1860
airports, 1851
allergies and pollen, 1863
alpine regions, 1866
biodiversity, 1834–1835, 1836, 1838, 1840
biodiversity: marine and coastal, 1840
biodiversity hotspots, 1834, 2137
blue carbon ecosystems, 1841
built environment, 1852–1856
business and industry, 1851–1852
carbon cycle/regulation, 1819, 1820, 1836–1837
cascading impacts, 1840–1841
cities, 1820, 1850–1859
cities: adaptation, 1855, 1856–1859, 1857, 1859
cities: multiple risks, 1820, 1852

cities: population in, 1850, 1852
climate, current, 1819, 1824
climate change: opportunities from, 1892
climate change: perceptions on, 1886–1887, 1886
climate change: public concern about, 1823, 1823
climate classification (Köppen-Geiger), 1834
climate impacts, regional assessments, 1824–1826
climate resilient development, 1821, 1883, 2726
climate risks, global interactions, 1870–1873, 1872
climate services, 1819, 1884–1885
coastal ecosystems, 1839–1843, 1840
coastal erosion, 1827
coastal flooding, 1824, 1827, 1832, 1852
coastal flooding: risks, 1827, 1874, 1878–1880, 1879
coastal flooding: Venice, 1828–1829
coastal regions, 1827
coastal regions: population density, 1826
coastal zone management, 1841–1842
cold waves, 1854–1855
Covenant of Mayors, 920
crop production, 1843–1844
cultural heritage, 1866, 1870, 1874, 1880
desertification, 1823
detection and attribution, 1873–1881, 1873
diseases, 293, 1045, 1844, 1862–1863, 1862
disproportionate impacts, 1819
droughts, 1824, 1826, 1867
droughts: projected, 61, 1825, 1826, 1827, 1853, 1854–1855
early warning systems, 1833
energy systems, 1850, 1851, 1857, 1859
European territories outside of Europe, 1872
FAQs, 1889–1892
fires, 272, 1819, 1835–1836, 1836, 1838, 1860
fires: area burned, 245
fisheries and aquaculture, 1840–1841, 1844–1846, 1845, 1849, 1866
floods, 590, 591, 1820, 1827–1828, 1830–1832, 1852, 1874
floods: projected, 59, 1820, 1852
floods: risks and management, 1830–1832, 1874, 1878–1880, 1879
floods: riverine and pluvial, 1827–1828, 1832–1833, 1832, 1852, 1853
floods: transmission of flood risks, 1872
food, fibre, and ecosystem products, 1843–1850
food production, 1843–1846, 1848, 1866–1867, 1876, 1877
food production: adaptation, 1846, 1847–1849, 1848, 1874, 1877
food quality and nutrition, 1863
food, self-provisioning, 1864
forestry and products, 1846–1847, 1849
forests, 1843, 1846, 1849
forests: pests, 200
glaciers, 1823, 1824, 1867
globalisation, 1849, 1870–1873, 1872
groundwater, 1830
harmful algal blooms, 1840–1841, 1840
health, 1860–1865, 1874
health: adaptation, 1863–1865, 1864, 1874
heat-related mortality, 59, 1819, 1860, 1864, 1874

- heat stress, 59, 1819, 1860, 1861, 1864, 1874
 heatwaves, 590, 591, 1824, 1850, 1854–1855, 1858, 1860
 heatwaves, adaptation to, 1891
 impact drivers, 1824, 1888
 impacts: observed and projected, 1824–1827, 1824–1826
 Indigenous knowledge and local knowledge, 1821, 2716
 inequalities, 1819, 1865–1870, 1889
 infrastructure, 1850–1859
 infrastructure: adaptation, 1856–1859, 1857, 1859
 infrastructure: overall hazards, 1854
 insurance, 1858
 inter-regional issues, 1820, 1870–1873, 1872
 key risks, 1819–1820, 1874
 key risks: KR1 (ecosystem effects of heat), 1819, 1874, 1875–1876
 key risks: KR1 (heat stress and deaths), 1819, 1874
 key risks: KR2 (agricultural production losses), 1819–1820, 1874, 1876, 1877
 key risks: KR3 (water scarcity), 1820, 1874, 1877–1878, 1878
 key risks: KR4 (flooding), 1820, 1874, 1878–1880, 1879
 key risks, multiple, 1820, 1880
 labour productivity, 1863
 land cover changes, 573
 livelihoods, 1865–1870, 1866–1867
 livestock, 1843, 1844, 1847, 1867
 local knowledge, 1884–1885
 losses and damages, 1819, 1823, 1823, 1828, 1866–1867, 1867–1870, 1880, 1881
 maladaptation in (Spain), 806
 Malmö, Sweden, 1883
 marine ecosystems and species, 1839–1843, 1890
 marine protected areas (MPAs), 1826, 1838, 1842–1843, 1842, 1872
 Mediterranean Region (See Mediterranean Region)
 mental health, 1863
 migration and displacement, 1867, 1870
 Milan, Italy, 1883
 mortality, climate-related, 1819, 1823, 1860, 1864, 1874
 mudflows, 1856
 observed impacts, 1824–1827, 1824–1826
 occupational health, 1863
 ocean and coastal ecosystems, 1839–1843, 1840, 1890
 olives, 1844
 permafrost, 1823–1824, 1855–1856
 pests and weeds, 1844
 phenology, 1835, 1836
 plant pests, 1844
 pollinators, 1836, 1837
 ports, 1850, 1871
 poverty, 1865, 1870
 precipitation, 573, 1824–1826, 1824, 2723
 precipitation extremes, 1824–1826
 production: agricultural, 1819–1820, 1843–1844, 1848, 1866, 1876, 1877
 production: marine and coastal, 1840, 1840, 1841
 projected impacts, 19, 59, 1819–1820, 1824–1827, 1825–1826
 protected areas, 1838
 railways, 1850, 1851
 risk perception, 1886–1887, 1886
 risks, 1819–1820
 risks: from outside Europe, 1820
 risks: key (See key risks, above)
 risks: multiple, 1820, 1880
 risks: residual, 1820, 1856–1858, 1880
 rivers, 1850–1851
 rivers: flooding, 1827–1828, 1832–1833, 1832
 Sami reindeer herding, 82, 1057–1058, 1868–1869
 sea level rise, 1820, 1824, 1826, 1827, 1831, 1850, 1871, 1878–1880
 sea level rise: planning for, 1831
 seas, 1824
 seas: acidification, 1824, 1841, 1846
 skiing, 1852
 snow, 1824, 1852, 1866
 social inequity, 1865–1870, 1889
 socioeconomic conditions, 1820, 1823, 1823
 soil erosion, 1836, 1837–1838
 soil moisture, 1828
 species extirpation, 1834–1835
 species range shifts, 1835, 1836, 1837, 1843
 storms, 1824, 1826
 streamflow, 573
 supply chain issues, 1849, 1871
 sustainable development goals, 1887, 1888
 temperature, 1819, 1824, 1875–1876, 2723
 temperature: sea surface temperature, 1826, 1827, 1867
 temperature: thermal comfort, 1819, 1858
 temperature extremes, 1824, 1824–1825, 1853, 1875, 2723
 temperature scenarios, 1819, 1820, 1825–1826, 1840, 1876, 1878
 terrestrial and freshwater ecosystems, 1834–1839, 1836
 terrestrial and freshwater ecosystems: adaptation, 1838–1839, 1890
 terrestrial and freshwater ecosystems: carbon sinks, 1819
 terrestrial and freshwater ecosystems: composition and integrity, 1819
 terrestrial and freshwater ecosystems: habitat space, 1819, 1836
 tourism, 1852, 1857, 2449
 trade and globalisation, 1849, 1870–1873
 transboundary risks, 1820
 transport, 1850–1851, 1857
 tree mortality, 249
 tropicalisation, 1839–1840
 Venice and its lagoon, 1828–1829
Vibrio pathogens, 1841, 1862, 1863
 vulnerabilities, 1823–1824, 1823, 1825–1826
 vulnerable settlement zones, 1864
 wastewater, 1852, 1857
 water, 1827–1834
 water: observed impacts, 1827–1830
 water: projected risks, 59, 1827–1830
 water: solution space and adaptation, 1830–1833, 1831–1832
 water: virtual water flows, 1871
 water management, 1830–1833, 1847
 water scarcity, 59, 1820, 1828, 1832, 1874, 1877–1878, 1878
 wind storms, 1824, 1860
 windows of opportunity, 1821
 wine, 1844
 world heritage sites, 1827, 1870
Eutrophication*, 252, 278–279, 401, 582
 in coastal areas, 401
Evapotranspiration (ET), 568, 568
 CO₂ effects on, 564
 observed changes, 568, 568
 projected changes, 599–600, 601
Evidence*, 31, 41, 159–160, 159
Evolution
 assisted, 474
 colour/melanism, 230
 extinction not prevented by, 201
 extreme events and, 48
 multiple-driver research, 410–411, 435
 observed responses to climate change, 236–237
 within populations, 201
Evolutionary adaptation*, 386, 407–409, 408
Exposure*, 9–10, 14–22, 54, 65
 about, 8, 14, 43, 44
 about: summary, 14–22
 to altered environments, 445–446, 449
 definition of, 43
 drivers of, 2421–2422
 to health risks, 1052, 1090
 interconnections, 14
 lock-in, 85, 86
 observed impacts, 14–22
 poverty and, 1051
 projected, 15, 16, 17
 risk and, 17, 148–149, 1214–1215
 scenarios, 44
 See also Vulnerability
Extinction*, 16, 56, 69, 200–201, 256–261, 2132
 Africa, 1302, 1334–1336, 1336
 Asia, 1476, 1476, 1477
 assisted migration of species, 221–222, 287
 attribution to climate change, 200–201
 Australasia, 1583, 1591–1594, 1597
 Bramble Cay melomys, 200, 221, 1583, 1591, 1595, 2132
 documented cases, 200–201
 ecosystem services and, 279
 extinction risk, 16, 56, 200, 202, 256–261, 259–260
 extinction risk: biodiversity hotspots, 2125, 2132–2133, 2135
 extinction risk: endemic species, 2125, 2132, 2135
 extinction risk: levels of, 16
 extinction risk: mountain regions, 2133, 2276, 2294–2295
 FAQ, 221–222
 global, 200–201, 257–261, 279
 golden toad, 201, 2132
 irreversibility of, 69, 202, 279
 IUCN Red list, 221, 257
 local, 56
 mountain regions, 2132, 2133, 2276, 2294–2295

observed impacts, 45
 past climate change and, 154–155
 projected changes, 16, 56, 69, 202, 1213–1214
 protected zones and, 222
 Small Islands, 2045, 2046, 2132
 temperature overshoot and, 69
 temperatures of 1.5°C and beyond, 56, 69
 terrestrial and freshwater ecosystems, 16, 200,
 202, 220–223, 221–222, 229, 256–261,
 259–260

Extirpation*, 45, 56, 1335
 Asia, 1476, 1476, 1477
 Europe, 1834–1835
 ocean and coastal systems, 382

Extratropical cyclones*
 Central and South America, 1711, 1712
 Small Islands, 2055

Extreme climate events. *See* Extreme weather events

Extreme sea level (ESL)*, 27, 62, 391, 2165
See also Sea level

Extreme weather events*, 47–48, 215–218, 2486,
 2488–2490, 2508
 about, 11
 atmospheric river events, 1953, 1962
 compound*, 208, 909
 COVID-19 and, 1068
 Cross-Chapter Box (EXTREMES), 215–218
 current exceedence of projected conditions, 48
 deaths/mortality, 1174
 detection and attribution, 215, 555, 587
 disproportionate impacts, 47, 1181, 1206
 droughts, 556
 event attribution, 1938–1939
 evolutionary responses and, 48
 FAQs, 1938–1939, 2508
 floods, 555
 frequency and magnitude of, 11, 47, 56
 frequency and severity of, 204, 215, 588
 freshwater systems, 214
 health and, 1045, 1053
 heatwaves and temperature extremes, 215–217
 IPCC Special Report on (SREX), 173–174
 irreversible impacts, 11, 48
 key risks and, 2508
 learning from, 217–218
 losses and damages, 47, 54–55
 mental health effects, 48, 1045, 1076
 migration and, 52, 65, 1045, 1078, 1084–1085,
 1100–1101
 observed changes, 11, 47–48, 208, 215–217, 717
 precipitation, 567
 projections, 15–17, 21, 56
 as public face of climate change, 588–591
 Reasons for Concern (RFC2), 18, 2417, 2486,
 2488–2490, 2501
 terrestrial and freshwater ecosystems, 200, 204,
 208–210, 214, 215–218
 unprecedented consequences of, 48
 urgency for climate action, 204
 vulnerability and, 217–218, 1181, 1181
 water-related, 565, 622
See also Disasters; Droughts; Floods; Heatwaves;
 and specific regions and sectors

F

Fairness*, 162–163, 2592
 between generations, 162

FAQs. *See* Frequently Asked Questions (FAQs)

Farming. *See* Agriculture

Farmworkers, 734, 795

Feasibility*, 23–28, 24–26, 2724–2732, 2733,
 2769–2807
 Cross-Chapter Box (FEASIB), 2769–2807
 knowledge gaps, 2787–2788
 linkages, 134
 of solutions, 23–28, 161, 161

Feedbacks, 34, 267, 274–277, 275, 276
 carbon balance and, 202–203, 274–277, 275, 276
 decision making and, 2577
 ecosystem-climate, 274–277, 275, 276
 fires, 275–276
 forests, 275–276

Fibre. *See* Food, fibre, and other ecosystem products

Finance, 8, 42, 55
 100 Billion (climate finance commitment),
 2586–2587
 access to, 98
 active ownership, 2710
 as adaptation barrier/limiter, 22, 84, 2445–2448,
 2504
 adaptation finance (*See* Adaptation finance)
 climate finance, 28, 35, 2586–2593, 2708–2709,
 2721
 Climate Policy Initiative, 2590
 COVID recovery packages, 2592–2593
 Cross-Chapter Box (FINANCE), 2586–2593
 crowdfunding, 2710
 as enabling condition, 106, 164, 488, 1115,
 2542–2543, 2584–2585
 equity and fairness in, 2592
 FAQ, 2617–2618
 financial flows, 2442, 2547, 2548, 2586–2593
 financial flows: diagram, 2591
 financial flows: tracking, 2609, 2612–2613
 financial instruments, 30, 826, 977, 1248, 2710
 forecast-based, 2489
 green strategies and investments, 2710
 institutional investors, 2710
 insurance, 814–817
 investment in physical capital, 1235
 losses and damages, 2565
 negative and positive screening, 2710
 private sector, 30, 719, 825, 977, 978, 2543, 2721
 public investment, 30, 719, 825, 977
 Rio Markers, 2613
 risk financing, 2553–2554
 risk transmission through, 68, 2441–2442
 various funds, 2710

Fires, 11, 50, 927–928
 air pollution and diseases, 1045, 1054, 1071
 Amazon region, 1220–1221
 attribution for, 1948
 Australasia, 589–590, 591, 1583, 1589,
 1589–1590, 1594, 1599–1601
 escalating impacts and risks, 1599–1601
 Europe, 1819, 1835–1836, 1836, 1838, 1860

feedbacks, 275–276
 North America, 1932, 1948–1950, 1962, 1967,
 1969
 urban areas, 927–928
See also Wildfires

Fiscal policy, 2719

Fish, 381–382
 biomass projection, 2678
 freshwater, 592
 mercury and, 49, 1076, 1098
 multiple drivers, effects on, 406–407
 ocean acidification and, 401, 406–407
 phenology, 437–438, 439
 range shifts, 382, 386, 433–434, 460, 724, 766,
 768, 2328
 temporal mismatches, 382, 437–438
 tuna, 462
 water temperature and, 460

Fisheries, 11, 48–49, 57–60, 381–382, 469, 770–773
 acidification and, 48
 adaptation, 476–480, 766–767, 807
 adaptation feasibility, 2770
 adaptive capacity, 772
 bycatch, 1952
 capture fisheries, 763
 catch composition, 457
 closures of, 1952, 1957
 competition issues, 805
 distribution and range shifts, 433, 724, 765, 766,
 769
 finfish culture, 776–779
 food fish consumption, 760, 765
 food safety, 725, 764, 765, 766, 789
 food security and, 764–765
 freshwater, 278–279
 Ghanaian fisheries, 769
 inland, 763, 764–765
 livelihoods, 717, 760
 maladaptation, 2438
 management, 457, 722, 765, 807–808
 marine, 764
 observed impacts, 11, 12, 46, 48–49, 388,
 428–429, 429, 717, 764
 overfishing, 381
 in polar regions, 433
 projected impacts, 57–60, 383, 613, 766
 small-scale/subsistence, 469, 613
 sustainable harvesting, 475, 485, 486, 766–767
 vulnerability/risk, 764–765, 770
 women in, 765
See also Aquaculture; specific regions

Floods, 81, 558, 573–577
 accommodating, 634–635
 adaptation, 23, 27, 310, 634–635, 640, 647, 802,
 950, 957–958
 adaptation limits, 2449
 agriculture and, 585, 613, 805–806
 cities and, 1964–1967
 coastal zones, 17, 81, 382, 950, 1964–1967
 compound risks, 67–68
 dam failures, 615
 detection and attribution, 555, 587
 economic impacts, 62, 577

- in Europe (2021), 590, 591
- examples, 575
- exposure, 573, 576, 1052
- extreme events, 555, 565
- FAQ, 310, 662–663
- flood risk, 556
- food safety/contamination, 789, 802
- frequency and magnitude, 573
- glacier lake outburst floods, 577, 1715, 2291
- hard infrastructure, 634
- heavy precipitation and, 575, 577
- human health and, 582, 616, 1064, 1219
- human migration and, 593–594
- human mortality, 50–51
- migration and, 1085
- natural flood management, 297, 310
- observed changes, 558, 573–577
- as percent of all disasters, 555, 558, 577
- planning for, 634
- projected changes, 16, 17, 61, 62, 81, 556, 605–608, 606, 2678
- return period, 17, 81, 2678
- risks, 81, 938
- river floods, 62, 573, 576–577, 606, 607, 950–951
- urban areas, 617, 925–926, 938, 957–958
- vulnerability/risk, 577, 608
- See also specific regions*
- Flying foxes**, 216–217, 1595, 1637
- Food, fibre, and other ecosystem products**, 713–906
 - about, 717–719, 721
 - about: storyline figure, 74–75
 - adaptation, 87–91, 718–719, 811, 812
 - adaptation implementation, 811–832
 - adaptation options, 90–91, 718, 721, 722–723
 - bioeconomies, 718
 - cascading impacts, 82, 724, 724
 - climate change impacts, 720–721, 721, 832–834
 - climate change interactions, 811
 - climate resilient development, 825–827, 2729
 - competition, trade-offs, and nexus interactions, 802–811, 835–836
 - crop-based systems, 728–746
 - Cross-Chapter Box (MOVING PLATE), 768–773
 - Cross-Working Group Box (BIOECONOMY), 828–831
 - cultural ecosystem services, 740, 741–742
 - diet and nutrition, 717, 799–802
 - equity considerations, 718, 719, 723, 734, 801, 818
 - FAQs, 832–838
 - fisheries, 770–773
 - food access (*See* Food security)
 - food-borne diseases, 1045, 1065–1066, 1095, 1107
 - food sourcing (MOVING PLATE), 768–773
 - food systems (*See* Food systems)
 - forestry systems, 753–757
 - impacts, detection and attribution, 723–724
 - impacts on vulnerable groups, 717, 719
 - key risks, 725, 2462–2463, 2503
 - land-related issues, 717, 719, 802–803
 - livestock-based systems, 746–753
 - medicinal plants, 757, 758, 759
 - methodologies and uncertainties, 725–728, 726
 - mixed systems, 723, 745, 782–787, 785
 - models and assessment in, 725–728, 726
 - nutrition and diet (*See* Diet; Nutrition)
 - observed impacts, 48–49, 717, 728–733
 - other natural products, 757–760
 - phenology, 717
 - policies and governance, 719
 - previous IPCC reports, 720
 - projected impacts, 717–718, 734–742
 - protein sources, alternate, 753
 - resin and gum, 757, 758
 - risks and vulnerability, 721
 - SDGs, 2729
 - supply chain/post-harvest, 787–792, 2443
 - transformations, 728, 822–823
 - vulnerabilities, 733–734, 733
 - water-energy-food (WEF) nexus, 655, 811, 1246, 1530–1531, 2769
 - wild foods, 758–760, 761–763
 - youth innovation and, 719, 820–821
- Food availability***, 48, 60, 717, 793, 794–795, 796–798, 834
- Food-borne diseases**, 64, 1045, 1065–1066, 1095, 1968, 1970, 2064–2065
 - adaptation options, 1107–1108, 1107
- Food insecurity**, 48, 717, 1174
- Food loss and waste (FLW)**, 788–789, 792
- Food prices**, 20, 48, 53, 82, 790–791, 798
 - conflicts and, 53, 1087
 - projected impacts, 1098
- Food production**, 11, 12, 16, 48–49, 82, 717–718, 2425–2426
 - about: storyline figure, 74–75
 - adaptation, 87–91, 742–746, 788, 951–952
 - adaptation limits, 85, 2449
 - aquaculture, 456, 459–460, 718, 773–782, 787
 - carbon dioxide effects on, 736, 1046
 - cascading impacts*, 82, 724, 724
 - climate hazards and, 733
 - climate resilient development (CRD) and, 1242–1243
 - coffee and cocoa, 784–785, 788, 825–827, 1211
 - crop-based systems, 728–746
 - crop failures, 731, 1250
 - crop yields (*See* Crop yields)
 - Cross-Chapter Box (MOVING PLATE), 768–773
 - Cross-Working Group Box (BIOECONOMY), 828–831
 - diversification of, 745
 - equity and, 723, 734, 768
 - extreme events and, 718
 - fisheries, 770–773
 - food imports/exports, 1695, 1699, 1736, 2443
 - food safety, 481, 764, 789–790, 791
 - human rights-based approaches, 801
 - hydroponics, 787
 - key risks, 725, 2462–2463, 2503
 - land areas for, 717, 802–803, 803–804
 - land deals and, 91, 802–803, 803–804
 - livestock-based systems, 746–753
 - mixed systems, 723, 745, 782–787, 785, 1356
 - nutritional quality, 1046
 - observed impacts, 46, 48–49, 468, 723–724, 728–734, 2425–2426
 - ocean and coastal systems, 456–460, 457, 458
 - ozone effects on, 732–733
 - pests and, 16, 718, 730–732
 - plant breeding, 728, 743–744, 745, 1356
 - post-harvest (*See* Food supply chain)
 - projected impacts, 16, 57–61, 59, 717–718, 734–742
 - risk transmission and, 2443
 - sudden losses of, 11, 20, 49, 74, 832–833
 - supply chain (post-harvest to food), 787–792
 - trade-offs, 804–805, 805
 - vulnerabilities and risks, 733–734, 733, 1492, 1495
 - water and, 74, 558
 - water-energy-food (WEF) nexus, 74, 655, 1246, 1347, 1530–1531, 2769
 - wild foods, 758–760, 761–763, 1353–1354
 - wine, 739
 - See also* Agriculture; Crop production; Fisheries; Livestock
- Food safety**, 49, 51, 789–790, 793, 798
 - adaptation, 791
 - fisheries, 725, 764, 765, 766, 789
 - projected impacts, 798, 798
 - risks, 20, 798
 - seafood safety, 20, 481, 764
- Food security***, 11, 16, 720, 792–802, 2462–2463
 - about: storyline figure, 74–75
 - adaptation feasibility, 1110
 - adaptation options, 798–799, 802, 836–837, 1111
 - climate-change impacts, 792–794, 793–794, 1076
 - compounding effects on, 67, 795
 - COVID-19 and, 792
 - desert locusts and, 795
 - drivers of, 792
 - droughts and, 585
 - FAQs, 835–838
 - fisheries and, 717
 - food access*, 16, 793, 795–798
 - food availability*, 48, 717, 793, 794–795, 796–798, 834
 - food demand, 811
 - food prices, 20, 48, 53, 790–791, 798, 1098
 - food quality, 793, 798
 - food stability, 793, 796
 - food utilisation, 793, 796
 - four dimensions of, 793–794
 - key risks, 2455, 2462–2463, 2503
 - nutrition and, 811, 1110–1111
 - observed impacts, 11, 48, 794–796
 - projected impacts, 16, 57–61, 67, 796–798
 - regional disparities in, 16, 57, 60
 - rural areas, 796
 - safety nets, 796
 - SDG2 (Zero Hunger), 798
 - undernutrition, 798, 1046
 - vulnerability/risks, 794
- Food shocks**, 832–833
- Food sovereignty**, 818, 1056
- Food supply chain**, 787–792
 - adaptation, 791–792, 792

food loss, 788, 790, 792
 food safety and, 789–790, 791
 food waste, 788–789, 792
 transportation and trade, 790–791, 791

Food systems*, 48, 57–61, 718, 802–811, 2425–2426
 adaptation (See Food systems adaptation)
 climate change impacts (FAQ), 834
 climate change interactions, 811
 competition and, 805–806, 835–836
 crop-based systems, 728–746
 dynamic nature of, 727–728
 financial actors in, 810–811
 human rights-based approaches, 801
 Indigenous knowledge and, 818–820
 models and assessment, 725–728, 726
 nexus interactions, 802–811, 1246, 1530–1531, 2769
 political action gap, 972
 post-harvest (See Food supply chain)
 projected impacts, 57–61
 strengthening, 818
 transformations, 728, 822–823

Food systems adaptation, 718–719, 721, 806, 811–832, 812
 actors, 812
 adaptation options, 721, 722–723
 aquaculture, 722, 779–782, 781
 bioeconomies, 718
 climate services, 813–814
 community-based adaptation, 817–818
 cost effectiveness, 718
 crop breeding, 728, 743–744, 745, 1356
 crop production, 742–746
 ecosystem-based, 718
 effectiveness indicators, 812
 enabling conditions, 818–825
 FAQs, 836–838
 feasibility and effectiveness, 718, 815, 1110
 finance and, 719, 823–825, 824, 825
 fisheries, 476–480, 766–767
 food sovereignty, 818, 1056
 forestry, 755–756, 756–757, 757
 implementation, 811–832
 insurance, 814–817
 land issues, 719
 maladaptation, 806, 807–809
 on-farm adaptations, 718
 policies and governance, 719
 SDGs and, 814
 state of adaptation, 811, 812, 813
 sustainable resource management, 718–719

Food webs, 67
 marine, 381, 395, 449–451, 2329–2330
 polar regions, 1950, 2321, 2329–2330, 2332

Forest fires. See Fires; Wildfires

Forestry, 753–757
 adaptation/maladaptation, 23–26, 643, 719, 756–757, 2437–2438, 2439, 2769, 2776–2777
 agroforestry*, 71, 640, 643, 647, 783, 1242–1243, 2775–2776
 climate resilient development (CRD), 1243–1244
 Indigenous knowledge and local knowledge and, 755–756

Karuk Climate Adaptation Plan, 755–756
 management and mitigation, 1243–1244, 2776–2777
 mixed systems, 782–787
 observed impacts, 48–49, 717, 753–754
 plantation forests, 204, 264, 265, 288, 2371, 2378
 projected impacts, 754–755
 REDD+ and, 757, 757, 1243–1244, 1512, 2384, 2440
 sustainable, 289, 757, 2371, 2372, 2393–2396
 tree planting, 310, 315–316, 1341

Forests, 204, 753–757
 adaptation, 23–26, 643, 719, 756–757, 2769, 2776–2777
 afforestation, 56, 91, 305, 2439, 2769, 2776–2777
 Amazon (See Amazon region/forest)
 boreal, 201, 237–238, 265–266, 269
 carbon stocks, 240, 250, 272
 deforestation (See Deforestation)
 dieback, 208, 239, 241, 272
 ecosystem services, 753
 feedbacks and, 275–276
 insect pests and damage, 16, 47, 248–249, 275–276
 land area, 56
 land rights and, 719
 management, 23, 2776–2777
 mangrove (See Mangroves)
 natural, 23
 observed impacts, 48–49, 753–754
 pest species, 200, 248–249, 273, 275–276
 plantation forests, 204, 264, 265, 288, 2371, 2378
 projected impacts, 265–266, 718, 754–755
 range/biome shifts, 201, 202, 238, 240
 recovery after fires, 754
 reforestation*, 165, 304–305, 314–316, 2776–2777
 sustainable management, 23, 304–305, 757, 2371, 2372, 2393–2396
 tree mortality, 22, 200, 201, 246–249, 272–273, 280–281, 753–754, 1946, 2499
 tree planting, 310, 315–316, 1341
 tropical (See Tropical forests)
 urban areas, 309, 935
 See also Amazon region/forest; Deforestation; Trees

Four Rs (reduce, remove, reuse and recycle), 631

Frequently Asked Questions (FAQs)

- 1.1 | What are the goals of climate change adaptation?, 179
- 1.2 | Is climate change adaptation urgent?, 180
- 1.3 | What constitutes successful adaptation to climate change?, 180–181
- 1.4 | What is transformational adaptation?, 181
- 2.1 | Will species become extinct with climate change and is there anything we can do to prevent this?, 221–222
- 2.2 | How does climate change increase the risk of diseases?, 233–235
- 2.3 | Is climate change increasing wildfire?, 247–248
- 2.4 | How does nature benefit human health and well-being and how does climate change affect this?, 282–283

- 2.5 | How can we reduce the risks of climate change to people by protecting and managing nature better?, 310–312
- 2.6 | Can tree planting tackle climate change?, 315–316
- 3.1 | How do we know which changes to marine ecosystems are specifically caused by climate change?, 387–388
- 3.2 | How are marine heatwaves affecting marine life and human communities?, 416–417
- 3.3 | Are we approaching so-called tipping points in the ocean and what can we do about it?, 447–448
- 3.4 | Which industries and jobs are most vulnerable to the impacts of climate change in the oceans?, 469–471
- 3.5 | How can nature-based solutions, including marine protected areas, help us to adapt to climate-driven changes in the oceans?, 486–487
- 4.1 | What is water security, and how will climate change affect it?, 660
- 4.2 | Which places are becoming wetter and which are becoming drier, and what risks do these bring to people?, 661–662
- 4.3 | How will climate change impact the severity of water-related disasters, such as droughts and floods?, 662–663
- 4.4 | Globally, agriculture is the largest user of water. How will climate change impact this sector, and how can farmers adapt to these changes?, 664–666
- 4.5 | Which principles can communities implement to sustainably adapt to the ways that climate change is impacting their water security?, 666–667
- 5.1 | How is climate change (already) affecting people's ability to have enough nutritious food?, 832–833
- 5.2 | How will climate change impact food availability by mid and late century and who will suffer most?, 834
- 5.3 | Land is going to be an important resource for mitigating climate change: how is the increasing competition for land threatening global food security and who will be affected the most?, 835–836
- 5.4 | What are effective adaptation strategies for improving food security in a warming world?, 836–837
- 5.5 | Climate change is not the only factor threatening global food security: other than climate action, what other actions are needed to end hunger and ensure access by all people to nutritious and sufficient food all year round?, 837–838
- 6.1 | Why and How Are Cities, Settlements and Different Types of Infrastructure Especially Vulnerable to the Impacts of Climate Change?, 992
- 6.2 | What Are the Key Climate Risks Faced by Cities, Settlements and Vulnerable Populations Today, and How Will These

- Risks Change in a Mid-Century (2050) 2°C Warmer World?, 993
- 6.3 | What Adaptation Actions in Human Settlements Can Contribute to Reducing Climate Risks and Building Resilience across Building, Neighbourhood, City and Global Scales?, 994
- 6.4 | How Can Actions That Reduce Climate Risks in Cities and Settlements Also Help to Reduce Urban Poverty, Enhance Economic Performance and Contribute to Climate Mitigation?, 995
- 6.5 | What Policy Tools, Governance Strategies and Financing Arrangements Can Enable More Inclusive and Effective Climate Adaptation in Cities and Settlements?, 996
- 7.1 | How will climate change affect physical and mental health and well-being?, 1126–1127
- 7.2 | Will climate change lead to wide-scale forced migration and involuntary displacement?, 1128
- 7.3 | Will climate change increase the potential for violent conflict?, 1128
- 7.4 | What solutions can effectively reduce climate change risks to health, well-being, forced migration and conflict?, 1128–1129
- 7.5 | What are some specific examples of actions taken in other sectors that reduce climate change risks in the health sector?, 1129
- 8.1 | Why are people who are poor and disadvantaged especially vulnerable to climate change and why do climate change impacts worsen inequality?, 1251
- 8.2 | Which world regions are highly vulnerable and how many people live there?, 1251–1252
- 8.3 | How does and will climate change interact with other global trends (e.g., urbanisation, economic globalisation) and shocks (e.g., COVID-19) to influence livelihoods of the poor?, 1252
- 8.4 | What can be done to help reduce the risks from climate change, especially for the poor?, 1253
- 8.5 | How do present adaptation and future responses to climate change affect poverty and inequality?, 1253
- 9.1 | Which climate hazards impact African livelihoods, economies, health and well-being the most?, 1399–1400
- 9.2 | What are the limits and benefits of climate change adaptation in Africa?, 1401
- 9.3 | How can African countries secure enough food in changing climate conditions for their growing populations?, 1401
- 9.4 | How can African local knowledge serve climate adaptation planning more effectively?, 1402
- 10.1 | What are the current and projected key risks related to climate change in each sub-region of Asia?, 1532–1533
- 10.2 | What are the current and emerging adaptation options across Asia?, 1534–1535
- 10.3 | How are Indigenous knowledge and local knowledge being incorporated in the design and implementation of adaptation projects and policies in Asia?, 1535–1536
- 10.4 | How can Asia meet multiple goals of climate change adaptation and sustainable development within the coming decades?, 1536–1537
- 11.1 | How is climate change affecting Australia and New Zealand?, 1648
- 11.2 | What systems in Australia and New Zealand are most at risk from ongoing climate change?, 1648–1649
- 11.3 | How can Indigenous Peoples' knowledge and practice help us understand contemporary climate impacts and inform adaptation in Australia and New Zealand?, 1650
- 11.4 | How can Australia and New Zealand adapt to climate change?, 1650–1651
- 12.1 | How are inequality and poverty limiting options to adapt to climate change in Central and South America?, 1765–1766
- 12.2 | How have urban areas in Central and South America adapted to climate change so far, which further actions should be considered within the next decades and what are the limits of adaptation and sustainability?, 1766–1767
- 12.3 | How do climatic events and conditions affect migration and displacement in Central and South America, will this change due to climate change, and how can communities adapt?, 1767–1768
- 12.4 | How is climate change impacting and how is it expected to impact food production in Central and South America in the next 30 years, and what effective adaptation strategies are and can be adopted in the region?, 1768–1769
- 12.5 | How can Indigenous knowledge and practices contribute to adaptation initiatives in Central and South America?, 1770
- 13.1 | How can climate change affect social inequality in Europe?, 1889
- 13.2 | What are the limits of adaptation for ecosystems in Europe?, 1890
- 13.3 | How can people adapt at individual and community level to heatwaves in Europe?, 1891
- 13.4 | What opportunities does climate change generate for human and natural systems in Europe?, 1892
- 14.1 | How has climate change contributed to recent extreme events in North America and their impacts?, 1938–1939
- 14.2 | What can we learn from the North American past about adapting to climate change?, 1986–1988
- 14.3 | What impacts do changes in the North American Arctic have within and outside the region?, 1988
- 14.4 | What are some effective strategies for adapting to climate change that have been implemented across North America, and are there limits to our ability to adapt successfully to future change?, 1998–1999
- 15.1 | How is climate change affecting nature and human life on small islands, and will further climate change result in some small islands becoming uninhabitable for humans in the near future?, 2095–2096
- 15.2 | How have some small island communities already adapted to climate change?, 2096–2099
- 15.3 | How will climate-related changes affect the contributions of agriculture and fisheries to food security in small islands?, 2099–2100
- 16.1 | What are key risks in relation to climate change?, 2502–2503
- 16.2 | How does adaptation help to manage key risks and what are its limits?, 2504
- 16.3 | How do climate scientists differentiate between impacts of climate change and changes in natural or human systems that occur for other reasons?, 2505
- 16.4 | What adaptation-related responses to climate change have already been observed, and do they help reduce climate risk?, 2506
- 16.5 | How does climate risk vary with temperature?, 2506–2507
- 16.6 | What is the role of extreme weather events in the risks we face from climate change?, 2508
- 17.1 | Which guidelines, instruments and resources are available for decision makers to recognise climate risks and decide on the best course of action, 2616
- 17.2 | What financing options are available to support adaptation and climate resilience?, 2617–2618
- 17.3 | Why is adaptation planning along a spectrum from incremental to transformational adaptation important in a warming world?, 2619
- 17.4 | Given the existing state of adaptation, and the remaining risks that are not being managed, who bears the burden of these residual risks around the world?, 2619
- 17.5 | How do we know whether adaptation is successful?, 2620–2621
- 18.1 | What is a climate resilient development pathway?, 2734
- 18.2 | What is climate resilient development and how can climate change adaptation (measures) contribute to achieving this?, 2734–2735

- 18.3 | How can different actors across society and levels of government be empowered to pursue climate resilient development?, 2736
- 18.4 | What role do transitions and transformations in energy, urban and infrastructure, industrial, land and ocean ecosystems, and in society, play in climate resilient development?, 2736
- 18.5 | What are success criteria in climate resilient development and how can actors satisfy those criteria?, 2737
- CCP1.1 | Why are biodiversity hotspots important?, 2151
- CCP1.2 | How can society ensure conservation of biodiversity in climate policies?, 2152
- CCP2.1 | Why are coastal cities and settlements by the sea especially at risk in a changing climate, and which cities are most at risk?, 2182
- CCP2.2 | What actions can be taken by coastal cities and settlements to reduce climate change risk?, 2183
- CCP2.3 | Considering the wide-ranging and interconnected climate and development challenges coastal cities and settlements face, how can more climate resilient development pathways be enabled?, 2184
- CCP3.1 | How has climate change already affected drylands and why are they so vulnerable?, 2217
- CCP3.2 | How will climate change impact the world's drylands and their people?, 2217–2218
- CCP3.3 | What can be done to support sustainable development in desert and semiarid areas, given projected climate changes?, 2218
- CCP4.1 | Is the Mediterranean Basin a 'climate change hotspot'?, 2253–2254
- CCP4.2 | Can Mediterranean countries adapt to sea level rise?, 2255–2256
- CCP4.3 | What is the link between climate change and human migration in the Mediterranean Basin?, 2256
- CCP5.1 | How is freshwater from mountain regions affected by climate change, and what are the consequences for people and ecosystems?, 2300
- CCP5.2 | Do people in mountain regions, and further downstream, face more severe risks to water-related disasters due to climate change, and how are they coping?, 2301
- CCP5.3 | Does climate change pose a risk to mountain species and ecosystems, and will this affect people?, 2302
- CCP5.4 | What types of adaptation options are feasible to address the impacts of climate change in mountain regions under different levels of warming and what are their limits?, 2303
- CCP5.5 | Why are regional cooperation and transboundary governance needed for sustainable mountain development?, 2304
- CCP6.1 | How Do Changes in Ecosystems and Human Systems in the Polar Regions Impact Everyone around the Globe? How Will Changes in Polar Fisheries Impact Food Security and Nutrition around the World?, 2333
- CCP6.2 | Is Sea Ice Reduction in the Polar Regions Driving an Increase in Shipping Traffic?, 2336–2337
- CCP6.3 | How Have Arctic Communities Adapted to Environmental Change in the Past and Will These Experiences Help Them Respond Now and in the Future?, 2339
- CCP6.4 | When Will Climate Change Impacts in Polar Regions Surpass Our Ability to Adapt?, 2351
- CCP7.1 | How Is Climate Change Affecting Tropical Forests and What Can We Do to Protect and Increase Their Resilience?, 2396–2397
- Freshwater ecosystems**, 197–377
adaptation measures, 629
biodiversity hotspots, 2128, 2134, 2138–2143, 2138, 2144
communities dependent on, 629
degradation of, drivers, 555
drivers and responses, 223–224
extreme events and, 214
observed impacts, 592–593
physical changes, 210–229
projected risks, 617–618, 622
See also Terrestrial and freshwater ecosystems
- Frogs**, 1703
- Fruit bats**, 47–48
- Fuels extraction**, 933
- Fungi**, 789
Batrachochytrium dendrobatidis (Bd), 200, 231–232, 1703
chytrid fungus, 200, 201, 231–232
toxins (mycotoxins), 20, 51, 789, 1098
- G**
- Galapagos islands**, 1701
- Ganges-Brahmaputra region**, 1485–1488, 1489–1490
- GDP**. See Gross Domestic Product
- Gender**, 13, 53, 96–97, 107, 656–657, 734, 734, 1192, 2700–2704
about (key messages), 2699
adaptation options and, 107, 801, 1174
aquaculture, 775
cities/urban areas, 911
climate change and, 2700, 2703–2704
conflict/violent conflict and, 1045, 1088, 1971
Cross-Chapter Box (GENDER), 2700–2704
disproportionate impacts, 96–97, 555, 587
empowerment of women, 27, 97
equity and, 53, 656–657, 734
fisheries, 765
food and fibre systems, 734, 734, 748, 775, 818
- Gender Equality Index, 2672
gender equality SDG (SDG5), 101, 1174, 2703–2704
gender gaps, 1175
gender-responsive action, 911
gender roles, 2700, 2704
health and, 63, 1051–1053, 1055
Indigenous Peoples and, 1055
invisible women, 973
justice and, 53, 2700
leave policies, 55
mainstreaming, 1349
migration and, 1085
mountain regions, 2275, 2276, 2289, 2290, 2293, 2297, 2298
pay gaps, 55
peacebuilding and, 1119
small islands and, 2050, 2077, 2091
vulnerability and, 49, 65, 1052–1057, 1052, 1192
water-related issues, 555, 586–587, 656–657, 1346
women in governance, 973
- Genetic responses**, 201, 236–237, 407–408, 408
- Genetically modified (GM) crops**, 71, 798–799, 799
- Genetics in agriculture**, 71, 743–744, 745
genetically modified (GM) crops, 798–799, 799
- Ghanian fisheries**, 769
- Giardia**, 1095
- Glacial lakes**, 1715
- Glacier lake outburst floods/outbursts***, 61, 577, 1715, 2291
- Glaciers**, 50, 570–571, 1219, 2275, 2291, 2300
adaptation limits, 1224
adaptation limits and, 28
Africa, 1290, 1329
Asia, 1459, 1463, 1465, 1485, 1532
Australasia, 1583, 1625
Central and South America, 1691, 1701, 1702–1703, 1714, 1717, 1718
Europe, 1823, 1824, 1867
mass loss, 11, 16, 61, 555, 570, 571
melting of, 21, 50, 558, 563
meltwater/runoff, 564, 582, 605
North America, 1954
observed changes, 11, 50, 565
polar regions, 2324
projected changes, 16
- Global aggregate impacts**, 18, 2417, 2486, 2492–2494, 2501
projected, 17
See also ANNEX I: Global to Regional Atlas
- Global greening**, 564
- Global warming***, 130–132
adaptation limits and, 28
adaptive capacity and, 2666
benefits of limiting, 556
Cross-Chapter Box (CLIMATE), 137–145
current level of, 44
escalating impacts with each degree of warming, 16, 22, 55–56, 57
future pathways, 2662
mid to long-term risks, 16–17, 18–20, 63, 69
near-term risks, 15, 55, 69
outcomes, 44

- overshoot scenarios, 21–22, 35, 57, 69
 potential amplification of, 22
 projected time to reach 1.5°C, 10, 44, 144–145
 projections, 16, 18, 130, 391
 public perceptions about, 1939–1942, 1941
 risks at 1.5°C, 15, 68–69
 risks beyond 1.5°C, 16–17, 69
 temperature targets, 2417, 2420, 2447, 2657
 unprecedented nature of, 45, 55–56, 68
See also Temperature
- Global warming levels (GWs), 137, 139–143**
 escalating risks and impacts, 16, 22
 and projected climate change, 16, 2677–2678
- Globalisation, 68, 1849, 1870–1873, 1872, 2416**
 risk transmission and, 21, 2441–2444
 supply chains, 21
- Gondwana refugia, 300, 1599**
- Governance*, 96–97, 106, 1245–1246, 2581–2584**
 adaptation and, 29, 35, 71, 91, 126, 166–168, 480, 2542, 2581–2584, 2583
 adaptation implementation and, 1510–1514
 Circulating and Ecological Sphere (CES), 1462, 1515
 city and local, 110–111
 climate resilient development and, 35, 110–111, 2659–2660, 2706–2707, 2712–2717
 climate shocks, anticipating, 976–977
 enabling condition, 106, 126, 990–991, 2542, 2581–2584, 2712
 environmental and social, 2584
 examples, 2583
 FAQ, 996
 goals for climate action, 125
 inclusive, 30, 31, 35, 110, 383, 996
 informal, 110–111
 knowledge and, 2593
 local, 910, 991
 multi-level*, 91, 111, 166, 964, 966, 2659
 networked, 910
 oceans, 383, 389, 488–489
 partnerships, 26, 97
 polycentric*, 658–659, 1246, 2542
 regulations and standards, 2583–2584
 transboundary, 30, 480, 659, 719, 768–769, 2276, 2304
 transformative, 383
 transnational legislation, 659
 urban governance, 910, 913, 964, 973, 996
 water governance, 658–659
 women in, 973
- Governance capacity*, 166–167**
- Grains. *See* Agriculture; Crop yields; Maize; Rice; Wheat**
- Grasslands, 239–240, 264, 269, 309, 717, 822**
 alpine, 202
 Central and South America, 1696, 1700, 1717, 1724, 1768
 North America, 1956
 urban, 309
 woody encroachment, 47, 201, 238, 240, 275
- Grazing systems/land, 717, 748, 820, 1243**
 net primary production, 748
See also Livestock; Pastoralism
- Great Barrier Reef, 57, 301, 442, 1584, 1602, 1605–1607**
- Green bonds, 2710**
- Green buildings, 1245**
- Green Climate Fund (GCF)*, 1229**
- Green GDP, 2717–2718**
- Green infrastructure*, 910, 913, 925, 932, 935, 1369, 1461**
 feasibility, 2780
- Green jobs, 1460**
- Green spaces/infrastructure, 289, 948**
- Green strategies and investments, 2710**
- Greenhouse gases (GHGs)*, 34, 42**
 interconnections, 8, 42
 mitigation, 2657
 from peatlands, 242, 249
 from permafrost thawing, 251, 279
 planetary boundaries and, 2661
 temperature overshoot and, 21–22, 69
See also Carbon dioxide; Emissions; Methane
- Greenland ice sheet*, 130, 2500**
- Grief, 467, 1078, 1971, 2340**
 anticipatory, 594
- Gross Domestic Product (GDP)*, 2661, 2717**
 Green GDP, 2717–2718
 projected, 67, 1092
 water-related impacts, 556
- Groundwater, 23, 563, 579–582**
 coastal groundwater, 382
 demand for, 62
 drinking water, 579
 extraction by humans, 564
 groundwater-dependent ecosystems, 582, 611
 observed changes, 555
 projected changes, 16, 62, 610–611
 recharge*, 61
 salinisation, 21, 382, 611
- Groundwater recharge*, 555, 565**
- Growing season, 200, 224, 242, 244, 251, 255**
See also Phenology
- Growth**
 in consumption, 2664, 2693
 degrowth, 174–175, 2672, 2705
 economic growth, 54, 67, 2671–2672
 growth orientation, 67
 population growth, 65, 72–73, 2421, 2659, 2673
 post-growth period, 2672
 scenarios, 2673
- Gum, 758**
- ## H
- Habitability*, 82, 2068, 2069, 2073, 2074, 2095–2096, 2165, 2286**
- Habitats**
 availability, 84, 435
 climatically suitable, 2133
 creation/maintenance, 457, 458, 461, 468, 474
 hard limits and, 84
 restoration, 109, 483–484, 485, 486
 thermal habitat, 210
See also Biodiversity; Ecosystems
- Happiness Index, 48**
- Happiness Indexes, 2672**
- Hard and soft limits, 28, 84, 127, 171, 649–650, 1224–1225, 1250, 2415, 2444, 2445, 2560**
- Hard protection, 86, 2075–2076, 2078–2079, 2081, 2084**
 cities and settlements by the sea, 2172, 2174, 2183
- Harmful algal blooms (HABs), 20, 64, 404, 463, 469, 789, 1076, 1098, 1840–1841**
- Hazards*, 57, 67, 76–77, 148–149, 208, 1059, 1249**
 about, 8, 76–77, 82–83
 adaptation-related responses and, 2432, 2433
 compound, 67–68
 hazard-vulnerability interface, 1181
 health impacts, 1044, 1045, 1059
 linkages, 67, 82–83, 134, 1178–1180, 1179
 mortality per hazard event, 77
 multiple, 48, 67, 82–83
 observed changes, 208–209
 poverty and inequality linkages, 1178–1180, 1179
 water-related, 555–556
- Health: of planet and ecosystems. *See* Ecosystem health; Planetary health**
- Health and well-being, 1041–1170**
 about, 1044–1059, 1058
 about: summary, 12, 13, 17, 50–52, 63–64
 about: storyline figure, 79
 adaptation (*See* Health adaptation)
 aeroallergens, 1071, 1095–1096
 air quality, 939, 1045, 1095–1096
 biodiversity and, 253
 carbon dioxide effects, 1046
 cascading effects, 1050–1051
 cascading risks, 67, 1065
 children, 1053, 1089
 climate actions and, 1124–1125
 climate change and, 1049–1050, 1126–1127
 climate hazards and, 1044, 1045, 1050–1051, 1106
 climate resilient development, 1119–1123, 1120
 communicable diseases*, 1045, 1062–1071
 compound risks, 67
 conflicts and, 1044, 1045, 1086–1088, 1102, 1128
 COVID-19 and, 1047, 1067–1070
 Cross-Chapter Box (HEALTH), 1124–1125
 definitions, 1049
 disease burdens, 1046, 1060–1062, 1096
 diseases, 1045–1046, 1062–1072
 droughts and, 578
 early warning systems, 1113
 ecosystem services and, 47, 282–283
 elderly people, 1045, 1053
 extreme events and, 1045, 1053
 FAQs, 1126–1129
 food-borne diseases, 1045, 1065–1066, 1095, 1107
 gender and, 63, 1051–1053, 1055
 grief, 467, 594, 1078, 1971, 2340
 hazards, exposure and vulnerability, 1050–1059, 1051, 1052, 1059, 1106
 health engagement scores, 1105
 heat and cold-related impacts, 1045, 1060–1061, 1072–1074, 1091–1092
 heat-related deaths, 946, 1072–1074, 1089, 1090, 1090, 2461
 heat risk, 924

- heatwaves and, 1046, 1091
 Indigenous Peoples, 53, 1053, 1054–1058
 infectious diseases, 291–295, 462–463, 1063
 injuries, 1074–1075
 key risks, 2455, 2461–2462, 2503
 malnutrition*, 11, 51, 60–61, 1045, 1046, 1062, 1075, 1097
 maternal, foetal and neonatal health, 1075, 1097
 mental health (See Mental health)
 migration and, 1044–1048, 1079–1086, 1080–1083, 1128
 natural system health and, 282–283
 nutrition, 1097–1098
 observed impacts, 12, 13, 46, 50–52, 1044, 1045, 1059–1079
 occupational health, 1063, 1074, 1091–1092
 ozone and, 52, 1090, 1095–1096
 projected outcomes, 58, 1371
 projected risks, 17, 18–20, 58, 63–64, 1046, 1089, 1090, 1091–1092, 1371
 public health, 63, 269–270, 294–295
 risks, 1059, 1063, 1090
 rural areas, 1053
 SDGs, 1121–1122, 2730
 seafood safety, 481, 764, 765, 789
 social determinants, 1371–1372
 solutions, 1046–1047, 1128–1129
 urban areas, 13, 1050, 1053
 vector-borne diseases, 1062–1064, 1092–1095, 1093
 vulnerability, 50, 63, 1046, 1050–1051
 water and, 558, 1058–1059
 water quality and, 481, 582, 586–587
 Water, Sanitation and Hygiene (WaSH), 596–597, 616, 622
 waterborne diseases, 1064, 1065, 1095
 See also Diseases; Mental health; Well-being
- Health adaptation**, 95–96, 1044, 1090, 1102–1119, 1104, 1128–1129
 adaptation deficit, 1103
 adaptation gaps, 1050
 adaptation limits, 85, 2415, 2449
 adaptive capacity, 95, 1050, 1104
 air pollution, 1109–1110, 1110
 climate resilient development and, 1044–1047, 1119–1123, 1120
 co-benefits, 1048, 1124–1125, 2657
 current state of, 1105, 1105
 disaster risk reduction, 1113–1114
 diseases, 1107–1108, 1107
 early warning systems, 1113
 enabling conditions, 1115–1116
 equity and, 1047
 FAQs, 1128–1129
 feasibility and effectiveness, 1106–1107, 2770, 2782–2783
 financing for, 95, 96, 1115
 food security and nutrition, 1110–1112, 1111
 future health systems, 1121
 governance and, 1114
 health emergency and disaster management, 1114
 health engagement scores, 1105
 heat-related risks, 1108–1109, 1109
 malnutrition, 1110–1112, 1111
 mental health, 1112–1113, 1112, 1127
 migration and, 1116–1118
 mitigation and, 1122–1123
 monitoring, evaluation and learning, 1114
 options and solutions, 1046–1047, 1127–1128
 outcomes, 1090, 1106
 peacebuilding, 1047, 1118–1119, 1123
 policies and programmes, 1105–1107
 solution space, 1103, 1104, 1128–1129
 strategies for, 1105–1114
 sustainable development (SDGs), 1046–1047, 1121–1122
 targeted investments, 1047
- Health systems**
 capacity and resilience, 95, 1102
 climate resilient, 946, 1119–1123, 1120
 future (SSPs), 1121
 universal health coverage, 1121, 2657
- Heat action plans (HAPs)**, 27, 1047
- Heat islands**. See Urban heat islands
- Heat-related deaths**, 17, 51, 57, 58, 63–64, 1061, 1062, 1090, 1968, 1968, 2426, 2461, 2490
 adaptation options, 1108–1109, 1109
 global map, 80
 regional projections, 1089, 2678
- Heat stress***, 54, 717, 770, 1371
 adaptation options and, 1047, 1107, 1109, 1383
 livestock and, 717–718, 747, 750, 770
 outdoor workers, 54, 717–718, 796–797, 797
 urban areas, 924, 946
- Heatwaves***, 51, 80, 215–216, 922–925, 1046, 1091–1093
 Africa, 1329, 1345
 Antarctica, 217
 Asia, 1460, 1464, 1464, 1533
 Australasia, 216–217, 1618, 1624–1625, 1639, 1648
 compound risks, 67–68
 Europe (2019), 590, 591
 human mortality from, 17, 51, 442–444, 590, 1046
 lake heatwaves, 1290, 1345, 1345
 marine (See Marine heatwaves)
 mass mortality events, 215–216
 observed and projected changes, 16, 17, 51, 382, 392–393, 392, 415–418, 1091
 population exposed to, 17
 tipping points and, 382
- Helminth worms**, 200, 231
- Himalayas/Hindu Kush**, 983–984, 983, 1219, 1462, 1485–1486, 1485, 1488, 1489–1490, 2280
- HIV**, 1371, 1375
- Housing**, 934
- Human capital**, 1234–1235, 1387
- Human Development Index (HDI)**, 2671, 2722
 planetary pressures (PPAHD), 2672, 2722
- Human health**. See Health and well-being
- Human migration**. See Migration
- Human population**, 157
 in cities, 17, 34, 53, 65, 80, 909, 912, 914, 916–917
 growth of, 65, 72–73, 2421, 2659, 2673
 in vulnerable locations, 52, 76, 80, 1174, 2657
 See also specific regions
- Human rights***, 31, 801, 1945, 2707
 rights-based approaches, 31, 101
- Human security***, 2673
 key risks, 2503
- Human systems***
 adaptation-related responses, 2431–2437
 climate change and, 8, 11–13, 12, 42
 human agency, role of, 2444
 impacts of climate and weather on, 2430
 irreversible impacts, 11, 57
 observed impacts, 12
 rebalancing, 99
 soft adaptation limits, 28, 84, 2444
- Human vulnerability**, 14–22, 52–53, 65, 76–78
 See also Vulnerability
- Humanitarian crises**, 13, 65
- Hunger**, 717
 FAQ, 837–838
 SDG, 798
- Hurricanes**
 Caribbean Region, 2071
 Central and South America, 1699
 Florence (2018), 1952–1953
 Harvey (2017), 589, 591, 1952–1953
 Irma (2017), 1084, 1182–1183
 Maria (2017), 1084, 1182–1183
 migration and, 52
 Newton (2016), 1962
 North America, 1936, 1952–1953, 1962
 Patricia (2015), 1962
 Sandy (2012), 1086, 2182
 Small Islands, 2071
 See also Tropical cyclones
- Hydrological cycle***, 49, 50, 74, 210, 565–596, 565
 climatic and non-climatic drivers, 564–565
 extreme events, 565, 622
 human alteration of, 565–567
 intensification of, 584
 models, 573, 596
 observed changes, 49, 210, 555, 565–584, 566–567
 observed sectoral impacts, 50, 555, 584–596
 projected changes, 61, 62, 596–612
 records and evidence, 565
 See also Droughts; Floods; Precipitation; Water
- Hydrological droughts***, 578–579
- Hydroponics**, 787
- Hydropower**, 50, 279, 555, 585–586, 614–615, 625, 2283
 adaptation in, 27, 647
 Africa, 1348–1349, 1367, 1370–1371
 Central and South America, 1701, 1708, 1710, 1718
 Europe, 556
 maladaptation, 21, 68
 projected impacts, 16, 62
 river regulation for, 807
- Hypoxia***, 401, 406–407
 ocean and coastal systems, 401, 406–407
 oxygen minimum zones, 401, 426–427, 1937, 1938–1939, 1951
 tolerance, 401
 See also Eutrophication

- Ice cover**, 211–214, 213
- Ice sheets***, 21, 70, 2500
Greenland and Antarctic, 130, 2500
sea level rise and, 27
- ILLNESS (Cross-Chapter Box)**, 291–295
- Impact assessment***, 44, 149–150, 1049–1050
methodologies, 725–727, 726
regional assessment, 158
- Impacts***, 125, 2430
about, 10, 44
about: reference periods and years, 10, 44
about: summary, 10–22, 44–55
biological responses not sufficient for, 45
cascading*, 20–21, 67–68, 82–83
cascading, 724, 724, 909, 916
climate change and, 11–13
climatic impact drivers (CIDs), 391, 397–409, 794
compound, 20–21, 82–83
compound events, 909, 935–936, 2071–2072
cumulative, 2071–2072
definition of, 2505
detection and attribution of, 125–126, 2422, 2505
development status and, 2661
disproportionate (See Disproportionate impacts)
distribution of, 147
escalating, with degree of warming, 16, 22, 55–56, 57, 67
evidence of, 31, 129
global aggregate, 17, 18
global aggregate (RFC4), 2417, 2486, 2492–2494, 2501
inequalities in, 909
interconnections, 8, 42
irreversible, 21–22, 48, 57, 69
multidimensionality of, 383
on natural and human systems, 2430
non-climate factors and, 386
observed, 10–22, 44–55
overshoot scenarios, 21–22, 57, 69
past climate (paleo), 150, 154–157
projections, 10–22, 55–70
residual, 1180
societal, 1174, 1176, 1194
temperature pathways and, 16
transboundary, 21, 83
unavoidable, 26, 110
vs. responses, 2431, 2441, 2505
See also Observed impacts; Projections; *specific systems and regions*
- Incentives**, 2707
- Inclusion**
in adaptation, 909, 911, 1821, 1892, 2659
in adaptation implementation, 31, 86, 112
in decision making, 23, 31, 86, 101
in governance, 30, 31, 35, 112, 383, 996
See also Social inclusion
- Income inequality**, 2461, 2468, 2657
- Incremental adaptation***, 22, 71, 2558–2562
insufficiency of, 71, 1044
urban areas, 963
vs. transformational adaptation, 2558
- India**
agriculture, 806
Bhojtal Lake, 300–301
Cyclone Amphan (2020), 588–589, 590
Ganges river, 593
Himalayas/Hindu Kush, 983–984, 983
Sundarbans, 462, 611, 1480
See also Asia
- Indian Ocean**, 1333, 1481
coral reefs and fisheries, 1479
dangerous climate conditions, 55
tsunami (2004), 2071, 2076
- Indian Ocean Dipole (IOD)**, 1329, 1591
- INDIG (Cross-Chapter Box)**, 2713–2715
- Indigenous knowledge (IK)***, 108–109, 126, 150–158, 492, 1650, 2593, 2657
adaptation and, 107, 204, 557, 640, 657–658, 722, 945, 1056–1058
adaptation planning, 919, 2714
Africa, 1293, 1313, 1330–1332
Asia, 1463, 1525–1526, 1535–1536
case studies, 2715–2716
in Central and South America, 1692, 1693, 1705, 1733–1734, 1749, 1770
climate resilient development and, 35, 108–109, 2657
co-production of knowledge, 1942
Cross-Chapter Box (INDIG), 2713–2715
definition/description of, 2713
drought resilience, 578–579
enabling transformations, 982
examples, 2715–2716
food systems, 818–820
forestry, 755–756
free and prior-informed consent, 2714
incorporating, 34, 41, 107, 108–109, 818–820
Karuk Climate Adaptation Plan, 755–756
livelihood transitions and, 1175
mariculture, 782
oral histories, 2714–2715
polar regions, 2343–2344
small islands, 2050, 2067, 2068, 2077, 2091, 2092
urban planning, 982
vulnerability reduction, 53
water-related, 564, 657–658
- Indigenous Peoples***, 1054
adaptation, 157–158, 486, 1056–1058, 1585, 1629–1632, 1631, 1642, 1650, 1652, 1704–1705, 1733–1734, 1749, 1770
agriculture expansion and, 809
Amazon region, 1221
Arctic region, 2321, 2322, 2323, 2325, 2352
Asia, 1525–1526
Australasia, 1585, 1586, 1602, 1629–1632, 1630–1631, 1650
cascading impacts, 69
case studies, 1056–1058
Central and South America, 1692, 1695, 1704, 1705, 1716, 1770
climate change and, 806–809, 1942–1945
common experience of, 1054
Convention on Indigenous and Tribal Peoples, 157
Cross-Chapter Box (INDIG), 2713–2715
- of cryosphere, 572
cultural heritage, 65, 383, 1943
cultural uses of water, 565, 572, 594–596, 595–596, 636, 2464
definition of, 157
disproportionate impacts, 555, 564
duty of care, 1943
fish consumption, 765
food safety, 49
future risks, 1219
gender inequalities, 1055
health and well-being, 51, 53, 1053, 1054–1058
holistic perspective of, 1942, 1943–1944
indigenous foods, 1057
land tenure rights, 107
land use and, 809
leadership positions for, 97, 1943–1944
livelihoods, 1219, 1224
maladaptation effects, 85–86
marine-dependent communities, 383
in North America, 1931, 1942–1945, 1943–1944, 1949, 1986
nutrition/malnutrition, 51, 60
observed impacts, 1054–1055
oral histories, 2714–2715
projected risks, 62–63, 1055–1056
relocation of, 52, 1086
responsibility-based thinking, 1943–1944
rights of, 23, 107, 157–158, 810, 819, 1585, 1630, 1945, 2707
sea level rise and, 806–809
self-determination, 1932–1933, 1945, 2342–2344, 2353–2354
UN Declaration on the Rights of Indigenous Peoples, 157–158, 1585, 1630, 2707
vulnerability, 49, 53, 65
vulnerability/risk, 1052
water-related adaptation, 633–634, 636
worldviews, 2713
- Indonesia**
adaptation finance, 1248
City of Semarang, 984–985
- Industrial systems**, 2693, 2699, 2736
- Inequality***, 52, 65, 1174, 1178–1180, 1217, 2657
adaptation decision making and, 1253
addressing, 30, 31, 34, 91, 96, 818, 973–974, 1229
constraining climate resilient development, 2657
COVID-19 and, 1175, 1188
disproportionate impacts, 555, 564, 587, 909, 928–930
equity weighting, 2733
FAQs, 1251, 1253
gender, 96–97, 1174, 2700–2704
of impacts, 909
income inequality, 2461, 2468
livelihoods and, 1217–1218, 1224
maladaptation and, 85–86
near-term adaptation and, 96
potential worsening by climate actions, 2657
poverty and, 96, 1251
scenarios (SSPs), 65, 96, 1174, 1213–1214, 2673–2675, 2674
structural, 1191–1192

thermal inequity, 924–925
 vulnerabilities and, 52–53, 909, 2657
See also Equity; Gender; Vulnerable groups

Infectious diseases, 291–295, 462–463, 1063
See also Diseases

Influenza, 1070

Informal settlements*, 53, 909, 911, 912, 917
 adaption capacity, 53, 917
 climate-resilient pathways in Africa, 987–988
 COVID-19 impacts, 917
 drivers of risk in, 911
 risks, 993, 1219
 unplanned, 909, 912
 vulnerability, 929, 1052, 1224

Information, 2543
 climate services (CS), 2543, 2594–2595, 2782
See also Knowledge

Information and communication technologies (ICTs), 910, 931, 954
 infrastructure, 910, 931, 934, 954

Infrastructure*
 about, 26, 54, 66
 about: summary, 13, 17, 54, 65–66
 adaptation, 26–27, 81, 472, 910, 942–947, 952–958
 blue*, 910, 935, 2692, 2780–2781
 blue-green, 935, 1460, 1461, 1692
 built infrastructure, 472, 474, 474, 476, 482, 634
 cascading impacts, 83
 cascading impacts and, 916, 935–936
 climate resilient development, 33, 2730
 coastal areas, 807, 935, 958
 compound risks, 67, 83, 936
 costs, 17, 66, 652
 critical, 26, 54, 65, 66, 2456, 2458–2459
 decision making on, 910
 ecological, 935, 940
 energy-related, 931–933, 954–955
 failures, 83
 FAQs, 992
 flood risks, 938
 fuels and extraction, 933
 green*, 910, 913, 925, 932, 935, 1369, 1741–1742, 1964
 green: feasibility, 2780
 grey (physical)*, 81, 948, 952–958, 1741–1742
 health system infrastructure, 935
 hybrid, 1692
 information and communication technologies, 910, 931, 954
 interconnections through, 912
 interdependencies, 932, 988–989
 investments in, 910
 key risks, 2455, 2456, 2458–2459, 2503
 losses and damages, 17, 66
 maladaptation, 21
 natural, 632, 935
 observed impacts, 12, 13, 46, 53–54
 on permafrost, 17
 projected impacts, 17, 63, 65–66
 retrofitting, 952
 risk, 83, 930–935, 931, 938–939
 risk creation, 66, 910, 921–922

SDGs, 54, 2730
 social infrastructure*, 910, 942–947
 technology and, 1503–1504, 1507
 transition (system transition), 26–27, 2691–2692, 2699, 2780–2781
 transportation, 933–934, 955–956
 urban, 17, 66, 83, 910, 914, 921–940
 utilities, urban, 922–923
 Vision 2030 (LAPSSSET) program (Kenya), 2669–2670
 vulnerability/risk, 15, 938–939, 992
See also specific regions, sectors, and systems

Innovation, 93, 101, 2165, 2166, 2709
 science, technology and (STI), 2709, 2718–2720
 youth innovation, 719, 820–821

Insect pests, 16, 47, 57, 200, 248–249, 275–276
 bark beetles, 248–249, 273
 forest infestations, 200, 248–249, 273

Insects
 as food, 753
 food loss from, 790

Institutions*, 30, 110–111, 967–969, 970
 adaptation constraints, 649
 institutional capacity*, 2709
 institutional change, 967–969
 institutional investors, 2710
See also Governance

Insurance*, 108, 814–817, 945–946
 adaptation and, 814–817, 2589–2590
 catastrophic insurance pools, 1523
 climate insurance, 1389–1390, 1390
 crop insurance, 814–817
 risk financing, 2553–2554
 risk insurance, 1522–1523, 2771
 risk transfer, 945–946, 961
 social insurance, 944

Integrated coastal zone management (ICZM), 475, 2769, 2775

Inter-regional flows of risk, Cross-Chapter Box (INTEREG), 2441–2444

Interconnections, 8, 41, 42, 55, 68, 82–83, 92–93, 133, 134, 136
 planetary and ecosystem health, 8, 35, 55, 92, 134, 2659
 risk, 41, 55, 117, 2235, 2416, 2441–2444
 urban areas, 68, 910, 916

Interdecadal Pacific Oscillation (IPO), 1591

INTEREG (Cross-Chapter Box), 2441–2444

Internal displacement. *See* Displacement (of humans)*

International agreements, 128–129, 491, 919, 920, 1048

International justice, 162

International trade, 790–791, 2336–2339

Invasive species*, 205, 208, 224, 1594
 Africa, 1338
 Asia, 1476–1477
 Australasia, 1594
 North America, 1944, 1946
 observed changes, 730
 Small Islands, 2070

Invertebrates
 extinction risk, 202

freshwater, 223–285

Investments. *See* Finance

IPCC Assessment Reports

Fifth Assessment Report (AR5), 40–43, 130–132
 Sixth Assessment Report (AR6; this report), 40–44, 123–198
 attribution in, 151–154
 certainty and uncertainty treatment in, 159–160, 159
 common climate dimensions, 139
 new information and emphasis, 132–133
 risk assessment in, 148–149, 149–158
 Special Report on Climate Change and Land (SRCCL), 40, 131, 720, 913–914, 1240
 Special Report on Extreme Events and Disasters (SREX), 173–174
 Special Report on Global Warming of 1.5°C (SR1.5), 40, 559, 720, 913, 1182, 2444
 Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC), 40, 130–131, 386–389, 720, 913
 urgency of current moment, 128–133, 146
See also Sixth Assessment Report (AR6)

IPCC Working Groups, 123, 131, 176

Working Group II, 40, 123, 176, 178

Iran, sand and dust storms, 1478

Irreversible changes. *See* Tipping points

Irrigation, 23, 556, 564, 584, 613–614, 1304

evaporative losses, 654
 groundwater and, 579
 land use for, 613
 maladaptation, 806, 807
 solar pumps for, 653, 1240
 water-saving technologies, 626

Islands. *See* Small Islands

J

Japan. *See* Asia

Japanese encephalitis, 1063

Joshua trees, 299

Justice*, 41, 93, 96–97, 107, 126, 162–163,

958–960, 2604–2605, 2606

adaptation and, 86, 107, 162–163, 656–657, 2657
 for all, 30, 31, 33, 86, 107, 2661
 climate justice*, 96–97, 126, 921, 1180, 2657, 2700

distributive justice*, 107, 126, 162, 924, 958–959, 2605, 2606

environmental justice, 2599–2600

gender and, 2700

human rights-based approaches, 31, 101, 801

interconnected risks and, 93

international justice, 162

land deals and, 802–803

leave no one behind, 2661, 2671

linkages, 53, 134

procedural justice*, 107, 126, 162, 960, 2605, 2606

recognitional justice, 126, 162, 2604–2605, 2606

social justice*, 133

social movements for, 2598–2600, 2720–2721

of solutions, 93, 160–163, 161

See also Equity; Fairness

K

Karuk Climate Adaptation Plan, 755–756

Kelp, 11, 399, 418–420, 419, 464, 1602, 2457
 Australasia, 1584, 1635, 1636, 1638
 biodiversity hotspot, 2145, 2146
 marine heatwaves and, 416, 442
 North America, 1947

Kenya: Vision 2030 (LAPSSET) program, 2669–2670

Key concepts, 133–145, 134

Key Risks*, 55, 113–114, 118, 2411–2538
 See also Risk: Key Risks

Knowledge, 9, 35, 41, 2543, 2585–2596, 2713–2714
 artificial intelligence, 2585–2593
 climate services (CS) and, 2594–2595
 co-production of, 30, 1942, 2594
 in CRD, 31
 Indigenous (IK) (See Indigenous knowledge)
 local knowledge (LK) (See Local knowledge)
 motivation to action, 2595–2596
 practitioner knowledge, 2593
 on risks, 30

Krill, 47, 59, 460, 2330, 2333

Kyoto Protocol, 162, 1229

L

Lakes, 200, 210, 213, 214
 adaptation (Bhojtal Lake, India), 300–301
 browning, 200, 243
 dissolved oxygen, 200, 210, 214, 243, 278
 droughts and, 200
 eutrophication, 278–279
 fish drying out in, 200
 GHG emissions from, 277
 glacial lakes, 1715
 heatwaves, 200, 1290, 1345, 1345
 lake ice, 200, 213, 214
 nutrient dynamics, 618
 observed changes, 210, 223, 592
 thermal regime, 210
 water temperature, 201, 210, 211

Land*, 47, 56, 203–204
 biodiversity, percent land area needed to maintain, 109, 203–204
 competition for (FAQ), 835–836
 conservation, 26, 109
 crop production and, 717, 802–803, 803–804, 835–836
 five challenges, 1240
 land deals, 91, 719, 802–803, 803–804
 land management*, 23–26
 land rights, 719
 large scale land acquisitions (LSLAs), 719, 802–803, 803–804
 nexus interactions, 802–811, 2769
 planetary boundaries, 2661
 protected areas, 56, 87, 222, 270–271, 286, 287
 restoration of, 203, 718, 722
 Special Report on Climate Change and Land, 40, 131, 720, 913–914, 1240
 sustainable land management*, 23–26

transition, adaptation and, 23–26

Land cover*, cities and, 935

Land use*, 831, 2779–2780
 biofuel production, 1245, 1697
 carbon balance, and, 274
 cities, 959
 climate resilient development and, 34
 Cross-Working Group Box (BIOECONOMY), 828–831
 food production, 717, 719, 802–803
 forest plantations, 165, 265, 2378
 Indigenous Peoples and, 809, 810
 opportunities, 829
 planning, 23, 24, 81, 942–943, 2779–2780
 social justice and, 802–803, 803–804
 sustainable, 24–25
 unsustainable, 14, 265

Land use and cover change (LUCC), 14, 205, 206, 274

Land-use change*, 14, 202, 206, 209
 Asia, 1460, 1473
 biome shifts and, 202, 237
 carbon balance and, 202, 273
 Central and South America, 1693, 1695, 1697, 1714, 1739, 1763
 cities, 66, 935
 conversion for agriculture, 272, 2372, 2375, 2378
 diseases and, 51
 global (1982–2016), 209
 mountain regions, 21
 projected impacts, 55, 56
 terrestrial and freshwater ecosystems, 202–203, 209, 238, 274
 water quality and, 555

Landslides, 927, 933, 1208, 2275–2276, 2285, 2292, 2293
 prevention, 26, 289

Large-scale singular events (RFC5), 18, 2417, 2486, 2494–2500, 2501
 See also Tipping points

Lawsuits, 650, 2598, 2599

Least Developed Countries (LDCs)*, 1519

Legumes, 745

Leishmaniasis, 1699, 1705

Leptospirosis, 1064, 1702

Likelihood*, 40, 41, 159, 160
 See also Confidence; Uncertainty

Livelihoods*, 82, 1171–1284, 2779
 adaptation and, 1175, 1204–1205
 adaptation limits, 1218–1222, 1224, 2447
 agricultural, 585, 1174
 climate change linkages, 82, 1176, 1252
 climate change responses, 1187–1192
 climate extremes and, 717
 climate-related hazards and, 1178–1187, 1179, 1249
 climate resilient development (CRD), 2731
 climate-sensitive, 15, 55, 107–108, 1175
 compound risks, 67–68, 82
 COVID-19 and, 1252
 development measures, 944
 disasters and, 1236–1237
 disproportionate impacts, 54, 55

diversification of, 624–625, 807, 808, 2779
 extreme events and, 1209
 FAQs, 1252, 1399
 fisheries, 717, 760
 future risks, 67, 1218–1220
 future vulnerabilities, 1213–1227
 green jobs, 1460
 Indigenous knowledge and local knowledge and, 1175, 1209
 informal employment, 1387–1388
 interactions with poverty, inequality, and climate change, 1174–1175
 key risks, 1178
 livelihood resources, 1179
 livestock-related, 1243
 loss, conflict and, 53
 loss, mental health and, 51
 losses and damages, 1205, 1208–1211, 1249–1250
 maladaptation and, 1204–1205
 mountain areas, 2283, 2284, 2285, 2286–2288, 2292–2294, 2294, 2302
 multi-hazard risks, 1178
 observed impacts, 45, 48, 54, 1177–1187, 1179, 1200–1201
 ocean and coastal systems, 382, 456, 469–471
 ocean-related, 469–471
 projected risks, 57, 67, 1216–1227
 SDGs, 2731
 shifts in (See Livelihood transitions)
 social tipping points, 1174, 1176
 vulnerabilities, 1175, 1204–1205, 1213–1227
 See also Agriculture; Pastoralism

Livelihood transitions, 1174, 1175, 1181–1182, 1204–1205
 climate change and, 1208–1211
 crop failures and, 1209
 inequalities and, 1217–1218
 migration and, 1181–1182, 1249
 proactive, 1216–1217
 Small Islands, 1211
 vulnerability and, 1204–1205
 on Yap, 1185–1186

Livestock, 49, 57, 746–753
 adaptation, 751–753, 752
 adaptation: andean pastoralists, 298
 adaptation feasibility, 2770, 2778–2779
 alternate protein sources, 753
 Asia, 1492, 1493, 1511
 Australasia, 1615–1616
 Central and South America, 1697, 1699, 1718, 1737–1739
 climate resilient development (CRD), 1243
 climate variability and, 751
 diseases, 747, 750–751, 1354
 diversification, 722, 747
 droughts and, 585
 gender and inequities, 748
 grazing/rangelands, 717, 748–749, 749, 820
 heat stress, 717–718, 747, 750, 768, 1354, 1355
 Indigenous knowledge/local knowledge and, 752–753
 livelihoods, 1243

mixed systems, 783, 785
 North America, 1956, 1958–1959, 1960
 observed impacts, 746–748
 projected impacts, 613, 748–751
 temperature and, 747, 749–750, 750
 vulnerabilities and risks, 614, 747–748, 770
 water needs, 747, 748, 751
 See also Pastoralism

Livestock keepers, 748, 795

Living standards, 2455, 2459–2461, 2460, 2503

Lobsters, 1947, 1951

Local knowledge (LK), 41, 108–109, 126, 150–158, 492
 adaptation and, 657–658, 722, 945
 Africa, 1293, 1313, 1330–1332, 1393, 1396–1398, 1402
 Asia, 1463, 1525–1526, 1535–1536
 Central and South America, 1692, 1693, 1705, 1733–1734, 1749, 1770
 climate resilient development (CRD) and, 108–109, 2657
 Europe, 1884–1885
 mountain regions, 2289, 2298
 polar regions, 2322, 2345
 Small Islands, 2050, 2067, 2068, 2077, 2091
 urban planning, 982
 See also Indigenous knowledge (IK)

Lock-in, 29, 34, 85, 86

Locusts, 795

Loss and Damage (L&D)*, 11, 13, 66–67, 172–173, 650–652, 651, 1180–1181, 1249–1250
 about, 2563–2565
 climate extremes and, 1174
 coastal areas, 17
 Cross-Chapter Box (LOSS), 2563–2565
 decision making and, 2544
 disproportionate distribution of, 28, 67
 disproportionate impacts, 1205–1208
 economic losses, 54–55, 66–67, 68, 1176
 extreme weather events and, 47
 flood-related, 16, 62
 gender and, 1218
 global aggregate, 17
 interconnections, 41
 livelihoods and, 1208–1211, 1249–1250
 measuring, 1205
 non-adaptation, losses due to, 652–653
 non-economic (NELD), 1176, 1207–1208, 1210–1211, 1240–1250
 observed, 13, 45, 47, 54–55, 1203–1204
 poor and vulnerable populations, 1174, 1205
 projected, 17, 66–67
 in risk management, 2544
 systemic and cascading, 909
 unavoidable, 28
 UNFCCC and, 2073
 vulnerability assessment, 1193–1194, 1218, 1226

Low regrets policies and actions, 33, 94, 98, 652–653

Lyme disease, 51, 64, 261, 1045, 1063–1064, 1090, 1094, 1862, 1969, 2427

M

Machine learning, 655

Madagascar: baobab tree, 270–271, 760

Mainstreaming, 1245–1246
 adaptation, 30, 93–94, 167, 909
 equity considerations, 656

Maize, 584–585, 805, 1956
 Central and South America, 1699–1700, 1708, 1710, 1716
 observed changes, 728–729
 projected yields, 736–737, 1352, 1492, 1848

Maladaptation (maladaptive actions)*, 21, 68, 85–86, 167–168, 313–314, 806, 807–808, 2437–2440
 about: summaries, 21, 29, 68, 85–86
 avoiding, 29, 34, 86, 98, 107, 111, 809
 bioeconomies, 313
 categories of, 1222
 continuum of actions, 2600–2602, 2603
 definition of, 2600–2601
 examples, 29, 68, 807–809
 human migration, 633
 indicators of, 815
 key risks and, 2436–2437, 2437–2440
 livelihoods and, 1204–1205
 lock-in, 29, 34, 85, 86
 observed, 85–86, 2436–2437, 2437–2440
 poor populations, impacts, 1189, 1220–1222
 potential for, 68, 2543–2544
 rebound vulnerability, 806
 reducing, 86, 107, 1175
 risks of, 313–314
 by sectors, 2437–2440
 short-term gains and, 29
 sustainable development and, 1174
 water-related, 557, 627–628, 638–643

Malaria, 1060, 1062, 1062, 1372–1373, 2427
 Africa, 64, 1371, 1372–1373, 1383
 Asia, 1507–1508, 1509
 Central and South America, 64, 1699, 1702, 1702, 1705
 ENSO and, 1373, 1702
 Europe, 1862
 future risks, 64, 2462
 observed changes, 292–293, 1063, 2427
 prevention, 1383, 1384
 projections, 58, 64, 261, 1089, 1090, 1093
 regional occurrence, 64, 292–293

Maldives Islands, 2071–2072, 2076

Malmö, Sweden, 1883

Malnutrition*, 11, 48, 51, 798, 1045, 1046, 1062
 adaptation options, 1110–1112, 1111
 observed impacts, 11, 48, 51, 1075
 projected impacts, 60–61, 717, 1089, 1097–1098

Managed retreat, 633–634, 1117–1118

Mangroves, 305, 421–424, 422, 423, 464–465, 2692
 adaptation, 305, 310, 485, 2149
 Asia, 1480, 1482, 1483, 1516
 Australasia, 1602, 1604
 benefits and trade-offs, 308
 carbon sequestration, 56, 459, 464
 Central and South America, 1691, 1710, 1713, 1729–1730
 observed impacts, 388
 protection services, 56, 463
 range shift, 2136
 sea level rise and, 265
 Sundarbans, 462, 611, 1480, 1516

Marginalised people, 26, 29, 31, 33, 50, 52, 76, 101, 717, 1052, 1053, 1174–1175, 1198–1199, 1249, 2657
 empowerment of, 27, 97
 participation of, 30, 31, 96
 partnerships with, 31, 34

Marine birds and mammals, 439, 443–445

Marine ecosystems. See Ocean and coastal ecosystems

Marine ecotourism, 480–481

Marine fisheries. See Fisheries

Marine heatwaves*, 381, 391, 392–393, 392, 415–418, 435, 2560–2562
 Asia, 1483, 1491
 attribution to climate change, 215
 Australasia, 1583, 1584, 1589, 1590, 1602, 1603–1605
 coral reefs and, 416, 442–444, 1951, 2560–2562
 ecosystem shifts and mortality, 442–444
 FAQ, 416–417
 key risk, 2457
 New Zealand, 1583
 projections for, 393, 427
 tipping points and, 382, 445

Marine mammals, 439, 441

Marine protected areas (MPAs), 383, 475, 481–483
 Africa, 1342
 Central and South America, 1730
 Europe, 1826, 1838, 1842–1843, 1842, 1872
 FAQ, 486–487
 Great Barrier Reef, 1584, 1602, 1605–1607

Mass mortality events, 45, 47–48, 200, 215–217, 275–276, 1595
 corals, 1602, 1604, 1605, 1606, 1648
 projections, 22, 55
 temperature overshoot and, 22

Medicinal plants, 757, 758, 759, 2283–2285

Mediterranean Region, 2233–2272
 about, 2235–2237, 2238
 adaptation, 2236, 2247–2252, 2251
 adaptation limits, 2250
 adaptive capacity, 2236
 agriculture, 2242, 2246–2247, 2246, 2249
 aridity and desertification, 2245
 bioclimatic regions, 2241
 biodiversity, 2145, 2235, 2245
 biodiversity hotspots, 2241
 climate change, 2237–2240, 2242, 2253–2254
 co-production of knowledge, 2236, 2244
 coastal settlements, 2235, 2239, 2243
 coastal systems, 2245
 cooperation and sharing, 2236, 2244
 cultural richness/heritage, 2235, 2237, 2247, 2248
 detection and attribution, 2240, 2242
 diversity within, 2236, 2237
 droughts, 2237–2238, 2246

- economic vulnerability, 2242–2243
ecosystems, 2235–2236, 2237
equity issues, 2236, 2250
FAQs, 2253–2256
finance, 2250–2252
fires, 239, 245, 2235, 2237
fires, adaptation, 2249
fisheries, 2242–2243, 2244–2245, 2246–2247, 2252
flooding, 2235, 2245
food systems, 2243, 2245–2247, 2246, 2249
forests, 2235, 2243, 2245, 2249
governance, 2250–2252
groundwater, 2245, 2246
habitat changes, 2235
hazards, 2235
heat-related deaths, 2247
heatwaves, 2235, 2243, 2249
heatwaves: marine, 2237, 2245
history and sites, 2235, 2237, 2247, 2248
human health, 59, 2243, 2247, 2249, 2250
human mobility, 2243–2244, 2256
human population, 2235, 2237, 2239, 2243, 2248
human systems, 2236
infrastructure, 2243
inland systems, 2245
land ecosystems, 2237
livelihoods, 2243
marine ecosystems, 2237
mass mortality events, 2245
Mediterranean Basin, 2237–2240, 2238
migration and conflict, 2243–2244, 2256
Natura 2000 protected area, 2235, 2245
observed climate change, 2237–2240, 2242
observed impacts, 2235, 2237–2240, 2242
ocean acidity, 2235, 2239
ocean systems, 2244–2245
precipitation, 2235, 2237, 2239
precipitation extremes, 2237
primary productions, 2244–2245
projected changes, 2235, 2237–2240, 2239, 2240
projected climate change, 2237–2240, 2239, 2240
projected climate risks, 2244–2247
regional statistics, 2240
resilience, 2236
risks, 2235, 2247
risks: interconnected, 2235
risks: key risks, 2247, 2248, 2254
risks: projected, 2244–2247
salinisation, 2246
sea level rise, 2235, 2239, 2240, 2243, 2244, 2245
sea level rise: adaptation, 2247, 2255–2256
sea level rise and, 59
seawater intrusion, 2246
social and human vulnerability, 2243–2244
storms and tides, 2244, 2245
sustainable development, 2236, 2250, 2252, 2253
temperature, 2235, 2237, 2239, 2240
temperature: sea surface, 2235, 2237–2238
temperature extremes, 2240, 2247
temperature level, current, 2235, 2240
tides, 2244, 2245, 2255
topography and bathymetry, 2238
tourism, 2235, 2237, 2242, 2243
vulnerability, 2242–2244, 2250
water availability, 2235
water management, 2249
water quality, 59
water resources, 2235, 2242, 2245–2247
water scarcity, 2237, 2242
World Heritage Sites, 2235, 2248
See also Europe; Small islands
- Mediterranean Sea**, 427, 2048, 2052, 2056, 2057
about, 2237, 2238
acidity, 2235, 2239
bathymetry, 2238
biodiversity hotspot, 2145
governance, 2250–2252
sea level, 2235, 2239, 2240, 2244, 2245
sea level: projected, 2255
- Mediterranean-type ecosystems (MTEs)**, 239, 263–264, 269
fires, 239, 245
- Mega-disturbances**, 1946
- Megacities***, 916–917, 1194, 1499, 1503
arid areas, 2199
coastal, 2167, 2174, 2175
- Mekong River/delta**, 1487, 1489
- Mental health***, 51, 467, 1061, 1076–1079, 1077, 1127, 1863
adaptation options, 1112–1113, 1112, 1127
anxiety about climate change, 1077–1081
extreme events and, 48, 51, 1045, 1077, 1098
grief, 467, 594, 1078, 1971, 2340
observed impacts, 13, 50, 51, 1044, 1076–1079, 1126
polar regions, 2340, 2341
projected impacts, 17
projected impacts and risk, 1046, 1098–1099, 1126
PTSD, 1076, 1863
wildfires and, 1076–1078
- Mercury**, 583, 1076
in food chain, 49, 64, 1076, 1098
methylmercury, 49, 462, 481, 1076
- Mesoamerica**, 1695, 1700
See also Central and South America
- Methane (CH₄)***, 48, 275–277, 724
- Methylmercury**, 49, 64, 462, 481, 1076
- Metrics***, 168–171
Gross Domestic Product (GDP), 2661, 2717
monitoring and evaluation (M&E), 126–127, 2607–2608
multi-metric decision making, 163
vulnerability assessment, 1194–1195
well-being, 163
- Mexico**. See North America
- Microbes**, 231
- Mid-term reference period (2041–2060)**, 10, 44
- Migration (of humans)***, 13, 17, 52, 64–65, 95, 96, 556, 624–625, 1079–1086, 1080–1083, 1100–1101
as adaptation strategy, 476, 633, 930, 1116–1118, 1469–1470, 2076–2077
adaptative vs. maladaptive, 633, 638–643, 807, 2439
- attitudes towards, 1117
choice in, 27
climate change and, 64–65, 1079, 1080, 1084–1085, 1116–1117, 1128, 1181–1182, 1469, 2428
climate resilient development and, 1044
climate traps, 1183–1184
climatic drivers, 52
conflict and, 17, 65, 1087–1088
conflict resolution through, 1395, 2465
COVID-19 and, 1469
Cross-Chapter Box (MIGRATE), 1080–1083
differentiated vulnerability, 929–930
drivers of, 1080, 1084–1085, 1100, 1249
drought and, 52, 64, 578, 593–594
enabling conditions for, 1182
extreme events and, 52, 64, 65, 1045, 1084–1085, 1100–1101, 1469, 2428
FAQ, 1128
feasibility assessment, 2771, 2783–2785
fires/wildfire, 1085
floods and, 595
forced migration, 1128, 1979, 2077
gender and, 1085, 1470
Global Compact for (2018), 1124
health and, 1044–1048, 1079–1086, 1080–1083, 1128
humanitarian crises and, 13, 65
immobility, 52, 1045, 1081, 1082, 1085–1086, 2465
internal, 52, 1082, 1183–1184, 2428
international, 52, 1082, 1083–1084, 2076
international policies on, 1252–1253
involuntary, 13, 17, 52, 96, 1045, 1046, 1128, 2077, 2465
key risks, 2455, 2463–2464
labour markets and, 1116–1117, 2681
livelihood transitions and, 1181–1182, 2076–2077, 2771
as maladaptive, 633, 638–643, 807, 2439
managed retreat, 633–634, 1117–1118
morbidity associated, 1049
numbers of people displaced, 556, 1045, 1046, 1084
observed impacts, 13, 52, 1079–1086
outcomes/success, 52
planned relocation*, 27, 52, 65, 96, 1082, 1086, 1117–1118, 2771, 2783–2785
policy frameworks, 1082–1083, 1122–1123
positive potentials of, 1395
poverty and, 1178
projections, 17, 64–65, 556, 619, 1046, 1099–1102, 1100
refugees, 1183–1184, 1249, 2428
region-specific changes, 64–65, 1099–1101
relocation, 52, 96, 633–634
Representative Key Risk, 2455, 2463–2464
risk reduction and, 96, 1047
rural to urban, 930, 1082, 1083, 1350, 1704
SDGs and, 1044, 1047, 1121
sea level rise and, 1099–1100, 2465–2466
small islands and, 1185–1186, 2067–2068, 2070, 2076–2077, 2078–2079, 2084

spontaneous, 633
 sudden-onset events and, 1099–1100, 1100
 temperature level and, 17
 temporary, 1082, 1085
 types of, 1082
 urban areas, 929–930
 vulnerability and, 96, 1052
 water resources and, 593–594, 622

Migration of species. See Range shifts; Species distribution

Migration corridors, 285–287, 286

Milan, Italy, 1883

Milk, heat stress and, 717–718, 749

Millennium Ecosystem Assessment (MEA), 206, 2694

Mining, 586, 1714–1715

Mitigation (of climate change)*, 105, 2657, 2683–2684, 2785–2787
 adaptation and, 24–26, 308–309, 558, 653–654, 910, 2687, 2785–2787
 bioeconomy and, 828–831
 climate justice and, 1175
 climate-resilient pathways and, 105, 2660, 2683–2687, 2686
 co-benefits, 308–309, 910, 960–961, 1123
 constraints, 2658
 delay/inaction, risks of, 1585, 1586, 1587
 developing and transitional economies, 2658
 emissions reductions, 2685
 FAQ, 995
 linkages, 2657–2658, 2687
 maladaptive potential, 313–314
 near-term, 15, 16
 ocean and coastal systems, 383
 regional implications, 2686
 synergies and trade-offs, 24–26, 108, 308–309, 910, 2785–2787
 time horizons for, 2666
 triple-wins, 1240, 1528
 urgent need for, 55
 water footprint of options, 557
 water security and, 558–559
 See also Adaptation; Adaptation and mitigation inter-relationships

Mobility. See Migration (of humans)

Models*, 44, 725–727, 726
 See also Climate models

Molluscs, 407, 462, 1480–1481
 extinction risk, 257

Monetary policy, 2718

Monitoring and evaluation (M&E)*, 30, 126–127, 167, 168–171, 2605–2614, 2620
 adaptation process, 30, 2607–2608, 2608
 Cross-Chapter Box (PROGRESS), 2610–2613
 decision making and, 2544, 2547, 2605–2614, 2610–2613, 2620
 and learning (MEL), 161, 1114, 2613–2614
 metrics, 126–127, 2607–2608
 national adaptation M&Es, 2608–2609, 2610
 purpose of, 2605–2607
 system transitions and, 2709–2711
 urban adaptation, 980–981

Monsoons*

Africa, 1325–1326
 Asia, 1459, 1463, 1466
 South American Monsoon (SAM) region, 1695, 1706–1709, 1724–1726

Mortality, 50–51, 57, 58, 63–64
 climate change and, 1089, 1090
 climate-related, 50–51, 63–64
 cold-related, 1061, 1072–1074
 compound risks, 67–68
 extreme weather events and, 1174
 heat-related, 17, 57, 63–64, 946, 1072–1074, 1371, 1375–1377, 1378, 2426, 2461, 2490
 heat-related: adaptation options, 1108–1109, 1109
 heat-related: map of, 80
 heat-related: projections, 58, 63, 1089, 1090, 2678
 per hazard event, 77
 regional variations, 1174
 vulnerability and, 1197

Mosquito-borne diseases, 51, 261, 1063–1064, 1092–1094, 1093, 1373, 1507–1508, 1509, 1969–1970, 2427
 See also Dengue fever; Malaria

Mosquitoes, 231, 232, 261, 1092–1094, 1093, 1373
Aedes, 231, 232, 261, 1063, 1093, 1094, 1373, 1702, 1712, 1862, 2427
Anopheles, 232, 1093, 1862, 2427
Culex, 232, 2427

Mountains*, 2273–2318
 about, 2275–2277, 2284
 about: delineation of regions, 2278
 adaptation, 2276, 2277–2291, 2284, 2286–2288, 2295–2298, 2303
 adaptation feasibility, 2303
 adaptation, incremental, 2276, 2295
 adaptation limits, 84–85, 2276, 2289–2290
 adaptation NAPAs, 2298
 adaptation pledges and NDCs, 2298
 adaptation priorities, 2298
 adaptation, solution space, 2296–2297
 adaptation synergies, 2288
 adaptation, synthesis of, 2289–2291, 2295, 2296
 adaptation, urgent need for, 2276
 agriculture, 2275, 2276, 2284, 2287
 assessment limitations, 2298, 2299–2300
 avalanches, 2285
 biodiversity, 2276, 2279, 2283
 carbon sequestration, 2283, 2284
 cascading risks, 21
 cities and settlements, 2285
 climate change impacts, 2275, 2284, 2302
 climate resilient development (CRD), 2276, 2297–2298
 cryosphere, 2275, 2276, 2277, 2291
 cultural losses, 2295
 cultural values and identity, 2276, 2295, 2298
 dams, 2283
 decision-making, inclusive, 2276, 2290, 2298
 detection and attribution, 2275, 2288–2289, 2290
 downstream effects, 2276, 2280, 2301
 droughts, 2275
 early warning systems, 2276, 2288
 ecosystem services, 2275, 2277–2279, 2284

ecosystems, 2277–2279, 2281, 2284, 2291, 2294
 ecosystems: ecosystem shifts, 45–46
 endemic species, 2276, 2284
 energy production, 2275, 2279–2280, 2280–2283
 equity and inclusion, 2276, 2297
 extinction, 2276, 2291
 extinction risk, 2133, 2276, 2294–2295
 FAQs, 2300–2304
 floods, 2275–2276, 2285, 2292, 2293
 floods: flash floods, 2275–2276
 food, fibre and products, 2283–2285, 2291
 forests, 2277, 2302
 gender dynamics, 2275, 2276, 2289, 2290, 2293, 2297, 2298
 glacier lake outburst floods, 2291
 glaciers, 2275, 2291, 2300
 groundwater, 2280, 2300
 habitability, 2286
 health and well-being, 2276, 2285, 2286, 2295
 human population densities, 2278
 hydropower, 2275, 2283
 ice mass, 2291
 importance of, 2275
 infrastructure, 2285, 2292, 2293
 intangible losses, 2295
 irreversible and severe losses, 21, 2276
 key risks, 2276, 2292–2295
 key risks: adaptation, 2295, 2296
 knowledge gaps, 2297, 2298, 2299–2300
 knowledge systems, 2276, 2289, 2298
 landslides, 2275–2276, 2285, 2292, 2293
 livelihoods, 2275, 2276, 2283, 2284, 2285, 2286–2288, 2292–2294, 2294, 2302
 livestock, 2275, 2284
 local knowledge, 2289, 2298
 losses and damages, 2276
 medicinal plants, 2283–2285
 migration, 2286, 2289
 mountain-top species, 45, 2277, 2302
 natural hazards and disasters, 2275–2276, 2284, 2285–2289, 2292, 2293, 2301
 non-native species, 2277, 2279
 observed impacts, 2275–2276, 2277–2291, 2286–2288
 observed impacts: attribution, 2275, 2288–2289, 2290
 pastoralism, 2275, 2287
 permafrost, 2275, 2280, 2292
 phenology, 2275, 2283–2285, 2291, 2294
 pollination, 2275, 2284
 poverty, 2275, 2276, 2284, 2286
 power imbalances, 2275, 2280
 precipitation, 2275
 projected impacts and risks, 2276, 2291–2295
 regional cooperation, 2276, 2304
 regional variation, 2276
 risk (key risks), 2276, 2292–2295
 risk perception, 2276, 2288, 2290, 2301
 risk reduction, 2276, 2288, 2295, 2296
 rivers, 2275, 2280, 2291–2292, 2300
 snow cover, 2275, 2302
 snowmelt, 2275, 2276, 2291–2292, 2300
 species, 2276, 2277, 2284, 2302

species range shifts, 2277–2279
 species refugia, 2276, 2277–2279
 streamflow, 2280, 2291–2292, 2302
 sustainable development, 2276, 2288, 2297–2298
 synthesis of adaptation, 2289–2291, 2295, 2296
 synthesis of impacts, 2288–2289, 2291–2292
 temperature, 2276, 2302
 tourism and recreation, 570, 2275, 2287–2288, 2292
 transboundary governance, 2276, 2304
 transboundary issues, 2280, 2304
 treeline, 1472–1473, 1475, 2277, 2294, 2302
 vulnerability, 15, 2275, 2276, 2297
 water, 2275, 2276, 2279–2280, 2282, 2292–2294, 2300, 2301
 water: conflicts over, 2275, 2280
 water: lowland dependence on, 2280, 2282, 2291–2292, 2301
 water cycle, 2275
 water towers, 1484, 2279–2280
 wildfires, 2281, 2284
MOVING PLATE (Cross-Chapter Box), 768–773
Mozambique: Cyclones Idai and Kenneth (2019), 588, 590, 1208, 1377
Multi-metric decision making, 163
Multiple stressors, 48, 67, 82–83, 147–149
 ocean and coastal systems, 401–409, 402–403, 405
Mussels, 414, 1712

N

Narratives*, 126, 137
 See also Storylines
National adaptation M&Es, 2608–2609, 2610
National Adaptation Plans (NAPs), 911, 2444, 2544
 water and, 557
National Adaptation Programmes of Action (NAPAs), 1192
National capabilities, 1229, 1241
National parks, 270–271
Nationally Determined Contributions (NDCs), 659, 911, 920, 1229, 1246, 2542
 differentiated responsibilities, 1229, 1241
 equity in, 1241
 water and, 557
Natural capital, 1233–1234
Natural infrastructure, 632, 935
Natural systems*
 adaptation-related responses, 2431
 Cross-Chapter Box (NATURAL), 303–309
 hard limits, 28, 84, 2444, 2560
 human relation with, 99
 impacts of climate and weather on, 2430
 impacts vs. responses, 2431, 2441
 irreversible impacts, 11, 16, 57
 observed climate change impacts, 11–13
 protecting, 222, 286, 310–312
 urgent need for action, 55–56, 204
 See also Observed impacts; *specific systems and regions*
Nature-based solutions (NbS)*, 165, 303–309, 808, 812–814, 1996–1998
 about, 283–284, 303–304
 agriculture, 1496–1497, 1496
 agro-ecological farming, 306–307, 309
 cities/urban areas, 81, 305–306, 909, 948–952, 995
 Cross-Chapter Box (NATURAL), 303–309
 effectiveness and feasibility, 383, 482
 FAQ, 310–312, 486–487
 livelihoods and, 829
 ocean and coastal ecosystems, 383, 388, 472, 474–475, 475, 492
 poverty reduction and, 1175
 sustainable development goals and, 487
 temperature regulation, 948–949
 terrestrial and freshwater ecosystems, 283–284, 303–309, 310–312
 as vulnerable to climate change, 87, 203
 water-related adaptation, 632
Near-term period (2021–2040), 10, 44
 projections and risks, 15, 55, 69
NELD (non-economic loss and damage), 1207–1208, 1210–1211
Nepal
 Himalayas/Hindu Kush, 983–984, 983
 landslides, 1208
 vector-borne diseases, 200, 232
 water resources, 1489, 1490
Net primary production (NPP)*. *See* Primary production
Net zero CO₂ emissions*, 1121–1122, 2658
New Urban Agenda*, 40, 93–94, 911, 912, 920
New Zealand. *See* Australasia
Nexuses, 910
 climate change and poverty, 1190
 climate–security nexus, 1190
 food systems, 802–811
 health–climate change nexus, 1380–1381
 interconnections, 41, 910
 water–energy–food (WEF) nexus, 655, 811, 1246, 1347, 1530–1531, 2769
Nitrous oxide, 275–276
Non-climatic drivers*, 66, 68, 108, 386, 391
Non-communicable diseases (NCDs)*, 52, 64, 1045, 1046, 1071–1072
Non-governmental organizations (NGOs), 34, 40, 110, 909
Nonlinearities, 17, 66, 2253, 2687
North America, 1929–2042
 about, 1931–1935
 about: regions and subregions, 1935
 adaptation, 1931, 1932–1933, 1934, 1989–1995, 1992–1993, 1998–1999
 adaptation barriers, 1991
 adaptation, co-benefits with mitigation, 1985
 adaptation, conflicting interests and, 1931
 adaptation, decision making, 1933
 adaptation, effectiveness of, 1932, 1991–1993, 1998–1999
 adaptation, equity and justice in, 1933, 1994–1995, 1995
 adaptation, governments and, 1989–1990
 adaptation, historical evidence and, 1986–1988
 adaptation implementation, 1932, 1933, 1991, 1998–1999

adaptation inaction, risks of, 1982
 adaptation, Indigenous peoples/knowledge and, 1932–1933, 1943–1944, 1949, 1955, 1986, 1999
 adaptation, Joshua trees, 299
 adaptation limits, 1947, 1991–1993, 1998–1999, 2449
 adaptation, nature-based solutions, 1996–1998
 adaptation, prioritising, 1985
 adaptation, private sector, 1990–1991
 adaptation, proactive, 1959
 adaptation, SDGs and, 1959
 adaptation, solution space, 1991–1997
 adaptation, to sea level rise, 1964–1967
 adaptation, transformational, 1933, 1993–1995, 1994, 1999
 adaptive capacity, 1991
 agriculture, 1931, 1956–1962, 1960, 1974, 1976
 agriculture: adaptation, 1958–1962, 1959, 1997
 agriculture: crop yields, 1931, 1956, 1957
 algal blooms, 1946, 1947, 1951
 alpine development, 2658
 alpine ecosystems, 1946–1947
 aquaculture, 1957–1962, 1958, 1960–1961, 1997
 Arctic region, 1932, 1936, 1938, 1973, 1988
 atmospheric river events, 1953, 1962
 biodiversity, 1939, 1958, 1984, 2137
 carbon storage/cycling, 1946, 1947, 1996
 caribou, 1945
 cascading impacts, 1947, 1962, 1984
 Chagas disease, 1969
 chikungunya, 1969
 cities, 1932, 1962–1967, 1985, 1992, 1997
 cities: sea level rise and, 1962–1964, 1964–1967
 cities: wildfires and, 1962, 1967
 climate, current and future, 1936–1939, 1937
 climate assessments, 1934, 1936
 climate change, observed, 1936–1937, 1937
 climate change, perceptions of, 1931, 1939–1942, 1941
 climate refugia, 1946–1947
 climate resilient development in, 2727
 climate variability, past, 1986–1988
 coastal ecosystems, 1932, 1947–1952, 1984
 coastal regions, 1938, 1962–1963
 coastal regions: flooding, 1963–1964, 1964–1967
 Colorado River, 1946, 1955
 construction, 1975, 1976
 coral reefs, 1950, 1971–1973
 cultural losses, 1971
 dams and levees, 1946, 1952–1953
 dengue fever, 1969–1970
 deserts and drylands, 2202, 2203–2204, 2205
 detection and attribution, 1931
 disease, 1968, 1969–1970
 disproportionate impacts, 1942, 1945, 1962
 droughts, 62, 580–581, 1936, 1953, 1954–1955, 1954, 1960, 1984
 economic sector and services, 1932–1933, 1973–1976, 1976, 1984
 ecosystem transformations, 1946
 energy, 1974–1975, 1976
 equity and justice, 1933, 1994–1995, 1995

- erosion, 1932, 1950, 1960, 1962, 1994
 extinctions, 1947
 extreme events, 1931–1932, 1938–1939, 1960, 1982–1984, 1994
 FAQs, 1938–1939, 1986–1988, 1998–1999
 fires/wildfires, 201, 1932, 1948–1950, 1962, 1967, 1969
 fish, 1946, 1947–1950, 1947
 fisheries, 1947–1952, 1957–1962, 1958, 1960–1961, 1974
 fisheries: closures of, 1952, 1957
 floods, 1952–1953, 1955, 1962–1963, 1964–1967, 1967, 1994
 food-borne diseases, 1968, 1970
 food, fibre and products, 1956–1962, 1957, 1974, 1976
 food, fibre and products: adaptation, 1958–1962, 1959, 1992
 food production, 1931, 1932, 1956–1962, 1957, 1959, 1974, 1984
 food security, 1931, 1932, 1984–1985
 food webs, 1950
 forestry, 1956–1957, 1974, 1976
 forests, 1945, 1956–1957, 1984
 forests: insects pests, 200, 248–249, 273, 1956
 forests: tree mortality, 248–249
 forests: trees, 1932, 1946
 glaciers, 1954
 grasslands, 1956
 greenhouse gas emissions, 1934
 groundwater/aquifers, 1953, 1955
 hazards, 1931, 1932, 1934
 health and well-being, 1931, 1964, 1968–1971, 1968, 1984, 1992
 health and well-being: Indigenous Peoples, 1942–1944
 heat-related mortality, 1931, 1968, 1968
 heatwaves, 1937, 1963, 1964
 human–bear conflicts, 1945
 human population, 1934, 1963
 human systems, 1934, 1948–1949
 humidity, 1938
 hurricanes, 1936, 1952–1953, 1962
 Indigenous knowledge (IK), 1934
 Indigenous Peoples, 1931, 1942–1945
 Indigenous Peoples: adaptation, 1932–1933, 1943–1944, 1949, 1955, 1986, 1999
 Indigenous Peoples: climate change and, 1942–1945
 Indigenous Peoples: disproportionate impacts, 1942, 1945
 Indigenous Peoples: health, 1942–1944
 Indigenous Peoples: leadership positions for, 1943–1944
 Indigenous Peoples: livelihoods, 1942
 Indigenous Peoples: relocation, 52, 1963
 Indigenous Peoples: responsibility-based thinking, 1943–1944
 Indigenous Peoples: self-determination and rights, 1932–1933, 1945
 inequality in, 1962, 2658
 infrastructure, 59, 1932, 1962–1967, 1985, 1992
 insurance, 1952, 1962, 1990, 1999
 international agreements, 1982
 invasive species, 1944, 1946
 key risks, 1982–1985, 1983
 labour productivity, 1975
 lakes, 1938, 1946, 1947, 1961
 land management, 1958
 livelihoods, 1976–1980
 livestock, 1956, 1958–1959, 1960
 losses and damages, 1931–1932, 1949, 1978–1979
 Lyme disease, 51, 59, 64, 1045, 1063, 1094, 1969
 manufacturing, 1975
 marine basins, 1935
 marine ecosystems, 1932, 1947–1952, 1984
 marine heatwaves, 1947, 1951, 1960, 1984
 Mediterranean-type ecosystems in, 239
 mega-disturbances, 1946
 mental health, 1931, 1944, 1968, 1971, 1972
 Mexico, 1695
 Mexico: cloud forests, 1945
 migration and displacement, 1963, 1979–1980
 mining, 1974–1975, 1976
 mortality, heat-related, 1962, 1968, 1968
 natural disturbances, 1946
 natural systems, 1934, 1948
 nutrition, 1931, 1932, 1970–1971
 observed changes, 1936–1937, 1937
 observed impacts, 1931, 1934, 1945–1982, 1958
 ocean acidification, 1937, 1938–1939, 1951, 1957, 1961
 ocean and coastal ecosystems, 1932, 1947–1952, 1984
 ocean and coastal ecosystems: adaptation, 1951–1952, 1992, 1997
 ocean management, 1952
 oxygen minimum zones, 1937, 1938–1939, 1951
 permafrost, 1945, 1975
 phenology, 1932, 1945, 1947
 precipitation, 1936, 1937, 1937, 1954, 2723
 projected impacts, 19, 59, 1932, 1937–1939, 1937
 quality of life, 1931, 1963, 1982, 1985
 risks, 1931, 1932, 1982–1985, 1983
 risks, cumulative, 1985
 runoff, 1938, 1954
 salmon, 1946–1947, 1952
 sea ice, 1936, 1938
 sea level rise, 1938, 1950, 1962–1964, 1964–1967
 snow, 1938, 1945, 1954, 1955, 1971
 socioeconomic conditions, 1931–1932
 soil quality, 1932
 species migration, 1946
 species, natural history, abundance, habitats, 1946–1952, 1957, 1961
 species range shifts, 1945, 1956, 1957, 1961
 species, threats and risks, 1932, 1961
 storms, 1938, 1962, 1963
 streamflow, 573, 1954
 supply chain, 1931
 temperature, 1931, 1932, 1936, 1937, 1961, 1962, 1963, 2723
 temperature extremes, 1937, 1962, 1963, 2723
 terrestrial and freshwater ecosystems, 1931, 1932, 1945–1947, 1947, 1984
 terrestrial and freshwater ecosystems: adaptation, 1946–1947, 1992, 1998
 thresholds, 1985
 tipping points, 1985, 1999
 tourism, 59, 1963, 1971–1973, 1974, 1976, 1992
 trade, 1931–1932, 1977
 transboundary issues, 1954–1955, 1957
 transportation, 1974, 1976, 1993
 tree mortality, 201, 1932, 1946
 tropical cyclones, 1938
 urgency of response, 1931, 1985
 vector-borne diseases, 293, 1968, 1969–1970
 violence, crime and security, 1980–1982
 water availability, 1953, 1992
 water-borne diseases, 293, 1968, 1970
 water diplomacy, 1956
 water management, 1931, 1964–1967
 water quality, 1953, 1954, 1955
 water resources, 1931, 1952–1956, 1954, 1955
 water scarcity, 1955
 water supply, 1931, 1954
 West Nile virus, 51, 1969
 wetlands, 1947
 wildfires, 201, 1948–1950, 1962, 1967, 1969
 wildfires: area burned, 201
 wind/wind storms, 1938, 1962
 See also Arctic region
- Nutrition**, 60–61, 64, 67, 717, 723, 792, 798–802, 1097–1098
 adaptation, 23, 798–799, 800, 801, 1047
 adaptation feasibility, 1110
 alternate protein sources, 753
 cascading impacts, 82
 dietary patterns, 799–802, 1097–1098
 effects on children, 1089, 1097
 FAQ, 832–833
 food (crop) quality, 1046
 food security and, 811
 iron, 1509, 1509
 malnutrition*, 60–61, 798, 1045, 1061, 1062, 1075, 1097
 micronutrient deficiency, 725, 2463
 nutritional density, 1098
 observed impacts, 48, 1074–1076
 undernutrition, 64, 798, 1045, 1046, 1061
 See also Diet
- O**
- Observed impacts**, 10–22, 44–55, 2422–2428, 2430
 about: summary, 10–22, 44–55
 aggregate impacts, 2417, 2486, 2492–2494, 2501
 cascading impacts, 67–68
 climate and non-climate drivers, 391
 from climate change, 11–13
 confidence levels, 40, 44, 159–160
 detection and attribution (See Detection and attribution)
 regional summaries, 12, 44, 46
 synthesis, 2422–2428, 2430
 See also specific regions and sectors

- Occupational health**, 1063, 1074, 1091–1092, 1863, 2064
- Ocean acidification (OA)***, 395–396
 animals, effects on, 406–407
 Asia, 1465, 1466
 Australasia, 1587, 1589–1590, 1593–1594, 1607
 calcifiers and, 396, 401, 412–413, 2329
 chemistry of, 395–396
 coastal impacts, 420
 coral reefs, 412–413
 detection and attribution, 396
 fish and, 401, 406–407
 fisheries, impact on, 401
 livelihoods and, 1225
 Mediterranean Region, 2235, 2239
 North America, 1937, 1938–1939, 1951, 1957, 1961
 observed impacts, 391, 396, 717
 polar regions, 2324, 2329
 primary production and, 401
 projections, 391, 394, 396, 399, 1225
 regulation of, 457
 Small Islands, 2046
See also Coral bleaching; Coral reefs
- Ocean and coastal ecosystems**, 379–550
 about, 381–391, 389, 391
 adaptation, 23, 72–73, 383–384, 467–489
 adaptation: best practices, 492–493
 adaptation: policy frameworks, 491–492
 adaptation capacity/limits, 456
 adaptation feasibility and effectiveness, 482, 2769
 adaptation finance, 488
 adaptation implementation, 475–489, 485
 adaptation level needed, 383–384
 adaptation limits, 383
 adaptation solutions, 468–475, 472
 animals, 406–407
 biodiversity, 72, 382, 438–446, 456, 458
 biodiversity hotspots, 2125, 2128, 2131, 2134, 2138, 2143–2148
 carbon storage, 440–441, 458–459, 463, 464–466, 468, 1602
 circulation, 391, 395
 climate change impacts, 381–382, 387–388
 climate-induced drivers, 397–400
 climate-induced drivers: biotic responses, 400–407
 climate regulation, 457, 458–459, 461
 climate resilient development (CRD), 2728
 community composition, 381, 434–435, 438–446
 compound changes, 397
 concept map of chapter, 389
 Cross-Chapter Box (Sea Level Rise), 477–480
 cultural services, 457, 459, 467, 468, 484–488
 drivers of change, 386, 387–388, 391, 397–409
 economic impacts, 383
 ecosystem services, 383, 386, 456–467, 457, 458–459
 evolutionary adaptation, 386, 407–409, 408
 extinctions, 382
 FAQs, 387–388, 416–417, 447–448, 469–471, 486–487
 fisheries, 381–382
 food provision, 456–460, 457
 food webs, 381, 449–451, 2329–2330
 global ocean, trends and projections, 392–400
 governance and, 383, 389, 467–468, 488–489
 habitat creation, 457, 458
 human dependence on, 385
 human impacts on, 386
 impacts, climate-driven, 381–382
 impacts, escalating, 67
 impacts, non-climatic drivers, 381
 interactive effects, 381–382
 irreversible losses, 57
 light and, 386, 404–406
 macroalgae, 401, 404
 marine birds and mammals, 439, 443–445
 marine heatwaves, 381, 382, 391, 415–418, 416–417, 2457
 marine mammals, 439
 mitigation, 383, 475–489
 multiple drivers, responses to, 401–409, 402–403, 405
 natural adaptation in, 386
 nature-based solutions (NbS)*, 383, 472, 474–475, 475, 492
 nutrients, 381, 382, 397, 401, 404
 observed changes, 11, 410–455
 observed impacts, 72, 388, 391
 overshoot scenarios, temporary, 453
 Oxygen Minimum Zones (OMZs)*, 401, 426–427, 1937
 phenology, 12, 46, 436–438, 437
 primary production, 401, 404–406, 451–453, 453
 projected changes and impacts, 18–20, 57, 58, 382–383, 391, 392–400, 394, 410–455
 recreational activities, 381–382
 renewable energy, 458, 461, 489
 salinity, 382, 391
 sea level and impacts, 391, 393–395, 477–480
 sea surface temperature, 391
 seabirds, 215, 439, 443–445
 seasonal events/timing, 381, 382, 436–438
 solutions and trade-offs, 383–384
 Special Report on (SROCC), 130–131, 386–389
 species richness, 72
 supporting and regulating services, 461–466
 sustainable development goals (SDGs), 383–384, 467–468, 489–492, 490, 491, 2728
 temperature, 391, 392–393, 392, 393
 temperature and impacts, 391
 time of emergence, 399–400, 445–446, 448, 449
 tipping points, 382
 tourism (marine ecotourism), 480–481
 transitions (system transitions), 2692–2693, 2699, 2774
 upwelling, 391, 399, 429–431, 430, 2329
 vulnerabilities, 381–382, 381–384, 456–467
See also Coastal areas and ecosystems; Fisheries; Ocean acidification; Oceans
- Oceans**, 379–550
 about, 385–391, 433
 abrupt ecosystem shifts, 442–445, 445
 adaptation options, 383
 aquaculture, 456, 459–460, 773–782
 benthic zone, 431–432, 454–455
 biodiversity, 16, 381, 438–446, 441, 456, 458
 biogeography, 433–436
 biomass, 16, 57–60, 67, 382, 446–451, 450, 452
 blue carbon, 383, 464–466, 468, 2692
 chemical changes, 395–397
 chlorophyll concentrations, 445
 circulation and currents, 391, 395
 closure areas, 1952
 community composition, 381, 438–446
 coral reefs, 410–414
 deep-sea ecosystems, 454–455
 deoxygenation*, 391, 394, 396–397, 401
 Eastern Boundary Upwelling Systems (EBUS), 391, 395, 429–431, 430
 extinctions, 382
 extreme events, 442–445
 FAQ (industries and jobs), 469–471
 fisheries, 381–382
 food webs, 381, 449–451, 2329–2330
 human dependence on, 385
 light penetration, 386, 404–406
 livelihoods, 469–471
 marine heatwaves, 381, 391, 392–393, 392, 415–418, 435
 marine protected areas, 383, 475, 481–483
 non-climate drivers, 386
 observed changes, 391, 392–400
 ocean management policies, 1952
 oceanic zone, 385, 433
 oxygen concentration, 391, 401, 435
 paleoclimatology data, 400
 pelagic zone*, 385, 410, 433
 pH, 396
 phenology and trophic mismatches, 46, 436–438, 437
 physical changes, 392–395
 polar seas, 431–433, 432
 pollution, 381, 386
 projected changes, 391, 392–400, 398, 399
 resilience, 382
 SDGs and, 383–384, 467–468
 sea ice and, 391, 395, 399
 sea level, 391, 393–395, 394
 semi-enclosed seas (SES), 426–427, 426
 species range shifts, 12, 433–436, 434, 766, 768
 stratification*, 56, 391, 395
 surface salinity, 391
 temperature, 391, 392–393, 392
 tourism (marine ecotourism), 480–481
 vulnerabilities, 456–467
 zones of, 385
- Outdoor workers**, 51, 54, 60, 717–718, 796–797, 797
- Overshoot scenarios**, 35, 57, 69
 greenhouse gas release, additional, 21–22
 temporary overshoot, 21–22, 57, 69, 267, 453
 terrestrial and freshwater ecosystems, 267
- Oxygen**
 concentration (in oceans), 401, 435
 dissolved oxygen concentration, 200, 210, 214, 243, 278
 ocean deoxygenation, 391, 394, 396–397, 401
- Oxygen deficiency**. *See* Hypoxia

Oxygen minimum zones (OMZs)*, 401, 426–427, 1937, 1938–1939, 1951
Oysters, 462, 1480–1481, 1603, 1616, 1712, 1952
Ozone (O₃)*, 1096
 effects on crop yields, 736
 health effects, 52, 1090, 1095–1096
 mortalities, 58, 1096

P

Pacific Ocean

Blob in, 215, 417
 dangerous climate conditions, 55

Paleo-ecological evidence

Cross-Chapter Box (PALEO), 154–157
 extinctions and, 154–155
 ocean systems, 400, 438

Pandemics*

COVID-19, 628, 959, 1066–1069

Paris Agreement (2015)

40, 127, 128, 911, 912, 919–920, 920
 adaptation finance, 1231–1232
 feasibility assessment, 2771
 goals, 2657
 NDCs, 659, 911, 920, 1229, 1241, 2298
 sustainable development and, 2666

Particulate matter (PM)*

1095–1096

Partnerships

26, 31, 34, 97, 966, 2659, 2671

Past climate changes

126, 154–157, 438

Cross-Chapter Box (PALEO), 154–157

human responses to, 155–156

Pastoralism*

657, 746, 1054, 2198, 2210, 2215
 Africa, 1208–1209, 1218, 1350, 1354
 andean pastoralists, 298, 1703
 Bedouins, 1056
 coping/adaptation strategies, 1182, 2210
 Kenya, 1208–1209
 Maasai, 1218
 mountain regions, 2275, 2287
 poverty and, 2422

Pathogens

fisheries, 765, 789
 regulation of, 461–463
 toxins, 20, 51, 64, 382, 462, 789
Vibrio, 13, 1841, 1862, 1863

Pathways*

145, 145
 adaptation pathways, urban, 940–963
 climate change responses and, 1215
 climate resilient development pathways (CRDPs), 2655–2807
 climate-resilient pathways*, 2662–2663, 2734
 definition of, 2734
 development pathways*, 2662–2663
 emissions pathways*, 138, 1647, 2658, 2686
 future, societal choices and, 32, 35, 2658, 2661, 2664–2665
 overshoot pathways*, 453, 2484
 Representative Concentration Pathways (RCPs)*, 9, 44, 138
 Shared Socio-economic Pathways (SSPs)*, 138, 1121, 1213–1214, 2673–2675, 2674
 Shared Socio-economic Pathways (SSPs)*, 9–10, 44
Payment for ecosystem services (PES), 1692, 2384

Peacebuilding, 937, 1047, 1119, 1123

Pearls, 461

Peatlands*

241–242, 266–267, 309
 adaptation, 301, 305
 adaptation: tree planting, 315
 in Asia, 301
 biodiversity protection (case study), 301
 carbon stocks, 241–242, 266, 273, 315
 CO₂ emissions from, 242, 249
 drying/draining of, 22, 56, 69
 projected risks, 22, 266–267, 272

Pelagic biomes and ecosystems*

382
 biomass, 436
 carbon export, 451, 453
 climate and, 393
 fauna, 464, 484
 food webs, 431
 phenology, 448
 primary production, 404
 projected changes, 397, 398
 species range shifts, 433, 436

Pelagic zone*

385, 410, 433

Penguins

298–299, 1718, 2323, 2328

People

Perception

of climate change, 1316, 1645–1646, 1886–1887, 1886, 1931, 1939–1942, 1941, 2596
 risk perception*, 99, 150, 1115, 1518, 1886–1887, 1886, 2288, 2290, 2301
 values and, 2596

Peri-urban areas*

agriculture, 799, 800
 expansion of, 918
 observed water-related impacts, 587–592
 projected risks, 616–617
 supply chains, 33

Permafrost*

202, 251, 266–273, 279, 570–571
 active layer thickness, 570
 Asia, 1459, 1464, 1465, 1485, 1500
 carbon stocks, 201–202, 249–251, 273
 degradation, 202, 241, 242, 570
 diseases and, 232–233, 2340
 Europe, 1823–1824, 1855–1856
 Indigenous knowledge on, 1944
 infrastructure and, 17, 66
 observed changes, 11, 570, 592
 polar regions, 2321, 2325, 2331, 2332, 2339
 projected changes, 22, 61, 272–273
 temperature, 570
 thaw*, 11, 22, 61, 202, 210, 232–233, 241–243, 279, 592, 1076, 2321, 2325, 2332, 2339
 water resources and, 266

Peru

1211
 Coastal Niño (2017), 589, 591

Pests

16, 47, 57, 200, 730–732, 1844
 control of, 23, 109
 food production and, 718, 730–732
 forest insect pests, 248–249, 273, 275–276
 projected impacts, 16, 57, 718
 range expansion of, 200

pH*

oceanic, 395–397
 See also Ocean acidification

Phenology*

11, 12, 45, 46, 55, 67
 diseases and, 261
 feedbacks and, 275–276
 growing season, 200, 224, 242, 244, 255
 observed changes, 12, 45, 224–225, 226–227, 382, 717, 2424–2425
 observed impacts, 11, 12, 45, 46
 ocean and coastal systems, 382, 436–438, 437, 438
 projected changes, 55, 67, 382, 437–438, 440
 spring advancement, 224–225
 temporal mismatches, 45, 382
 terrestrial and freshwater ecosystems, 12, 55, 200, 224–225, 226–227, 252, 275–276
 trophic mismatches, 436–438, 437
 vernalisation, 225

Phenotypic plasticity

407–408, 408

Photosynthesis

258, 273, 2376
 browning and, 243
 CO₂ effects on, 568
 respiration and, 251, 277, 2377

Physical capital

125

Phytoplankton

405, 1603
 adaptation in, 408
 Antarctic, 2328
 biomass, 382, 446, 450, 451
 carbon sequestration, 440–441
 chlorophyll and, 445
 food webs and, 381
 light and nutrients, 401, 404–406
 phenology, 224, 439, 440
 in polar regions, 431–432, 2328
 primary production and, 251–252, 446, 451
 See also Algal blooms; Zooplankton

Planet

8, 42, 2671

Planetary boundaries

2661
 exceedence of, 2661

Planetary health*

8, 30, 35, 42, 109, 134, 2659
 climate change as threat to, 35
 Happy Planet Index, 2672
 planetary pressures HDI (PPAHD), 2672, 2722
 societal choices and, 32, 35, 2658, 2661, 2664–2665

Planetary urbanisation*

914, 917–918

Plankton

diversity, 1480
 seasonal effects, 381, 382
 temporal mismatches, 382
 See also Phytoplankton; Zooplankton

Planned relocation (of humans)*

27, 52, 65, 96, 1080, 1082, 1085, 1086, 1117–1118, 2771, 2783–2785

Plants

breeding, 728, 743–744, 745, 1356
 C₃ and C₄ plants, 264, 614, 734–735, 748
 carbon dioxide effects on, 724, 736, 749, 754, 1046
 flowering, extinction risk, 202
 functional types, 264, 268
 guidelines for planting semi-natural vegetation, 316
 leaf area, 564, 568
 medicinal, 757, 758, 759
 ozone and, 736

- pests and, 57, 717
phenology, 439
pollinators, 717, 718, 739–740
as protein sources, 753
respiration*, 251, 277, 317
spring advancement, 224–225
transpiration by, 564
- Plasmodium**, 1062
- Plasticity (biology)***, 236, 407–408, 408
behavioural, 225
- Polar bears**, 221, 237, 284, 2323, 2328
possible extinction, 2321
- Polar Regions, 2319–2368**
about, 2321–2325, 2323, 2354
about: regions and subregions, 2323
adaptation, 2321–2322, 2344–2351, 2346–2349, 2350
adaptation: current, 2344–2345
adaptation: flexible, equitable and inclusive, 2322, 2352–2353
adaptation: integrated, 2322
adaptation feasibility, 2349
adaptation gaps, 2350
adaptation, Indigenous Peoples, 2339, 2343–2344
adaptation, key risks and sectors, 2344, 2346–2349, 2350
adaptation limits, 2351
adaptation, local involvement, 2322, 2345
adaptation, maladaptation, 2321, 2350–2351
adaptation, regional differences, 2322
adaptation, self-determination and, 2342–2344, 2345
agriculture, 2332, 2335
Antarctica: heatwave, 217, 2331
Antarctica: research stations, 2325, 2335, 2336
Antarctica: temperature projections, 2723
aquaculture, 2332
biodiversity, 2322
biodiversity hotspots, 2140, 2145, 2148
cascading risks and impacts, 20, 2321, 2325, 2333, 2347–2349
climate change, pace and magnitude, 2321–2322, 2323, 2333, 2351, 2354
climate change: pace and magnitude, 68
climate resilient development, 2322, 2352–2354, 2353
climate zone contraction, 2321
climatic impact drivers, 2324, 2325, 2332
cooperation, 2322, 2345
culture and heritage sites, 2321, 2331, 2339–2340, 2352
decision making, 2322, 2342–2344, 2344–2345, 2351, 2352
diseases, 45, 51–52, 232–233
economies, 2321, 2335–2336
ecosystem shifts, 45–46
ecosystems, 2323, 2324–2325, 2325–2331, 2333, 2348–2349, 2350
equity and inclusiveness, 2322
extinctions, 2321
FAQs, 2333, 2336–2337, 2339, 2351
fires/wildfire, 2324, 2330–2331
fish/fisheries, 59, 433, 2321, 2328, 2329–2330, 2333–2335, 2333, 2334, 2348
fish/fisheries: transboundary, 2334
floods, 2321, 2324, 2325
food, fibre and products, 2331–2335, 2332
food webs, 1950, 2321, 2329–2330, 2332
forecasting services, 2322
forestry, 2332
future risks, 2321, 2325–2341, 2326, 2327–2328
glaciers, 2324
global impacts of, 2323, 2333
global importance of, 2323–2325, 2333
governance, 2322, 2352–2353
growing season, 2332
heatwaves, 217, 2331
human health and wellness, 2340, 2341, 2347
human settlements, 2323–2325, 2347
human settlements: Arctic, 2336–2340
hydrology, 2321, 2330
ice, 2324–2325
ice cover, 213
ice-free areas, 2331
impacts, 2321, 2325–2341, 2326, 2327–2328, 2350
impacts: drivers of, 2324
impacts: pace and magnitude of, 2321–2322, 2323, 2333, 2351, 2354
Indigenous Peoples, 2321, 2322, 2325, 2352
Indigenous Peoples: adaptation, 2339, 2343–2344
Indigenous Peoples: population, 2323
Indigenous Peoples: self-determination, 2322, 2342–2344, 2353–2354
infrastructure, 59, 66, 933, 2321, 2334–2335, 2339, 2347
invasive species, 2325–2328
key risks, 2344, 2346–2349
livelihoods, 2321, 2339–2340, 2342, 2345
livestock, 2332
losses and damages (including intangible), 2352
marine and coastal ecosystems, 431, 2324, 2325–2330, 2348
maritime trade routes, 2338–2339
nomadic lifestyles, 2342
observed impacts, 594, 2321, 2325–2341, 2326, 2327–2328
ocean acidification, 2324, 2329
permafrost thaw, 2321, 2325, 2331, 2332, 2339
permafrost thaw, diseases and, 2340
phenology, 2332
phytoplankton, 2328
polar bears, 221, 237, 284, 2323, 2328
polar seas, 431–433, 432
primary productivity, marine, 431, 2328–2329
projected changes, 2323
projected impacts and risks, 2321, 2325–2341, 2326, 2327–2328
range contraction, 2321
range shifts, 2328
regional differences, 2322
reindeer herding, 1057–1058, 1868–1869, 2332, 2342, 2348
resource extraction, 2335, 2348
Sámi women, 2342
scale and pace of impacts, 2322
sea ice, 59, 391, 395, 399, 2321, 2324, 2325, 2332, 2336–2339
sea ice loss, 2321, 2338–2339
sea level, 2324
seals, 2321, 2328
shipping, 2321, 2332, 2334–2335, 2336–2339, 2347
snow, 2324, 2331
Southern Ocean, 431–433, 432
species distribution shifts, 2321
subsistence resources, 2331, 2332, 2335, 2348
system transitions, 2693
temperature, 2324, 2325, 2326, 2332
temperature (sea surface), 2326
terrestrial and freshwater ecosystems, 2324–2325, 2330–2331, 2349
tipping points, 20
tourism, 2321, 2325, 2335, 2348
trade and trade routes, 2335, 2338–2339
transboundary governance, 2322
transboundary issues, 2334–2335, 2336–2339
transportation systems, 2335–2336, 2347
tundra, 242–243, 267, 269, 2321
warming of, 211–214
whales, 2332, 2336
zoonoses, 51–52
zooplankton, 2329, 2330
See also Arctic region; Boreal forests; Tundra
- Poleward movement**, 433, 457, 460, 730, 1957
See also Range shifts
- Policies***
adaptation and, 23, 30, 909–910, 996
biodiversity conservation, 2152
co-production of, 97
context for climate action, 40, 128–129
gender integration, 2701–2702
integration, 1246, 2577
policy action gap, 969–974, 972, 989–990
policy leaders/entrepreneurs, 97, 2600
political commitment and follow-through, 29, 98
transitions and, 91
See also Governance
- Poliomyelitis**, 1064
- Political commitment and follow-through**, 29, 98
- Political economy***, 2705–2706
- Pollen, allergies and**, 1863
- Pollinators**, 16, 23, 109, 202, 717, 718, 739–740
in Europe, 1836, 1837
extinction risk, 202
- Population**. See Human population
- Poverty***, 1171–1284, 2421–2422
about, 1174–1175, 1249–1250
adaptation constraints, 1175
adaptation costs and, 1183
adaptation decision making, 1253
adaptation: enabling environments, 1175, 1228–1239
adaptation finance, 1230, 1247–1249, 1253
adaptation limits, 1224
adaptation needs, 1174–1175
adaptation options, 1227–1238
adaptation responses, 1191

- climate change linkages, 1176, 1182–1183, 1194, 1252
- climate change responses, 1187–1192
- climate-compatible development (CCD) and, 1238–1239, 1238
- climate justice and, 1175
- climate resilient development (CRD) and, 1238–1249, 1238, 2731
- compound challenges, 1174–1175, 1182
- conflicts and, 1178
- COVID-19 and, 65, 909, 959, 1188, 1202, 2666
- crop losses and, 1178, 1187
- differential vulnerability, 1180–1181, 1181, 2421–2422
- disproportionate impacts, 555, 1174, 2421–2422
- extreme weather events and, 2422
- FAQs, 1251–1253
- governance failures and, 1178
- hazards, climate-related, 1178–1180, 1179
- indicators/assessment, 1194–1195
- inequalities and, 1178–1180, 1179, 1182–1183, 1191–1192
- key risks, 1178
- losses and damages, 1174, 1205
- maladaptation and, 1189, 1220–1222
- migration and, 930, 1178, 1181–1182
- mitigation responses, 1191
- nutrition/malnutrition, 51
- observed impacts, 1177–1187, 1179
- projections, 65, 1051, 1213–1214
- relative vs. absolute, 979
- scenarios (SSPs), 96, 1213–1214
- social protection and, 943–944
- sustainable development and, 1174, 1249–1250
- Sustainable Development Goals (SDGs), 1174, 2731
- trends, 1201–1204
- urban, 80, 921, 929, 943–944, 1701, 1712, 1746
- urbanisation and, 921
- vulnerability and, 80–81, 929, 1174–1175, 1251–1252
- Poverty reduction**, 95, 101, 943, 1175, 1193
- adaptation and, 95, 1228–1238, 1253
- FAQ, 995, 1253
- investments in, 1232
- mitigation and, 1240
- Poverty traps***, 57, 930, 1174, 1178, 1187–1192, 1187
- Practitioner knowledge**, 2593
- Precipitation**, 49–50
- extremes, 11, 49–50, 567, 1053
- FAQ, 661–662
- floods and, 575, 577
- heavy metals and, 789
- heavy precipitation, 555, 558, 577
- intensity, 556, 563–564, 567
- modeling, 597–598, 598
- observed changes, 49–50, 555, 558, 565, 566–567, 567
- projected changes, 556, 595–598, 599, 600
- projected changes: regional, 2677
- regional projections, 2723
- unfamiliar regimes, 555, 567, 619
- See also Droughts; Floods; *specific regions*
- Pre-industrial period***, 10, 44, 157
- Primary production***, 404–406, 451–453
- feedbacks and, 275–276
- global NPP, 251
- heat/temperature and, 1092
- nitrogen/nutrients and, 401, 404
- observed changes, 451, 453
- ocean acidification and, 401
- ocean ecosystems, 401, 404–406, 451–453, 453
- by phytoplankton, 401
- projections, 451–453, 453
- terrestrial and freshwater ecosystems, 214, 251–252, 275–276
- time of emergence and, 399–400, 445–446
- tropical forests, 240–241
- upwelling and, 429–431, 2329
- Private sector engagement**, 965
- in adaptation, 965–966, 1232
- financing, 719, 825, 977, 978, 2543, 2721
- Procedural justice**. See Justice
- Production**. See Primary production
- PROGRESS (Cross-Chapter Box)**, 2610–2613
- Projections***, 55–70
- about: reference periods and years, 10, 44
- about: summary, 10–22, 55–70
- impacts and risks (summary), 10–22
- long-term period (2081–2100), 10, 44
- long-term risks, 16–17, 18–20
- mid-term period (2041–2060), 10, 44
- mid-term risks, 16–17, 18–20, 63
- near-term period (2021–2040), 10, 44
- near-term risks, 15, 55, 69
- overshoot scenarios, 21–22, 35, 57, 69
- projected risks, 14–22, 18–20
- regional summaries, 18–20, 58–60
- temperature, projected changes, 130–131, 139, 141–145, 18
- temperature and precipitation, global, 2677–2678
- temperature and precipitation, regionally, 2677–2678
- temperature pathways and, 16
- uncertainty and, 317–318
- See also Key risks; Temperature projections; *specific regions and sectors*
- Prosperity**, 2671
- Protected areas**, 222, 270–271, 286, 287
- Africa, 1339, 1340, 1342
- land area, globally, 14, 56
- marine protected areas, 383, 475, 481–483, 1342, 1584, 1730, 1838
- national parks, 270–271
- Thailand, 297
- Protein**, 753, 1097
- See also Diet
- Pteropods**, 433, 2329
- Public face of climate change**, 588–591
- Public health**, 63, 269–270, 294–295
- Public investment/finance**, 719, 825
- Puerto Rico**, 986–987
- Hurricane Maria, 1084, 1183
- Puffins**, 215
- R**
- Railways**, 931, 1850, 1851
- Rainfall**. See Precipitation
- Range contractions**, 45, 768
- Range shifts**, 11, 12, 45, 67, 72, 724, 779–780
- adaptation, 771
- Africa, 1332
- Asia, 1473–1474, 1475–1477
- Australasia, 1583, 1587, 1602, 1603–1604, 1616
- Europe, 1835, 1836, 1837, 1843
- feedbacks and, 275–276
- fish, 382, 386, 433–434, 460, 724, 766, 768, 769
- food sourcing and, 768–773
- kelp, 419
- maladaptation, 771
- multiple drivers of, 435
- North America, 1945, 1956, 1957, 1961
- observed changes, 11, 12, 45, 219–220, 224–225
- ocean and coastal species, 12, 381, 382, 386, 433–436, 434, 460, 724, 766
- past climate changes and, 155
- pelagic species, 433, 436
- projected changes, 55, 67, 436
- species replacement, 2131–2132
- terrestrial and freshwater ecosystems, 12, 200, 205, 219–220, 224–225, 227–229, 252, 275–276
- wetland species, 423–424, 592
- See also Extirpation; Species distribution
- Rangelands**, 289, 748–749, 749, 1243
- Reasons for Concern (RFCs)***, 15, 18–20, 58, 68–69, 69–70, 146–147, 2417, 2481–2500, 2482–2483, 2486
- adaptation limits and, 59–60
- adaptation/mitigation needs, 68–69
- climate change and, 2486
- dangerous anthropogenic interference, 69, 2450–2453
- distribution of impacts (RFC3), 2486, 2490–2492, 2501
- ecosystem degradation (RFC), 2417
- elicitation methodology, 2482–2483, 2483
- ember diagrams, 58, 114, 2482–2483, 2486, 2507–2508
- evidence for, 68
- extreme weather events (RFC2), 2486, 2488–2490
- global, 2485–2500
- global aggregate impacts (RFC4), 18, 2486, 2492–2494, 2501
- key risks and, 118
- large-scale singular events (RFC5), 18, 2486, 2494–2500, 2501
- Representative Key Risks and, 114, 118, 2481–2485, 2482
- risk levels, definition, 118, 2483
- risk level transitions, 69–70, 2483
- summary, 2501
- temperature and, 69–70, 2417, 2486, 2501, 2507–2508, 2666
- unique and threatened systems (RFC1), 18, 2485–2488, 2486, 2501
- updated, 2501

- warming levels and, 58, 2483
- Recognition**, 126, 162
- Recreation**, 202, 222, 235, 278, 282, 308, 381–382, 467
- losses in, 45
- mountain areas, 570, 2275, 2287–2288, 2292
- See also Tourism
- REDD+**, 757, 757, 1243–1244, 1512, 2384, 2440
- Reference periods***, 10, 44, 137–145
- long-term (2081–2100), 10, 44
- mid-term (2041–2060), 10, 44
- near-term (2021–2040), 10, 44
- pre-industrial, 10, 44
- Reforestation***, 304–305, 314–316, 2776–2777
- water and, 559, 654
- Refugees**, 1183–1184, 1249, 2428
- refugee camp locations, 1184
- Refugia***. See Climate refugia
- Regime shifts**, 47
- See also Biome shifts
- Regions***, 158, 178
- assessment of risks and impacts, 158
- observed impacts, 12, 44, 46
- projected climate change, 2677–2678
- projected impacts and risks, 18–20, 58–60, 67
- regional emissions pathways, 2685
- storyline figures, 72–83
- See also ANNEX I: Global to Regional Atlas
- Regions, specific**
- Africa, 1285–1455
- Asia, 1457–1580
- Australasia, 1581–1688
- Central and South America, 1689–1816
- Europe, 1817–1928
- North America, 1929–2042
- Small Islands, 2043–2121
- Regulations***, 458–459, 2583–2584
- Reindeer**
- herding, 82, 1057–1058, 1868–1869, 2332, 2342, 2348
- insect harassment, 233
- mass mortality, 232
- Renewable energy**, 458, 461, 489, 1047
- Representative Concentration Pathways (RCPs)***, 9, 44, 138
- Representative Key Risks (RKR)***, 88–90, 103, 113, 163, 2415–2416, 2420, 2453–2466, 2455, 2502–2503
- adaptation options for, 24–26, 88–90, 104, 2551, 2604, 2621
- identification and assessment, 2454
- interactions, 2471–2473, 2472
- key risks and, 118
- Reasons for Concern (RFCs) and, 114, 118, 2481–2485, 2482, 2483
- RKR-A (coastal systems), 2454–2456, 2455
- RKR-B (terrestrial and ocean ecosystems), 2455, 2456–2457
- RKR-C (critical infrastructure), 2455, 2458–2459
- RKR-D (living standards), 2455, 2459–2461, 2460
- RKR-E (human health), 2455, 2461–2462
- RKR-F (food security), 2455, 2462–2463
- RKR-G (water security), 2455, 2463–2464
- RKR-H (peace and human mobility), 2455, 2463–2464
- severity conditions, 113–114, 115–116
- Sustainable Development Goals (SDGs) and, 2479–2481, 2480
- synthesis of, 88–90, 2466, 2467–2468
- temperature levels and, 2466, 2675
- See also Risk: Key Risks
- Reptiles, marine**, 439, 1952, 2058
- Residual impacts**, 1180
- Residual risks***, 172, 383, 1174, 1368–1369, 2419, 2445, 2448–2449, 2544
- FAQ, 2619
- Resilience***, 134, 136–137, 2658, 2666
- about, 9, 43
- building, 86–90, 994, 2658
- building: urgent need for, 31, 204
- definition of, 43
- of ecosystems, 45, 55–56, 86–87, 109–110
- enabling conditions, 108–109
- linkages, 8, 134
- subjective, 1116
- See also Climate resilient development (CRD)
- Resin and gum**, 757, 758
- Respiration***, 251, 277, 317, 2377
- vs. photosynthesis, 251, 277
- Respiratory diseases**, 13, 52, 64, 1045, 1060, 1066–1071
- Responsibility-based thinking**, 1943–1944
- Retrofitting**, 34, 946, 952, 953, 989
- Rice**
- arsenic and, 798
- nutritional quality, 1046
- observed impacts, 728
- projected yields, 736–737, 1352, 1492
- Rift Valley Fever**, 51, 747, 750, 1063, 1354
- Rio Declaration (1992)**, 162
- Rio Markers**, 2613
- Risk***, 125, 145–160, 2411–2538
- about, 8, 16, 40–41, 43, 2418, 2419
- about: complex risk, 20–21, 67–68, 82–83
- about: summary, 15–17, 18–20
- adaptation limits and, 2415, 2420, 2444–2450, 2448–2449, 2451–2452
- adaptation responses, 2415, 2428–2441
- amplification, 2416, 2430
- assessment (See Risk assessment)
- burning ember diagrams, 18–20, 58–59, 114, 258, 281, 2482–2483, 2486, 2507–2508
- cascading risk, 20–21, 67–68, 82–83, 147, 909, 912, 935–936, 1065
- climate risk, nature of, 145–149, 146
- communication about, 126, 159–160, 159
- complex risk, 10, 20–21, 67–68, 82–83
- compound risk*, 20–21, 67–68, 82–83, 935–936, 1070, 1201, 1225–1227, 1226, 2420
- definition of, 43, 134–135, 2418, 2450
- definitions related to, 2422–2423, 2450–2453
- drivers of, 2421–2422
- dynamic (changing) nature of, 2544
- emergent risks*, 2484–2485
- framing, 134–135
- framing of, 8, 8, 40–41
- high risk, transition to, 2417
- indexes, 1196
- inequalities and, 1217
- infrastructure, 930–935, 931
- inter-regional flows of (Cross-Chapter Box: INTEREG), 2441–2444
- interactions of, 8, 42, 147, 2471–2473, 2472
- interconnected risks, 93, 117, 118, 910, 2235, 2441–2444
- key risks (See Risk: Key Risks)
- knowledge on, 30
- linkages, 8, 42, 134, 2658
- maladaptation and, 2415, 2436–2437, 2437–2440
- mid to long-term, 16–17, 18–20, 63, 69
- near-term, 15, 55, 69
- new risks, creation of, 20, 66, 67, 921–922, 2415, 2416–2417
- overshoot scenarios, 21–22, 35, 57, 69
- projected, 15–17, 18–20, 1213–1227
- realized risks, 2419
- Reasons for Concern, 15, 18–20, 146–147, 2473–2501, 2481–2500
- residual risk, 172, 1174, 1368–1369, 2419, 2445, 2448–2449, 2544, 2619
- from responses, 148–149, 149
- risk framing, 2418
- scale of risks, 2418
- severity of, 2416, 2450–2453, 2454, 2466, 2467–2468
- societal responses to, 160–173
- solar radiation modification (SRM), 21, 2416–2417, 2473–2478
- temperature and: risks at 1.5°C, 15
- temperature and: risks beyond 1.5°C, 16–17
- trade-offs, evaluating, 2576–2577
- transboundary risks, 21, 67–68, 82
- unavoidable, 15, 110
- uncertainty and, 2658
- understanding and evaluating, 145–160
- unprecedented levels of, 55–57, 68
- vulnerability and, 203, 208, 1196, 1217
- water-related, 61
- See also Risk management
- Risk: Key Risks***, 113–114, 118, 2411–2538
- about, 16, 55, 2414–2418, 2419, 2450–2453
- about: aggregated risk, 18
- about: definitions, 2415–2416, 2450–2453
- about: main messages, 16, 2466
- about: synthesis, 2466, 2467–2468
- abrupt changes, 2416, 2457
- adaptation, 2414–2415, 2428–2441, 2469–2471, 2504
- adaptation co-benefits, 2436–2437, 2437–2440
- adaptation effectiveness and adequacy, 2416, 2431, 2434–2436
- adaptation implementation, 2431, 2444–2450, 2449, 2451–2452
- adaptation investments for, 2554
- adaptation limits, 2415, 2420, 2444–2450, 2448–2449, 2451–2452, 2504
- adaptation, maladaptation, 2436–2437, 2437–2440

- adaptation, mix of responses, 2434
- adaptation, observed, 2414–2415, 2428–2441, 2506
- adaptation options, 24–26, 1753–1756, 1753–1754, 2449–2454, 2551, 2604, 2621
- adaptation progress and feasibility, 2428, 2610–2613, 2724–2732, 2772
- adaptation-related responses, 2415, 2420, 2428–2441
- adaptation-related responses: definition, 2431
- adaptation-related responses: hazards and, 2432, 2433
- adaptation-related responses: human systems, 2431–2437
- adaptation-related responses: natural systems, 2431
- adaptation-related responses: not all reduce risk, 15, 2431, 2440–2441
- adaptation, risk reduction and, 2434–2436, 2506
- adaptation scenarios, 2469
- adaptation, transformational, 2435–2436, 2435, 2436
- adaptation, types of responses, 2434
- adaptation, who is responding, 2433, 2433
- aggregated assessments, 113–114, 115–118
- agricultural deltas, 2470–2471
- attribution, 2422
- behavioural change, 2433–2434
- cascading impacts, 20–21, 67–68, 82–83, 2466
- cities, 938–939, 993
- climate attribution, 2423
- climate change and, 2502–2503
- climate change and weather fluctuations, 2430
- climate-related systems, 2422
- climate-related systems: observed impacts, 2424–2428
- coastal systems, 2415, 2425, 2454–2456, 2455, 2503
- combinations of, 2482, 2689
- complex risk, 10, 20–21, 67–68, 82–83
- compound risks, 20–21, 67–68, 82–83, 1070, 2420
- conflicts/violence, 2428, 2429, 2455, 2463–2464, 2503
- criteria for identifying, 2418, 2423–2424, 2450–2453
- crop yields, 2425–2426
- dangerous anthropogenic interference (DAI), 69, 2415, 2420, 2450–2453
- definitions, 2422–2423, 2444, 2450–2453, 2502
- detection, 2422
- diseases, 2462, 2467
- displacement and migration, 2414, 2428
- distribution of impacts, 2421–2422
- drivers of exposure and vulnerability, 2421–2422
- economic impacts, 2417, 2427–2428, 2450, 2468, 2494, 2495–2499
- ecosystems: observed adaptation, 2414
- ecosystems: observed impacts, 2424–2425
- ecosystems: projected risks, 55–70
- elicitation methodology, 2482–2483, 2483
- ember diagrams, 18–20, 58–59, 114, 2482–2483, 2486, 2507–2508
- exposure and, 2421–2422, 2468–2469
- extreme weather events, 18, 2486, 2488–2490, 2508
- FAQs, 2502–2508
- financial constraints, 2415
- food production, 725, 2416
- food security, 725, 2416, 2455, 2462–2463, 2503
- future risks, 2419, 2420–2422
- global-scale, 2453
- global temperature targets and, 2417, 2420, 2447
- globalisation and, 2416
- hard limits, 2415, 2444, 2445
- human health, 2455, 2461–2462, 2503
- human systems, 2415, 2430, 2431–2437, 2444
- identification and assessment, 2453–2466
- identification of weather sensitivity, 2423
- impact attribution, 2422, 2423–2424
- impact severity and, 2416, 2450–2453, 2454, 2467–2468
- impacts vs. responses, 2431, 2441, 2505
- income inequality, 2461, 2468
- individuals and households, 2433, 2433
- inequalities and, 2421–2422
- infrastructure, 2455, 2458–2459, 2503
- inter-regional flows (Cross-Chapter Box: INTEREG), 2441–2444
- interconnections, 41, 55, 117, 118, 2416, 2441–2444
- irreversible losses, 16, 69, 2417, 2455
- livelihoods, 2460–2461
- living standards, 2455, 2459–2461, 2460, 2503
- mitigation and, 2683–2687, 2686
- natural systems, 2430, 2431, 2441
- new risks, creation of, 20, 66, 67, 2415, 2416–2417
- observed adaptation, 2414–2415
- observed impacts, 2414, 2419–2420, 2422–2428, 2430
- potential impacts, 2418
- poverty, 2421–2422, 2459–2460
- rate of climate change and, 2431
- Reasons for Concern (RFCs)*, 18–20, 58, 68–69, 2417, 2420–2421, 2481–2500, 2482, 2483, 2501
- Representative Key Risks (RKR)*, 103, 2415–2416, 2420, 2453–2466, 2455, 2467–2468, 2502–2503
- Representative Key Risks (RKR): adaptation options, 24–26, 88–90, 104, 2551, 2604, 2621
- Representative Key Risks (RKR): identification, 2454
- Representative Key Risks (RKR): interactions, 2471–2473, 2472
- residual risk, 2419, 2445
- responses, 2415, 2420
- risk framing, 40–41, 2418
- risk interactions, 2471–2473, 2472
- risk reduction, 2434–2436, 2506
- risk transmission, 68, 2441–2444
- river flooding, 2425
- scale of risks, 2416, 2418
- severity of risk, 113–114, 115–116, 2416, 2450–2453, 2454, 2466, 2467–2468
- socioeconomic inequalities, 2421–2422
- soft limits, 2415, 2444, 2445
- solar radiation modification, 21, 2416–2417, 2473–2478
- species distribution and phenology, 2424–2425
- sustainable development and, 2416, 2473–2481, 2480
- Sustainable Development Goals (SDGs) and, 2479–2481, 2480
- synthesis of, 2466, 2467–2468
- temperature impacts, 15–17, 938
- temperature levels and, 15–17, 2417, 2420, 2466, 2466–2468, 2501, 2506–2507, 2666, 2675
- temperature-related mortality, 2426
- terrestrial and ocean ecosystems, 2455, 2456–2457, 2503
- transboundary risk transmission, 21, 2416, 2441–2444
- variation in, 2466–2471
- vector-borne diseases, 2427, 2462, 2467
- vulnerability and, 1052, 2421–2422, 2468–2469
- water availability, 2425
- water distribution, 2425
- water-related, 619–622
- water security, 2455, 2463–2464, 2503
- waterborne diseases, 2426–2427, 2462, 2467
- See also Reasons for Concern; Risk management; specific regions and sectors
- Risk assessment***, 9–10, 44, 113–118, 149–158, 970, 1941, 2418, 2423–2424, 2453–2466
- aggregated risk assessments, 113–114, 115–118
- human factors in, 1941–1942
- in IPCC reports, 9–10, 44, 148–149, 149–158
- Reasons for Concern*, 15, 18–20, 2417, 2481–2485, 2482–2483
- regional assessment, 158
- Risk financing**, 2553–2554
- Risk insurance**, 1522–1523, 2771
- Risk management***, 125, 133, 2539–2654, 2676–2689
- about, 43, 2542–2548, 2549
- about: 24 risk management options, 2551, 2604
- adaptation finance, 2584–2585, 2586–2593
- adaptation, incremental and transformational, 2558–2562
- adaptation investments, 2554
- adaptation limits, 2558–2562
- adaptation-maladaptation continuum, 2600–2602, 2603
- adaptation monitoring and progress, 2605–2614, 2610–2613, 2620–2621
- adaptation options, 2548–2553, 2551, 2604, 2621
- adaptation options: 24 options, 2557–2562, 2559–2560, 2604
- adaptation options: benefits of, 2552–2553, 2553
- adaptation options: portfolio of, 2542, 2553–2562, 2577–2580, 2614–2615
- adaptation options: transformation potential, 2559–2560
- adaptation spectrum, 2557–2558, 2561, 2619
- adaptation success, 2548, 2600–2605, 2620–2621
- cities and settlements, 944–946, 2601–2602

- climate resilient development (CRD) and, 2544, 2614–2615, 2676–2689
- climate services and, 2543, 2594–2595
- in conflict-affected areas, 2557
- for COVID-19, 1069
- decision-making for, 2542–2548, 2549, 2562–2580, 2569–2574, 2614–2615
- dynamic nature of climate risks, 2544
- enabling and catalysing conditions, 2542, 2580–2600
- equity and justice, 2604–2605, 2605
- FAQs, 1128, 2616–2621
- finance and, 2542–2543, 2584–2585, 2586–2593
- governance and, 2542, 2551, 2581–2584
- insurance and, 814–817, 2554
- integrated, 2544, 2577–2580, 2614
- iterative, 98, 135, 171, 2549
- knowledge and capacity, 2543, 2585–2596
- layered risk management, 2555
- legal and policy frameworks, 40, 2542
- Loss and Damage (L&D), 2544, 2563–2565
- mainstreaming, 2615
- maladaptative potential, 2543–2544, 2548
- monitoring and evaluation (M&E), 2544, 2547, 2605–2614, 2620
- National Adaptation Plans, 2544
- opportunities and, 2556
- portfolio of adaptation options, 2542, 2553–2562, 2577–2580
- portfolio of climate risks, 2614–2615
- private sector, 2552
- residual risk and, 2544, 2619
- risk assessment and, 2545–2546
- risk financing, 2553–2554
- risk prevention, 2553–2554
- risk spreading and sharing, 28, 2781
- Sendai Framework, 93, 591, 911, 912, 919, 920, 2545, 2581–2582, 2598, 2666
- transformation and, 2564, 2601–2602
- typologies for, 2556
- uncertainty and, 2543, 2568, 2569–2574, 2616, 2658
- urgency levels and, 2596–2597, 2597
- values and, 2546, 2547, 2567, 2568, 2578–2579, 2596, 2609
- windows of opportunity, 32–33, 2543, 2556, 2597–2598
- See also* Adaptation; Decision making; Risk
- Risk perception***, 99, 150, 1115, 1518, 1886–1887, 1886, 2288, 2290, 2301
- Risk reduction**, 68–69, 456, 2434–2436, 2506, 2659
- in cities, 994, 995
- FAQs, 994, 995, 1127–1128
- Sendai Framework, 93, 591, 911, 912, 919, 920, 2545, 2581–2582, 2598, 2666
- See also* Decision making
- Risk transfer***, 945–946, 961
- River floods**, 16, 573, 576–577, 606, 607, 950–951
- displacement and, 1085
- Rivers**, 16, 200, 211, 211, 213, 214, 288–289
- adaptation, 26, 288–290
- attribution of changes, 574
- browning of, 243
- dams on (*See* Dams)
- flow, 211, 212, 214
- GHG emissions from, 277
- mountain regions, 2280
- observed change, 573, 574
- projected changes, 16, 604
- regulation, 807
- river ice, 213
- 'Room for the River', 634
- water temperature, 210, 211
- water towers and, 1484, 2279–2280
- See also* Runoff; *specific regions*
- Roads**, 931
- road infrastructure, 1368, 1368
- Rodent-borne diseases**, 1064
- Rubber plantations**, 265
- Runoff***, 53, 564
- from glaciers, 564, 582, 605
- observed changes, 556, 592
- populations dependent on, 556
- projected changes, 61, 602–603, 604
- regionally, 1608, 1609, 1610, 1701, 1708, 1718, 1938, 1954
- urbanisation and, 564
- Rural areas**, 33
- adaptation for, 99
- basic services, provision of, 26, 99
- food security, 796
- health, 1053
- interconnections to cities, 91, 912, 918
- livelihoods, 657, 746, 1053, 1692, 1704, 1712
- pastoralism*, 657, 746, 1053
- population in, 27
- rural-to-urban migration, 170424171088, 930, 1082, 1083, 1350
- vulnerabilities and risks, 15, 1052
- ## S
- Safety nets**, 108, 808, 944, 1047
- in Africa, 1390–1393
- food, 796
- Salamanders**, 202
- Salinity**, 382, 391, 461
- desalination, 624, 631, 653, 655, 1349
- salt-water intrusion/encroachment, 21, 382, 461–462
- Salmon**, 1946–1947, 1952, 2716
- Salmonella/salmonellosis**, 51, 64, 1045, 1060, 1066, 1095, 1970
- Saltmarshes**, 56, 305, 421–424, 422, 423, 464–465, 2692
- benefits and trade-offs, 308
- Salt-water intrusion/encroachment***, 21, 382
- human health and, 461–462
- Sami**
- reindeer herding, 82, 1057–1058, 1868–1869
- Skolt Sámi, 2716
- women, 2343
- Sand and dust storms**, 1478, 2207–2208, 2207, 2216
- Sandy beaches**, 424–426, 424
- Sanitation and sewage**
- health risks, 939
- in urban areas, 925, 934–935, 949–950, 956–957
- Sargassum seaweed**, 1951, 2070
- Savannas**, 201, 239–240, 264, 269, 309, 2205
- afforestation and, 314
- woody encroachment, 47, 201, 238, 275
- See also* Deserts and semiarid areas
- Scales (spatial and temporal)***, 176, 401, 2418, 2453
- near-term, mid-term, and long-term, 10, 44
- Scenarios***, 137–145, 138, 2660, 2673–2675
- future development trajectories, 2660, 2673–2675, 2674
- global surface temperature, 18
- participatory scenario planning, 30
- reference periods, 10, 44
- Representative Concentration Pathways (RCPs), 9, 44, 138
- Shared Socio-economic Pathways (SSPs), 138, 1121, 2660, 2673–2675, 2674
- Shared Socio-economic Pathways (SSPs), 9–10, 44
- storylines and figures, 72–83, 137
- See also* Pathways
- Schistosomiasis**, 64, 1064, 1072, 1094–1095
- Science**
- citizen science, 30
- technology and innovation (STI), 2709, 2718–2720
- Sea ice***, 391, 395, 399, 2321, 2324, 2325, 2332, 2336–2339
- Antarctic, 391, 395
- Arctic, 391, 395, 1936, 1938
- Arctic maritime trade routes, 2338–2339
- importance of changes in, 433
- projections, 59, 399, 2338–2339
- shipping and, 2336–2339
- Sea level**, 62, 94, 391
- committed change, 21, 62
- extreme (ESL)*, 27, 62, 391, 2165
- global mean sea level (GMSL)*, 391, 393–395
- relative sea level (RSL)*, 393–395
- Sea level change***, 21, 391, 393–395, 477–480
- about: overview, 17, 391
- accommodation, 27, 94, 2076, 2078–2079, 2084, 2173, 2174
- adaptation, 26, 27, 94–95, 478–480, 1965–1967
- adaptation limits, 478–480
- cities and, 27, 53, 909
- coastal areas and, 15, 27, 53, 62, 477–480
- committed change, 21, 62
- Cross-Chapter Box (SLR), 477–480
- global mean sea level (GMSL)*, 391, 393–395
- ice sheet collapse, 27
- Indigenous Peoples and, 806–809
- magnitude possible, 17, 63, 478, 479
- migration and mobility, 1099–1100, 2465–2466
- observed changes and impacts, 11, 391, 393–394, 477
- projected risks and impacts, 62–63, 94, 382, 391, 393–395, 477–480, 1225
- regional variations in, 393
- relative sea level (RSL) rise, 393–395
- risks, 62–63
- risks with level of change, 17, 63
- Small Islands, 17, 2045, 2052, 2056, 2061

Sea surface temperature (SST)*, 391, 392–393

- Australasia, 1589, 1590
- climate velocity and, 392, 393
- Europe, 1826, 1827, 1867
- Mediterranean Region, 2235, 2237–2238
- observed changes, 391, 392, 392
- projected changes, 391, 394, 2723

Sea urchins, 405, 415**Seabirds**, 215, 439, 443–445**Seafood safety**, 481, 764, 765, 789**Seagrasses**, 47, 442, 459, 463, 464–465, 1602, 2146, 2692

- benefits and trade-offs, 309
- carbon sequestration by, 56, 1480
- in coastal areas, 421–424, 422

Seals, 2321, 2328**Seasonality**

- growing season, 200, 224, 242, 244, 255
- temporal/trophic mismatches, 45, 382, 436–438
- See also Phenology

Seaweed, 753, 1481, 1492, 1604**Security**. See Conflicts**Sediment**, 26, 62, 583–584, 612

- exposed, CO₂ from, 277

Semarang, Indonesia, 984–985**Semi-arid zones***. See Deserts and semiarid areas**Semi-enclosed seas**, 426–427, 426**Sendai Framework for Disaster Risk Reduction***, 93, 591, 911, 912, 919, 920, 2545, 2581–2582, 2598, 2666**Sequestration***. See Carbon sequestration**Settlements***. See Cities and settlements**Shared Socio-economic Pathways (SSPs)***, 138, 1121, 1213–1616, 2660, 2673–2675, 2674

- inequality scenario, 1174

Shared Socio-economic Pathways (SSPs)*, 9–10, 44

- integrated SSP-RCP framework, 10, 44
- temperature projections, 58

Shelf seas*, 427–429, 428, 429**Shrimp**, 1491, 1710**Sinks***. See Carbon sinks**Sixth Assessment Report (AR6)**, 40–44, 123–198

- about: core concepts, 7–9, 43
- attribution in, 151–154
- certainty, degree of, 159–160, 159
- climate risks, understanding and evaluating, 145–150
- common climate dimensions, 139
- entry points in, 133–145
- interconnections in, 8, 41, 42, 133, 134
- key concepts, 7–9, 43, 133–145, 134
- key developments since AR5, 40–43
- new approaches, 132–133
- policy context, 40, 128–129
- risk assessment, 40–41, 148–149
- structure of, 178–179, 178
- structure of report, 40
- transformation concept in, 173–177
- urgency of current moment, 128–133, 146, 180

Slow-onset processes, 11, 27, 54–55**Small Island Developing States (SIDS)**, 15, 1218, 2048

- loss and damage in, 2073

Small Islands, 2043–2121

- about, 2045–2050, 2049
- about: island types, 2051
- about: regions included, 2048
- accommodation and advance, 27, 2076, 2078–2079, 2084
- adaptation, 27, 2047, 2049, 2096–2099, 2175, 2432, 2436
- adaptation barriers, 2047, 2087–2091
- adaptation co-benefits, 2081–2086
- adaptation, community-based, 2047, 2079
- adaptation decision making, 2080
- adaptation, ecosystem-based, 2050, 2077, 2078–2079, 2082, 2084, 2097
- adaptation enablers, 2047, 2049, 2087–2091, 2092–2093
- adaptation finance, 2047, 2050, 2085, 2088–2089, 2092
- adaptation, governance and, 2087–2088, 2092
- adaptation, ILIK and, 2050, 2067, 2068, 2077, 2091, 2092
- adaptation implementation, 2081–2086
- adaptation, incremental, 2047
- adaptation limits, 28, 84–85, 2046, 2047, 2049, 2050, 2077, 2445–2446, 2448–2449
- adaptation limits, possible exceedence of, 28, 2046
- adaptation, maladaptation, 2091
- adaptation, need/urgency for, 2045, 2047, 2048
- adaptation options, 623, 2047, 2049, 2075–2086, 2098
- adaptation options, by key risk, 2081–2086
- adaptation, reactive vs. anticipatory, 2096–2097
- adaptation, slow- and rapid-onset events, 2047
- agriculture, 2046, 2065–2067, 2079, 2099–2100
- aridity, 2046, 2058
- artificial reefs, 2077
- atolls, 1185–1186
- beach nourishment, 2077
- beaches, 2057–2058, 2077
- biodiversity, 2046, 2062–2063, 2074
- biodiversity: adaptation, 2081–2083
- capacity building, 2047
- Caribbean Region, 2071–2072
- cascading impacts, 82, 2045, 2071–2072, 2073
- ciguatera fish poisoning, 2064–2065
- cities/urban areas, 2045
- climate education, 2089–2090
- climate models, 2047
- climate resilient development in, 2091–2093, 2680–2681, 2727
- climate services, 2050, 2080, 2088, 2092
- climate-smart development, 2077
- climate trends, 2054–2055
- coastal areas, 2053–2055
- coastal areas: adaptation, 2078–2079, 2081
- coastal areas: population in, 2053
- coastal cities, 2045
- coastal ecosystems, 2056–2058, 2074
- coastal erosion, 2055–2056
- community-based adaptation, 818
- compound events, examples, 2071–2072
- compound risks, 82
- coral bleaching, 2046

corals/coral reefs, 2045, 2046, 2048

COVID-19 and, 2050, 2070, 2093

culture, 2068–2069, 2074, 2086, 2090–2091

cumulative impacts, examples, 2071–2072

dengue, 2064

detection and attribution, 2073–2075, 2075

disaster risk management, 2080–2086

diseases, 2064–2065

droughts, 2046, 2052

early warning systems, 2050, 2064, 2080, 2088

economies, 2050, 2067, 2085–2086, 2092

ecosystem degradation and transformation, 2046, 2074

ecosystem services, 2045, 2058, 2059, 2074

ecosystem services: adaptation, 2081–2082

endemic species, extinction risk, 2046

energy transitions, 2093, 2681

ENSO and, 2053, 2054, 2071–2072, 2095

exposure, 2050–2052

extinction risks, 2045, 2046

extratropical cyclones, 2055

extreme events, 2061, 2074

FAQs, 2095–2100

fisheries and aquaculture, 2065–2067, 2070, 2099–2100

flooding, 17, 2045–2046, 2053–2055, 2053, 2060

food accessibility, 2065

food production, 2046, 2065–2067, 2099–2100

food security, 2070, 2099–2100

freshwater stress, 623, 2046

freshwater systems, 2045, 2058–2060

gender equality, 2050, 2077, 2091

groundwater, 16, 2045, 2065

habitability, 82, 2046, 2068, 2069, 2074, 2095–2096, 2165

habitability: atoll nations, 2073, 2165

hard protection, 86, 2075–2076, 2078–2079, 2081, 2084

health and well-being, 2064–2065, 2085, 2088

heat-related mortality, 2064

human population, 2053

human systems, 2063–2069, 2095–2096

hurricanes, 2071

Indian Ocean tsunami (2004), 2071, 2076

Indigenous knowledge and local knowledge, 2050, 2067, 2068, 2077, 2091

infrastructure, 2045, 2063–2064, 2074

infrastructure: adaptation, 2084, 2680–2681

insurance, 2089

interconnections, 2049, 2059

inundation, 2068, 2068

invasive species, 2070

irreversible changes/risks, 2417

key risks, 2046, 2069, 2074

key risks, adaptation options for, 2081–2086

labour migration, 2681

land reclamation, 2076

livelihoods, 1211, 1218, 2074, 2079–2080

livelihoods: adaptation, 1185–1186, 2081, 2085

livelihoods, migration for, 2077–2078

losses and damages, 2045, 2047, 2073

malaria, 2064

Maldives Islands, 2071–2072, 2076

- mangroves, 2046, 2057, 2071
 marine ecosystems, 2045, 2046, 2056–2058
 marine ecosystems: adaptation, 2081
 mental health, 2065
 microfinance, 2089
 migration, 1185–1186, 2067–2068, 2070, 2076–2077, 2078–2079, 2084
 natural systems, 2053–2063, 2054–2055, 2095–2096
 observed changes in climate, 2052, 2095–2096
 observed impacts, 2045, 2049, 2050–2073
 occupational heat stress, 2064
 ocean acidification, 2046
 planned relocation, 52, 2096–2097
 precipitation, 2045, 2052, 2054
 precipitation, extreme, 2046
 projected impacts, 623, 2045–2046, 2049
 projected risks, 19, 59, 62–63, 2046–2047, 2050–2073
 protected areas, 2083
 provisioning, 2046
 reef island destabilization, 2055–2056
 research and data gaps, 2047, 2049, 2093, 2094–2095
 resilience, 2047
 ridge-to-reef management, 2059, 2081, 2082
 risk accumulation/amplification, 2072, 2073
 risk transfer, 2088–2089
 risks, 82, 2048, 2069, 2074
 risks: key risks, 2046, 2069, 2074, 2081–2086
 sea level rise, 2045, 2052
 sea level rise: adaptation, 2096–2097
 sea level rise: impacts, 17, 2061
 sea level rise: losses and damages from, 2047
 sea level rise: projections, 17, 2056
 seagrasses, 2057
 settlements, 2063–2064, 2074, 2084
 slow-onset changes, 2047, 2069, 2074
 social capital, 2047
 social networks, 2047, 2093
 storm surges, 2045, 2048, 2053
 submergence, 2053–2055, 2053, 2068, 2068, 2074
 temperature, 2045, 2048, 2052, 2054
 temperature scenarios, 2046
 terrestrial ecosystems, 2045, 2046, 2061–2063, 2062–2063, 2074
 terrestrial ecosystems: adaptation, 2082–2083
 tourism, 2080, 2086, 2093
 transboundary issues, 2069, 2070
 tropical cyclones, 2045, 2048, 2052, 2053, 2055, 2064, 2095–2096
 tropical cyclones: losses and damages, 2047
 tropical cyclones: projections, 2064
 tropicalisation, 2065
 urgency, sense of, 2045, 2048
 vector-borne diseases, 2064
 vulnerability, 15, 1052, 2045, 2046, 2048, 2050–2052, 2061
 wash-over events, 623
 water insecurity, 623, 2046
 water resources, 2083
 water security/insecurity, 2046, 2065, 2074
 waves, 2045–2046, 2055, 2056, 2070, 2078
 Yap: livelihood strategies, 1185–1186
 zika, 2064
 See also Coral reefs
Snow cover, 563, 564, 570–571, 2275, 2302, 2324, 2331
 observed changes, 565, 570, 592
 projected changes, 16, 61, 603
Social capital, 108, 767, 1237–1238, 2047
Social conflict. See Conflicts
Social cost of carbon (SCC), 2420, 2495, 2498
Social governance, 2584
Social inclusion*, 112, 909, 911, 996
Social infrastructure*, 910, 942–947
Social insurance, 944
Social justice*. See Justice
Social movements, 101, 1693, 1749–1750, 2598–2600, 2720–2721, 2736
Social networks, 1208, 2047, 2093
Social policy-based adaptation, 909–910
Social protection*, 27, 943–944, 944, 1047, 1389–1393, 1523–1525
Social safety nets, 27, 808, 944, 1047, 1390–1393, 2781
Social tipping points, 65, 82, 1174, 1176, 1215–1216, 1216
Social vulnerability, 909
Societal choices, 32, 35, 2658, 2661, 2662–2665, 2720
Societal impacts of climate change, 1174, 1176, 1194
Societal resilience, 108–109
Societal responses to climate change risks, 160–173
Societal (social) transformation, 174, 2655, 2667
Societal systems, transitions in, 2665, 2693–2698, 2699
Socio-cultural factors, 1235–1238
Socio-economic pathways. See Pathways; Shared socio-economic pathways
Socio-institutional adaptation, 468, 472, 473, 482
Socio-technical transitions*, 2658, 2665, 2690–2705, 2733, 2736
Soil
 anthropogenic soils, 1757–1758
 carbon stocks, 250, 270, 317
 conservation, 624, 645
 health, 16, 741
Soil erosion*, 583–584, 612
Soil moisture*, 23, 564, 569–570
 observed changes, 569
 projected changes, 600–601, 602
Solar chimneys, 953
Solar power, 932–933, 1245
Solar radiation modification (SRM)*, 69, 2416–2417, 2473–2478
 risks, 21, 68, 69, 2475–2477
 termination effects, 2475, 2477
Solastalgia, 1078, 2339
Solution space*, 165–166, 2658
 for climate resilient development, 71, 2659, 2666, 2690, 2705, 2706, 2736
 expanding, 163–166, 165, 2658, 2666, 2736
 FAQ, 1127–1128
 governance and, 167
 for health adaptation, 1103–1104
 for policy action gap, 969–974, 972
Solutions*, 160–162
 adaptation, 71–99, 126, 160–162, 472
 cross-cutting, 27–28, 2781–2785
 definition of, 161
 effectiveness, 160–161, 161, 163
 feasibility, 161–162, 161, 1110, 2724–2733, 2769–2807
 just and equitable for all, 31, 33, 2657, 2659, 2661, 2668
 justice and, 160–163, 161
 linkages, 134
 solution frameworks, 133, 911
 See also Nature-based solutions (NbS)
South America. See Central and South America
Southern Annular Mode (SAM), 1329, 1591
Southern Ocean*, 431–433
 primary productivity, 2329
 species range shifts, 2328
 upwelling, 397, 2329
Soy/soybeans, 584–585, 805, 1956
 observed impacts, 728–729, 732
 projected impacts, 736–737
Spatial and temporal scales*, 176, 401, 2418, 2453
Special Report on Climate Change and Land (SRCCL), 40, 131, 720, 913–914, 1240
Special Report on Global Warming of 1.5°C (SR1.5), 40, 559, 720, 913, 1182, 2444
Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX), 173–174
Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC), 40, 130–131, 386–389, 563, 720, 913
Species, 45, 47–48, 67, 109
 about: storyline figure, 72–73
 adaptation limits and, 84
 assisted migration, 221–222, 286, 287
 climate change impacts on, 226–229
 climate change responses of, 45
 community composition, 381, 434–435, 438–446
 conservation, 109
 dispersal ability, 208–209, 259
 endemic*, 16, 47, 56, 2046, 2125, 2126, 2132, 2135
 exposure to altered environments, 445–446, 449
 extinctions, ecosystem services and, 279
 foundational, 415
 fundamental unit of ecosystems, 202, 279
 invasive (See Invasive species)
 keystone, 592, 2322
 managed relocation, 296–297
 migration corridors, 26, 285–287, 286
 mountain-top, 45, 2277, 2302
 non-indigenous, 456
 physiology and morphology, 200, 224–230
 refugia for, 87, 203, 271, 285, 286, 414, 435, 475
 relocations of, 71

resilience, 26
 responses to climate change, 2125
 richness, biodiversity hotspots, 2126
 severe impacts on, 47–48
 thermal tolerance, 407, 433, 2328
 vernalisation, 225
See also Habitats; Phenology; Range shifts

Species distribution, 45, 227–229, 717, 768–773, 2424
 adaptation and, 718–719
 observed changes, 592
 ocean systems, 433–436, 434
 poleward movement, 433, 457, 460, 730, 1957
 range shifts (*See* Range shifts)
See also Extirpation

Species extinctions. *See* Extinction

Sponge City Programme, 1503, 1504–1505

Spring advancement, 223–225
See also Phenology

SREX (Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation), 173–174

SRM. *See* Solar radiation modification

SROCC (Special Report on the Ocean and Cryosphere in a Changing Climate), 40, 130–131, 386–389, 563, 720, 913

Standards*, 2583–2584

State fragility, 1201, 1202

Storm surge*, 420, 476, 916
 Australasia, 1583, 1604, 1619, 1621, 1626
 Central and South America, 1712
 coastal areas, 420, 476, 909, 934, 950, 993
 Small Islands, 2045, 2048, 2053
 urban areas, 909, 925, 935–936, 993

Storms
 atmospheric river events, 1953, 1962
 human mortality, 50–51
 sand and dust storms, 1459, 1464, 1478, 1533, 2207–2208, 2207
See also Storm surge; *specific regions and topics*

Storylines*, 72–83, 137
 biodiversity, 72–73
 cities and settlements, 80–81
 complex risk, 82–83
 ecosystems and species, 72–73
 food–water, 74–75
 health and well-being, 79
 urban areas, 80–81
 vulnerability (human), 86–88

Stratification*, 391, 395

Streamflow*, 571–573
 climate change impacts on, 564
 dams and, 564
 modified, 556, 617
 observed changes, 555, 565, 571–573, 574
 populations dependent on, 556
 projected changes, 16, 61, 556, 603–605

Stressors*, multiple, 82–83, 147–149

Subsidence, 66, 386, 393, 933

Subsidies, 2719

Subsistence livelihoods/provisioning, 47, 61

Sudden-onset events, 1099–1100, 1100, 1174

Sugarcane, 1697, 1699, 1736

Sundarbans, 462, 611, 1480, 1516

Supply chains, 21, 33
See also Food supply chain

Sustainable adaptation, 1240

Sustainable development (SD)*, 1171–1284
 2030 Agenda for*, 40, 93–94, 128–129, 911, 912, 919, 920, 2545, 2598, 2657, 2671
 adaptation and, 132
 adaptation and mitigation links, 2658, 2687
 adaptation gap and, 1239
 climate action and, 2657, 2666
 climate change and, 1174, 2670–2671
 climate change as threat to, 35
 climate resilient development and, 31, 100–101, 2731
 current development pathways, 100, 2657
 decision making for (*See* Decision making)
 enabling principles, 557, 654–659
 five pillars (people, planet, prosperity, peace, partnership), 2671
 health benefits, 1046–1047
 implementing, 127
 key risks and, 2473–2481, 2480
 linkages, 134, 2658, 2660, 2670–2671
 maladaptation and, 1174
 narrowing options for, 32, 2657–2658
 observed impacts, 1177–1187
 pathways, 1240
 precursors for, 2658
 priorities in, 90, 100, 101, 2659, 2689, 2733
 system transitions and, 2658, 2690–2705
 trade-offs, 910
 transformations and, 2668–2669
 unsustainable development, 2661, 2671
 in urban areas, 910, 911, 912
 vulnerability reduction, 1249
 water security and, 557, 654–659
See also Climate resilient development pathways; Resilience

Sustainable Development Goals (SDGs)*, 163, 1174, 2662, 2728–2731
 adaptation and, 25, 814, 2681–2683
 cities and, 910, 911
 climate action (SDG 13), 2666
 climate change potentially worsened by, 2670
 climate resilient development and, 32, 2662, 2674, 2681–2683, 2737
 climate responses and, 2787
 COVID-19 and, 2661
 CRDPs and, 2662
 current development and, 2657
 development pathways and, 2662, 2670–2675, 2674
 disaster risk reduction and, 591
 key risks and, 2416, 2479–2481, 2480
 nature-based solutions and, 487
 oceans, 383–384, 467–468, 489–492, 490, 491
 poverty-related, 1174
 by sectors, 2728–2731
 synergies, 910
 water-related, 557, 558, 654–659
 window of opportunity for, 32–33, 2662
 Zero Hunger, 798, 1174

Sustainable development pathways (SDPs)*, 1240

Sustainable forest management*, 23, 304–305, 757, 2371, 2372, 2393–2396

Sustainable land management*, 23–26

Sustainable resource management, 90, 718–719

Sustainable water management, 75, 90, 1301–1302

Sweden
 Malmö, 1883
 Sami reindeer herding, 82, 1868–1869

Synergies, 24–26, 108, 129–132, 308–309, 910, 1239–1245, 2687–2689, 2785–2787
 mega-disturbances, 1946

Syrian Civil War, 2429

System transitions. *See* Transitions

T

Tasmanian Wilderness World Heritage Area, 300

Taxes, 2707–2708, 2719

Technology, 24, 79, 88, 106, 2709, 2718–2720
 capacity and access, 26, 35, 93

Teleconnections*, 1329

Temperate forests, 269, 308

Temperature
 adaptation limits and, 28
 adaptive capacity and, 2666
 extremes, 11, 57
 future pathways, 2662
 global, current, 10, 44, 1819
 global mean surface (GMST)*, 18
 global warming levels (GWs), 137, 139–143, 2677–2678
 key risks and, 2417, 2420, 2466, 2466–2468, 2501, 2506–2507, 2666
 likelihood of passing 1.5°C in near-term, 43
 overshoot*, 21–22, 35, 57, 69, 267, 453, 2484
 projected changes, 18, 58, 130–131, 391, 1090–1091, 2677–2678, 2723
 projected impacts (*See* Temperature impacts)
 projected time to reach 1.5°C, 10, 43, 44, 144–145
 regional projected changes, 2723
 risks at 1.5°C, 15, 17, 69
 risks beyond 1.5°C, 16–17, 66, 69
 scenarios, 2723
 sea surface (SST) (*See* Sea surface temperature)
 targets, 2417, 2420, 2447, 2657
 thermal tolerance (species), 407, 433, 2328
See also Global warming; Temperature impacts; Temperature projections; *and specific regions*

Temperature impacts, 72–73
 escalation with each degree of warming, 16, 22, 55–56, 57
 global/aggregate impacts, 17, 18, 2417, 2486, 2492–2494, 2501
 irreversible impacts, 11, 16, 21, 57, 69
 key risks and vulnerabilities, 938, 2417, 2420, 2466, 2466–2468, 2501, 2506–2507
 oceans, 391
 projected impacts of 1.5°C rise, 15–17, 19, 20, 55–56, 61, 66, 69, 556
 projected impacts of 2°C rise, 16, 19, 55–56, 57, 61–62, 64, 66

- projected impacts of 3°C rise, 16, 19, 56, 61–62, 64, 556
- projected impacts of 4°C rise, 16, 19, 55–56, 62, 598
- storyline figures, 72–83
- Temperature projections**, 139, 141–142, 391
- exceedence of critical risk thresholds, 1090–1091
- global, 2723
- likelihood of passing 1.5°C in near-term, 43
- regional, 2723
- storyline scenarios, 72–83
- Temporal mismatches**, 45, 382, 436–438, 437
- Terrestrial and freshwater ecosystems**, 197–377
- about, 200–206
- abrupt changes, 2457
- adaptation, 72–73, 203, 283–317, 286, 308–309
- adaptation: case studies, 296–301
- adaptation: not a substitute for emissions reductions, 15, 203
- adaptation, biodiversity conservation, 285–287
- adaptation, ecosystem-based (EbA), 203, 283–284, 288–290, 288–289, 310–312
- adaptation effectiveness, 203
- adaptation feasibility, 312–317, 313, 2769
- adaptation, guidelines for semi-natural vegetation, 316
- adaptation, Indigenous knowledge and, 203, 204, 298
- adaptation limits, 284–285, 301–302, 2415, 2448–2449
- adaptation, maladaptation, 204, 313–314
- adaptation, nature-based solutions (NbS), 283–284, 303–309, 310–312
- adaptation planning, 203, 285, 297, 302
- adaptation, right place and time for, 203, 290, 312
- adaptation, synergies and trade-offs, 308–309
- arid regions, 238–239, 263, 269
- atmospheric CO₂ and, 201
- biodiversity, 72, 203–204, 257–258, 280–281, 2456–2457
- biodiversity: adaptation, 285–287
- biodiversity: projected changes, 253–257, 258, 260
- biodiversity hotspots, 2125, 2127, 2136–2143, 2138–2142
- biogeochemical shifts, 217, 265, 275–276
- biomes, 201, 237–243
- biomes: biome shifts, 201, 202, 237–238, 252, 262, 269
- biomes: projected changes, 261–270, 262, 269
- biophysical feedbacks, 267, 275–276, 277
- boreal forests, 237–238, 241, 265–266, 269
- browning of rivers and lakes, 200, 243
- carbon: high-carbon ecosystems, 22, 201–203, 249–251, 273
- carbon balance, 47, 201–202, 204, 249–251, 253, 273–274, 279, 281
- carbon balance; feedbacks, 202–203, 274–277, 275, 276
- carbon sequestration, 47, 201–202, 204, 243, 249
- carbon sinks, 201–202, 243, 249–251, 253, 273–274
- carbon sinks: becoming sources, 47, 201–203, 241–242, 253, 273–274, 279, 281
- climate resilient development (CRD), 203–204, 302–317, 2728
- community composition, 223–224
- Cross-Chapter Box (EXTREMES), 215–218
- Cross-Chapter Box (ILLNESS), 291–295
- Cross-Chapter Box (NATURAL), 303–309
- deserts and arid lands, 238–239, 269
- detection and attribution, 200, 201, 206
- detection and attribution: uncertainties, 254–256
- diseases, 230–236, 233–235, 261
- diseases: adaptation, 290–291, 294–295
- diseases: case studies, 231–233
- diseases: vector-borne, 200, 231, 232, 261, 291–295
- diseases: wildlife diseases, 200, 230–236, 261
- diseases: zoonoses, 232–233, 233–235
- disturbance regimes, 208, 237, 280, 314
- ecosystem connectivity, 279, 285–287, 286
- ecosystem functioning, 55, 72, 208, 243–253
- ecosystem health, 55, 310–312
- ecosystem integrity, 55, 72, 201, 202, 205, 267, 276, 311
- ecosystem protection, 203–204, 310–312
- ecosystem restoration, 203, 204, 313, 315–316
- ecosystem services, 47, 201–202, 204, 243–279
- ecosystem services: carbon sequestration, 201–202, 204
- ecosystem services: connections to climate change, 206, 207
- ecosystem services: human health and, 47, 282–283
- ecosystem services: risks, 270–279
- ecosystems: past change vs. observations, 268–269
- ecosystems: projected changes, 261–270
- ecosystems: risks, 55–57, 270–279
- ecosystems: structural changes, 55, 201, 267, 280–281
- ecosystems: temperature overshoot and, 57, 267
- eutrophication*, 252, 278–279
- evolutionary responses, 236–237
- extinction, 200, 220–223, 221–222, 229
- extinction risk, 16, 200, 256–261, 259–260
- extreme events and, 200, 204, 208–210, 214, 215–218
- EXTREMES (Cross-Chapter Box), 215–218
- FAQs, 221–222, 233–235, 247–248, 282–283, 310–312
- fauna, 275–276
- feedbacks, 267, 274–277, 275, 276
- fish, 214
- fisheries, 278–279
- forests, 201, 204, 237–238, 265–266
- forests, tropical, 240–241, 265, 272–273, 308
- genetic and evolutionary responses, 201, 230, 236–237
- growing season, 200, 224, 242, 244, 251, 255
- hazards and exposure, 208–229
- heatwaves, 208, 216–217
- human health and, 282–283
- human interventions, 205, 283
- hydropower, 279
- ice, 200, 213, 214
- ice loss, 211–214, 213
- impacts, escalating, 67
- invasive species, 205, 208, 224, 1594
- key risks, 279, 280–281, 2455, 2456–2457
- lakes, 200, 210, 213, 214
- land: percent area needed for biodiversity, 203–204
- land use and cover change, 205, 274
- land use change, 202–203, 209, 238, 274
- mass mortality events, 200, 215–217, 275–276
- Mediterranean-type ecosystems, 239, 263–264, 269
- observed changes, 11, 208–209, 237–243
- observed changes: synthesis, 244
- observed impacts, 72, 200–202, 219–253
- observed impacts: conclusions, 252–253
- oxygen, dissolved, 200, 210, 214, 243, 278
- peatlands, 241–242, 266–267, 309
- permafrost, 202, 251, 273, 279
- phenology, 12, 46, 200, 224–225, 226–227, 252, 275–276
- physical changes, 210–229
- planetary boundaries for, 2661
- plant functional types, 268
- polar tundra, 242–243, 267, 269
- primary production, 214, 251–252, 275–276
- projected impacts, 58, 72–73, 209–210, 253–283
- projected risks, 18–20, 202–203, 270–279
- protected areas, 222, 270–271, 286, 287
- refugia, 203, 271, 299, 300
- risks, 270–279
- risks: key risks, 279, 280–281, 2455, 2456–2457
- rivers, 200, 211, 211, 213, 214, 288–289
- savannahs and grasslands, 201, 239–240, 264, 269, 309
- SDGs, 2728
- species, 67, 200, 202, 219–237, 279
- species: body size, 225–226, 230
- species: climate change impacts, 226–229
- species: distribution and abundance, 227–229
- species: extinctions, 200, 220–223, 221–222, 256–261, 259–260, 279
- species: physiology and morphology, 200, 224–230
- species: projected changes, 253–261
- species: range shifts, 12, 67, 200, 205, 219–220, 224–225, 227–229, 252, 275–276
- species: responses related to climate, 200, 236–237
- species dispersal ability, 208–209, 259
- temperature (surface air), 202
- thermal habitat, 210
- tipping points, 205, 208, 279
- transitions (system transitions), 2692–2693, 2699
- tree mortality, 200, 201, 246–249, 272–273, 280–281
- tree planting, 310, 315–316
- uncertainties, 254–256, 317–318
- urgent need for actions, 204
- water flows, 200
- water level, 210
- water quality, 205, 277–278
- water resources, 50
- water storage, 610

- water temperature, 200, 211
wildfires, 20, 201, 202, 243–246, 272, 280–281
wildfires: area burned, 201, 202, 243–246, 272
wildfires: FAQ, 247–248
wildfires: fire seasons, 201, 246
wildfires: projections, 202, 271–272, 281
wildlife diseases, 200, 230–236
See also Mountains
- Thailand, protected area planning**, 297
- Thermal habitat**, 210
- Thermal mismatch**, 232
- Thermal refuges**, 414
- Thermal stress**. See Heat stress
- Thermal tolerance**, 225
corals, 407
ocean species, 433, 2328
- Thermoelectric power**, 27, 555, 585, 586, 615, 932
- Thresholds, critical**, 1050, 1090–1091, 2417, 2456, 2458–2459
exceedence of, 55, 1090–1091
See also Tipping points
- Tibetan Plateau**
water extent, 212
See also Himalayas/Hindu Kush
- Tick-borne diseases**, 200
Lyme disease, 51, 261, 1045, 1063–1064, 1094, 1862, 2427
poleward shift of, 200, 234
tick-borne encephalitis (TBE), 1045, 1094, 1862
- Tigers (Bengal tiger)**, 1476, 1516
- Time of emergence**, 399–400, 445–446, 448, 449
- Time of exposure to altered environments**, 445–446, 449
- Time scales**, 176, 401, 2418, 2453
climate-induced drivers, 401
reference periods and years, 10, 10, 44
See also Scales (spatial and temporal)
- Tipping points***, 1215, 2417, 2424
Amazon region/forest, 82, 272, 1707
carbon balance/loss, 279, 281
cascading impacts and, 20
coupled, 1174
ecosystems, 208, 279, 2424
large-scale singular events (RFC5), 2417, 2486, 2494–2500
marine heatwaves and, 382
North America, 1985, 1999
ocean and coastal ecosystems, 382, 447–448
ocean (FAQ), 447–448
risks of crossing, 2661
social, 65, 82, 1174, 1176, 1215–1216, 1216
temporary overshoot and, 453
terrestrial and freshwater ecosystems, 205, 208, 279
- Tourism**
adaptation limits, 2449
adaptive capacity, 1973, 1974
Africa, 1338–1339
Australasia, 1583, 1605, 1607, 1617, 1625–1626
Central and South America, 1709, 1710, 1714
coastal areas, 383, 467
cruise ship, 481
ecotourism, 480–481, 1714
in Europe, 1852, 1857, 2449
last chance tourism, 1595
marine ecotourism, 480–481
Mediterranean Region, 2235, 2237, 2242, 2243
mountain areas, 570, 2275, 2287–2288, 2292
nature-based, 1338–1339
North America, 1963, 1971–1973, 1974, 1976, 1992
oceans and coastal areas, 469, 480–481
polar regions, 2321, 2325, 2335, 2348
protected areas, 1339
Small Islands, 2080, 2086, 2093
- Toxins**, 20, 49, 51, 64, 462, 789, 1098
aflatoxins, 789, 798, 1072, 1098
bioaccumulation of, 49, 64, 382, 789
harmful algal blooms (HABs), 20, 64, 404, 463, 789, 1076, 1098
mycotoxins, 20, 51, 789, 1098
- Trade**
Arctic maritime trade, 2336–2339
international, 790–791
risk transmission and, 68, 2441–2442
- Trade-offs***, 2657–2658, 2687–2689
adaptation, 129–132, 1239–1245, 2542
adaptation and mitigation, 307–308, 653–654, 1239–1245, 1304, 2687–2689
decision making and, 2576–2577
evaluating, 163
multi-metric valuation, 163
- Transboundary adaptation**, 1489
- Transboundary agreements**, 480
- Transboundary governance**, 30, 480, 659, 719, 768–769
mountain regions, 2276, 2304
- Transboundary issues**, 21, 67–68, 82–83
Africa, 1289, 1310–1312
Arctic maritime trade, 2336–2339
Asia, 1485, 1488, 1489
Australian megafires, impacts of, 83
collaboration on, 30
Europe, 1820
marine spatial planning, 475
risk transmission, 21, 2441–2444
water conflict, 593
- Transboundary risks**, 21, 67–68, 1820
- Transformation***, 41–43, 99, 111–112, 127, 173–178, 2665
adaptation limits and, 171–172, 2558–2562
barriers/resistance to, 2668
for climate resilient development, 111–112, 2658–2659, 2668–2669, 2736
definition of, 173, 823
deliberate*, 174–175, 175
ecomodernism vs. degrowth, 174–175
of ecosystems, 55
enabling, 175–177, 981–982, 2668
facilitating, 173–178
forced, 174–175, 175
goals, 133
linkages, 134
long-term, 173–178
role in this report, 41–43, 127, 133
societal (social)*, 133, 174
speed and scale of, 175–177
system transitions and, 2658, 2665, 2690–2705
transformative actions, 2665, 2668–2669
urban areas, 976
- Transformational adaptation***, 99, 174, 383, 2435–2436, 2435, 2436, 2557–2562
24 adaptation options, 99, 2557–2562, 2559–2560, 2604
adaptation limits and, 2558–2562
adaptation spectrum, 2557–2558, 2561, 2619
agroecology as, 815–817
cities and settlements, 910, 911, 915–916, 963, 971, 2601–2602
decision making and, 2601–2602
FAQ, 181
food, fiber systems, 822–823
incremental adaptation vs., 2558
need for, 111, 383, 2542, 2671
planned adaptation, 2561, 2562
relative lack of, 2415
for risk management, 2558–2562
trade-offs, 2542
- Transitions***, 99, 111–112, 2658, 2665, 2690–2705, 2733, 2736
accelerating, 2698–2705, 2733
adaptation options for, 23–28, 24–26
climate responses and, 2785
definition of, 173, 2690
energy, 27, 99, 2690–2691, 2699, 2769, 2773–2774
facilitating, 2699
FAQ, 2736
feasibility, 100, 2772–2781
industrial systems, 2693, 2699
just, 2604–2605, 2606
land, oceans, and ecosystems, 23–26, 2692–2693, 2699, 2774
linkages, 8, 42, 134
mitigation and, 2785–2787
monitoring and evaluation (M&E), 2709–2711
public policy and, 91
societal systems, 2665, 2693–2698, 2699
urban and infrastructure, 26–27, 2691–2692, 2699, 2780–2781
water importance for, 654
window of opportunity for, 2658
- Transpiration**. See Evapotranspiration
- Transportation**, 933–934
active transport, 1047
adaptation, 1369, 1370
infrastructure, 933–934, 955–956, 1369
ocean systems and, 481
railways, 931, 1850, 1851
roads, 931, 1368, 1368
sea ice loss and, 2336–2339
in urban areas, 955–956
- Trees**
carbon storage, 272
tree crops, 729–730
tree line*, 1472–1473, 1475, 2277, 2294, 2302
tree mortality, 22, 200, 201, 246–249, 272–273, 280–281, 753–754, 1946, 2499
tree planting, 310, 315–316, 1341

- in urban areas, 309, 935
 - See also Forests
 - Trees, specific**
 - acacia, 301
 - baobab, 270–271, 760
 - eucalyptus, 208, 290, 1594, 1599, 1615–1616, 2281
 - Triple-win approaches**, 1240, 1528
 - Tropical cyclones***, 11
 - Africa, 1290, 1329, 1333, 1361, 1362, 1363–1364, 1377–1378
 - Asia, 1463, 1465, 1500
 - Cyclone Debbie (2017, New Zealand), 1583, 1623
 - Eline (2000), 1333
 - Idai and Kenneth (2019), 588, 590, 1208, 1362, 1377
 - migration after, 52, 1084–1085
 - Tropical forests, 2369–2410**
 - about, 2371–2372, 2374
 - adaptation, 308, 2381–2388, 2384, 2389–2391
 - adaptation assessment, 2385
 - adaptation barriers, 2392–2393
 - adaptation, combination of options, 2387
 - adaptation, community-based, 2371, 2381, 2382
 - adaptation costs and benefits, 2386–2387, 2389–2391
 - adaptation, different scales of, 2384–2386, 2385
 - adaptation, IKLK in, 2371, 2381, 2382–2383
 - adaptive capacity, 2382–2383
 - afforestation, 2374–2375
 - agriculture and, 2371, 2372, 2375, 2376
 - biodiversity, 2371, 2373–2374, 2374
 - biome shifts, 2379
 - browning, 2379
 - carbon cycle, 2377, 2379, 2396
 - carbon stocks, 250, 2377, 2379
 - carbon stocks: becoming sources, 2377
 - climate change impacts, 2371, 2372, 2373, 2376–2380, 2396–2397
 - CO₂ fertilisation, 2377
 - current climate risks, 2378–2379
 - current state of, 2372–2373, 2374
 - deforestation, 249, 2371, 2374–2376, 2375
 - deforestation: carbon emissions and, 249, 2375
 - deforestation: climate responses, 2380
 - deforestation: drivers of, 2375–2376, 2376
 - deforestation: rate of, 2374–2375, 2375
 - degradation of, 2375–2376
 - droughts, 2377, 2378, 2378
 - FAQ, 2396–2397
 - feedbacks, 276
 - fire and, 2378, 2378
 - governance, 2371, 2387–2388
 - impacts, current and projected, 2373, 2376–2380
 - Indigenous knowledge and local knowledge, 2371, 2382–2383
 - Indigenous Peoples in, 2380–2381
 - interconnections, 2372, 2373
 - land conversion, 272, 2372, 2375, 2378
 - land use, 265, 2372, 2381, 2396–2397
 - lianas and, 241
 - livelihoods, 2372, 2380–2381, 2397
 - observed changes, 240–241, 2372
 - peatland forests, 308
 - photosynthesis, 2376
 - plantation forests, 265, 2371, 2378
 - primary production, 240–241, 2379
 - projected impacts, 2379, 2397
 - projected risks, 265, 269
 - reforestation, 2374–2375, 2375
 - resilience, 2371, 2380, 2392–2393, 2396–2397
 - Sustainable Development Goals, 2381, 2394–2396
 - Sustainable Management (STFM), 2371, 2372, 2393–2396
 - tipping points, 2379
 - transformative change, 2388, 2392–2393
 - tree mortality, 272–273, 2377, 2378
 - tree physiological responses, 2376–2377
 - tree regeneration, 2377
 - types and extent, 2372–2373, 2374
 - See also Amazon region/forest
 - Tropicalisation**, 438–440, 1839–1840, 2065
 - Tsunamis*: Indian Ocean (2004)**, 2071, 2076
 - Tuna**, 462, 1844, 1950
 - Tundra***, 242–243, 2321
 - biome shift, 201, 2321
 - browning, 2321
 - fire disturbance, 245, 272
 - polar, 242–243, 267, 269, 2321
 - projected changes, 267, 269
 - woody encroachment, 201
 - Turtles, marine**, 1952, 2058
 - Tuvalu**, 594
 - Typhoid fever**, 1064
- ## U
- Uncertainty***, 33, 145, 160, 317–318
 - Cross-Chapter Box (DEEP), 2578–2580
 - decision making and, 2543, 2578–2580, 2616
 - deep*, 2543, 2578–2580
 - in demographic projections, 1101
 - in detection and attribution, 254–256
 - language (confidence, likelihood), 40, 41, 159–160, 159
 - risk and, 2658
 - Undernutrition**, 64, 798, 1045, 1046, 1061
 - Unique and threatened systems (RFC1)**, 18, 2417, 2485–2488, 2486, 2501
 - United Kingdom (UK)**
 - flood management, 297
 - natural flood management, 297
 - United Nations**
 - Declaration on Human Rights, 2707
 - Declaration on the Rights of Indigenous Peoples, 157–158, 1585, 2707
 - United Nations Framework Convention on Climate Change (UNFCCC)***, 40, 128, 2443
 - 100 Billion (climate finance commitment), 2586–2587
 - common but differentiated responsibilities (CBDR), 162
 - Global Climate Action Portal, 920
 - loss and damage inclusion, 2073
 - Non-State Actor Zone for Climate Action, 921
 - United States**
 - Hurricane Harvey (2017), 589, 591
 - National Climate Assessment (2018), 1181
 - See also North America
 - Upwelling**, 429–431, 430, 2329
 - California EBUS, 429–430
 - coastal systems and, 395, 429–431, 430
 - Eastern Boundary Upwelling Systems (EBUS), 391, 395, 429–431, 430
 - primary production and, 429–431
 - projected trends, 399
 - upwelling zones, 429–431, 430
 - Urban adaptation**, 26–27, 71, 80–81, 91–94, 940–963
 - adaptation challenges in African cities, 979
 - adaptation constraints and limits, 26, 910
 - adaptation experiences, 964–967
 - adaptation gap, 71, 91, 93, 910, 941–942, 941, 976–978, 989–990
 - adaptation pathways, 940–963
 - adaptation planning, 909–910, 919
 - adaptive capacity, 26, 53, 909, 975
 - barriers to, 910, 964, 970, 978–980, 978
 - benefits and trade-offs, 309, 960–961
 - climate resilient development pathways, 961, 962–963, 989–990
 - co-production of strategies, 971–973
 - community-based adaptation, 26, 91, 965, 967
 - in conflict zones, 937
 - COVID-19 and, 909
 - diverse responses for, 91–93
 - enabling conditions, 913, 963–982, 990–991
 - equity and justice in, 958–959
 - FAQs, 994, 996
 - feasibility, 2779–2781
 - finance for, 910, 975–980, 996
 - health systems, 946
 - impacts and risks of, 937–940, 937
 - incremental adaptation, 963
 - Indigenous knowledge and, 919, 945
 - inequalities and, 909
 - infrastructure and, 910
 - institutional change and, 967–969
 - investment in, 910
 - local adaptation, 964, 974
 - mainstreaming, 93–94, 971
 - maladaptive responses, 909
 - monitoring and evaluation, 980–981
 - nature-based solutions (NbS), 81, 305–306, 909, 948–952
 - needs of most vulnerable, 971
 - non-state actors in, 964
 - partnerships for, 966
 - private sector and, 965–966
 - social infrastructure, 942–947
 - social policy-based adaptation, 909–910, 996
 - solution space, 969–974
 - suburbanisation, 918
 - trade-offs, 910
 - transformative adaptation, 910, 911, 915–916, 963, 971, 976
 - urban design, 26, 1128
 - water-related, 628–629, 630, 632, 640, 2780–2781

Urban areas*, 907–1040

about: summary, 53–54, 65–66
 about: storyline figure, 80–81
 adaptation (See Urban adaptation)
 agriculture in, 799, 800
 air quality, 928, 939
 building design, 26, 953–954, 989, 1047
 cascading impacts*, 909, 916
 cascading risks, 909, 935–936
 case studies, 983–988
 climate interactions of, 922–928
 cold spells, 927
 Cross-Working Group Box (URBAN), 988–991
 cultural heritage/institutions, 947
 decision making, 910, 947
 definitions, 914–916, 915
 disproportionate impacts, 909
 as drivers of climate change, 989
 early warning systems, 944–946
 economic impacts, 909
 ecosystem fragmentation, 2691
 ecosystems, 309
 equity and justice in, 958–959
 expansion of, 917–918
 exposure, 53–54
 FAQs, 992–996
 fire and, 927–928
 flooding, 617, 925–926
 global trends, 916–917
 government/governance, 910, 913, 964, 973, 996
 green infrastructure, 910, 913, 925, 935, 2780
 green spaces, 289
 health and disease, 13, 1053
 health system infrastructure, 935
 heat islands*, 922–925, 952
 housing, 934
 human population in, 80, 909, 912, 914
 impacts and risks, 910, 921–940
 informal settlements, 909, 911, 917
 infrastructure (See Infrastructure)
 interconnections, 34, 68, 91, 910, 916
 land use, 942–943, 959
 landslides, 927
 local adaptation, 964
 migration (of humans), 929–930
 morphology and design, 952–954, 974
 New Urban Agenda*, 40, 93–94, 911, 912, 920
 observed impacts, 53–54, 909
 observed impacts: water-related, 587–592
 planning (See Urban planning)
 poverty and, 80, 921, 929, 943–944, 1701, 1712, 1746
 projected risks, 65–66, 616–617
 resilience, 994
 risk reduction, 994, 995
 risks, 616–617, 909, 910, 921–940, 938–939, 993, 1052
 sanitation, 925, 934–935, 949–950, 956–957
 sea level rise, 53, 909
 social safety nets, 944
 solution space for policy action gap, 969–974, 972, 989–990
 storm surges, 909, 925, 935–936, 993

sustainable development and, 910, 911, 912
 temperature and, 922–925, 923
 transitions (system transitions), 26–27, 2691–2692, 2699, 2779–2781
 transnational networks, 967
 transportation, 955–956
 trees and forests, 309, 935
 vulnerabilities, 909, 928–930, 992, 1052
 wastewater, 586–587, 631, 655
 water demand, 616–617, 622
 water scarcity and security, 926, 1343–1344
 water systems, 2691, 2780–2781
 wind and, 927
 zoning, 942–943
 See also Cities; Urbanisation

Urban heat islands (UHIs)*, 922–925, 952, 1498, 1533**Urban planning, 26, 93–94, 909–910, 911, 1124–1125, 2440, 2779–2780**

action frameworks and, 911
 decision making in, 911
 IKLK and, 982
 provision of basic services, 26, 99
 SDGs and, 912
 shift to action, 910
Urbanisation*, 53, 617, 911, 988–989
 adaptation and, 911, 1124–1125
 attributable impacts, 587
 climate change and, 1182
 climate resilient development and, 33, 911
 coastal areas, 68, 1214, 2167–2169
 flood risk, 925–926
 future risks, 1226
 global, 33, 911
 health risks, 1045
 in Himalayas/Hindu Kush, 983–984, 983
 megatrend, 991
 opportunities of, 34
 planetary, 914, 917–918
 population growth, 53, 909, 916–917
 poverty and, 921, 929
 projected risks, 15
 risks, 15, 55
 suburbanisation, 918
 unplanned, 53, 617, 909, 912, 1460
 vulnerability and, 14–15, 53
 water management and, 617
 water runoff and, 564

Urgency, 31, 42, 127, 128–133, 146, 1203, 2596–2597, 2597

decision making and, 2543
 for ecosystem protection/maintenance, 204
 for emissions reductions, 55, 2733
 FAQ, 180
 levels of, 2596–2597, 2597
 need for action, 127, 128–133, 180, 1651, 2045, 2048, 2596–2597, 2597, 2657
 Small Islands and, 2045, 2047, 2048
 timeline for action, 55–56, 204
 youth-led and social movements, 911, 912, 946–947, 963, 2418, 2720–2721

V**Vaccines, 1188, 1375**

Values and beliefs*, 99, 108, 1116, 2596, 2657–2658, 2661
 cultural values, 2546, 2547, 2567, 2596
 decision making and, 2546, 2547, 2567, 2568, 2578–2579, 2596, 2609
 resolving divergent views, 33

Vector-borne diseases*, 51, 231, 232, 293, 585, 1062–1064, 1092–1095, 2427

adaptation options, 27, 295, 1107–1108, 1107
 Africa, 1372–1373
 Arctic region, 45, 200
 Asia, 1460
 burden of, 1046
 Central and South America, 293, 1691, 1692, 1699, 1702, 1702, 1705, 1722
 chikungunya, 51, 1063, 1093–1094, 1702, 1710, 1969, 2427
 climate change impacts on, 200, 218–220, 234, 248–251, 261, 291–295
 Cross-Chapter Box (ILLNESS), 291–295
 dengue (See Dengue fever)
 El Niño and, 1373, 1702, 2064
 hosts for, 231
 Japanese encephalitis, 1063
 Lyme disease, 51, 64, 261, 1045, 1063–1064, 1090, 1094
 malaria (See Malaria)
 Nepal, 200, 232
 North America, 293, 1968, 1969–1970
 observed changes, 45, 51, 200, 218–220, 231, 292–293
 projections for, 17, 64, 248–251, 261, 1046, 1092–1095, 1093
 range shift/expansion, 17, 45, 51, 64, 200, 234
 seasonal transmission, 64
 Small Islands, 2064
 tick-borne encephalitis (TBE), 1045, 1094, 1862
 See also Diseases; specific diseases

Vegetation. See Forests; Plants; specific types of vegetation**Venice, Italy, 1828–1829****Vernalisation, 225**

Vibrio sp., 13, 64, 293–294, 382, 765, 789, 1094
 in Europe, 1841, 1862, 1863
Vibrio cholerae, 292–294

Vietnam

dams in, 1209
 Mekong River/delta, 1487, 1489
 river flooding, 925

Violent conflict, 17, 1048, 1087–1088

gender impacts, 1045, 1088
 water-related, 593, 618, 622, 629–632, 1087
 See also Conflict

Vision 2030 in Kenya, 2669–2670**Vulnerability*, 135–136, 1052, 1193–1211, 1249**

about, 8, 43, 52–53
 about: summary, 14–22, 52–53
 about: storyline figure, 76–78
 adaptation limits and, 1222–1225
 aggregate, 1196

aspects and dimensions, 77, 1198–1199
 assessment (See Vulnerability assessment)
 capacity building needs, 68
 characteristics of vulnerable regions, 14
 climate impacts and, 1174
 complexity of, 52, 1177, 1177
 compound challenges, 1201
 COVID-19 and, 1047, 1175, 2661
 definition of, 43, 1251
 disproportionate, 52, 76, 928–930, 1050–1051, 1180–1181, 1249, 2657
 drivers of, 34, 2421–2422
 dynamic, multidimensionality of, 52–53
 elderly people, 172, 1053, 1107, 1174, 1181, 1206, 1217
 exposure (See Exposure)
 extreme events, 217–218
 FAQs, 992, 1251–1252
 future, 1213–1227
 gender and, 1052–1057, 1052, 1192, 2701
 hazards and, 76–77, 1181
 health and well-being, 50, 1050–1059
 hotspots, 14, 1195–1204, 1198–1199
 human vulnerability, 14–22, 52–53, 65, 76–78
 indicators of, 1194–1195
 inequality and, 909, 2657
 interactions, 1177, 1249
 linkages, 82–83, 134, 1193–1194
 lock-in, 85
 maladaptation and, 85–86, 806, 807–809
 marginalised groups, 26, 29, 31, 33, 50, 52
 measurement/assessment, 1195
 observed impacts, 14–22, 52–53, 1200–1201
 past climate changes and (PALEO), 154–157
 planetary boundaries, exceedence of, 2661
 population in vulnerable locations, 52, 76, 80, 1174, 2657
 poverty and, 80–81, 929, 1174–1175, 1251
 projections, 14–15, 1213–1227, 1217
 rebound, 806
 reducing, 2415, 2668
 regions, 1251–1252
 relevance of, 1197
 risk and, 148–149, 1217
 by sectors and regions, 1052
 social vulnerability, 909
 state fragility and, 1201, 1202
 systematic, 1181
 transboundary, 82, 1200
 trends, 1201–1204
 violence and (See Conflicts)
 vulnerability reduction, 11, 1249
See also Risk; specific regions and sectors
Vulnerability assessment, 1193–1211, 1198–1199
 global assessments, 1195–1197, 1196
 highly-vulnerable regions, 1197–1200
 indicators, 1194–1195
 INFORM Risk Index, 1196
 limits of, 1196–1197
 metrics, 1194–1195
 Reasons for Concern, 15, 2481–2485, 2482–2483
Vulnerable groups, 11, 17, 34, 49, 50, 76, 717, 1174–1175, 1198–1199, 1249, 2657

adaptation needs, 101, 1174–1175
 adaptation options*, 1227–1238
 decision making and, 30, 1175
 disproportionate impacts, 76, 555, 564, 587, 717, 1174, 2657
 empowerment of, 27, 97
 global locations, 1052
 land deals and, 802–803, 803–804
 maladaptation and, 29, 85–86
 marginalised groups, 26, 29, 31, 33, 50, 52, 76
 participation of, 30, 31, 96
 partnerships with, 31, 34

W

Warming. *See* Global warming; Temperature
WASH (Water, Sanitation and Hygiene), 596–597, 616, 622
 adaptation, 627–628, 635, 640
 COVID-19 and, 628
 maladaptation potential, 627–628
Wastewater, 586–587, 631
 four Rs (reduce, remove, reuse and recycle), 631
 management, 463, 587, 655
 treatment/reuse, 653, 655
Water, 551–712
 about, 49–50, 555–557, 559
 about: storyline figure, 74–75
 access to, 558, 656, 2657
 adaptation (See Water adaptation)
 centrality of water security, 558–565
 climate change impacts (FAQ), 664–666
 climate resilient development and, 107, 558–565, 2729
 compound risks, 67–68
 desalination, 624, 631, 653, 655, 1349
 disproportionate impacts, 555, 564, 587
 droughts (See Droughts)
 economy and, 556
 enabling principles, 107, 557, 654–659
 equity issues, 107
 FAQs, 660–667
 floods (See Floods)
 four Rs (reduce, remove, reuse and recycle), 631
 glaciers (See Glaciers)
 governance, 658–659
 groundwater (See Groundwater)
 health and, 558
 Indigenous knowledge and local knowledge and, 564
 key risks, 556, 619–622
 mitigation and, 557
 mountain regions, 2279–2280
 mountain regions: lowland dependence on, 2280, 2282, 2291–2292, 2301
 observed changes, 49–50, 555, 565–584, 566–567
 observed impacts, 46, 49–50, 555, 584–596
 precipitation (See Precipitation)
 projected changes, 16, 61–62, 556, 596–612
 projected sectoral impacts, 556, 558, 612–619
 regional changes and impacts, 621–622

sustainable development goals (SDGs) and, 558, 2729
 unfamiliar precipitation regimes, 555, 567, 619
 uses of (See Water uses)
 vulnerabilities, 556, 558
 water-energy-food (WEF) nexus, 655, 811, 1246, 1530–1531, 2769
 water-related hazards, 555–556
 water-related risks, 61, 556
 water security, 61–62, 558–565
See also Hydrological cycle; Terrestrial and freshwater ecosystems; and other water entries

Water adaptation, 23–26, 27, 74–75, 87–91, 556–557, 558, 622–654
 adaptation limits, 85, 557, 635, 649–652, 650
 agricultural sector, 622–625
 barriers to, 659
 benefits and co-benefits, 556, 557, 635–643
 case studies and examples, 638, 639–640, 642–643, 644
 communities and, 666–667
 costs of, 652–653
 current and future, compared, 647–649, 648
 economic outcomes, 642
 effectiveness, 556–557, 635–654
 effectiveness: aggregate assessment, 645
 effectiveness: future projections, 643–647
 environmental outcomes, 643
 ethics and, 557
 FAQs, 664–667
 feasibility, 2769, 2770, 2779
 financing, 656
 four Rs (reduce, remove, reuse and recycle), 631
 Indigenous knowledge and local knowledge in, 657–658
 institutional outcomes, 643
 integrated approach, 650
 losses and damages, 650–652, 651
 maladaptive outcomes, 557, 627–628, 638–643
 mitigation and, 653–654
 nature-based solutions (NbS)*, 632
 non-adaptation, losses due to, 652–653
 outcomes assessment, 557, 637–638, 642–643, 644
 participation, cooperative and bottom-up engagement, 658
 planning, 557
 policies/political support, 557
 political support for, 659
 polycentric governance and, 658–659
 responses, 622–637, 637, 640–641
 sociocultural outcomes, 643
 technologies for, 655–656
 top four responses, 637
 trade-offs and synergies, 653–654
 vulnerable people, outcomes for, 642
 water-related outcomes, 643
 water security and, 558–559
Water availability, 16, 54, 559
Waterborne diseases*, 382, 462–463, 558, 582–583, 616, 1064, 1065
 adaptation options, 27, 295, 1107–1108, 1107

- Cross-Chapter Box (ILLNESS), 291–295
 key risks, 2426–2427, 2462, 2467
 observed changes, 50, 51, 292–293, 1064–1065, 2426–2427
 projected impacts, 17, 64, 1046, 1095, 2462
- Water cycle.** See Hydrological cycle*
- Water Funds,** 961
- Water insecurity,** 16, 558, 560–563
 population experiencing, 554, 558
 See also Water security
- Water management,** 74–75, 90, 2779
 adaptation, 74–75, 2439–2440, 2769
 sustainable water management, 75, 90, 1301–1302
- Water pollution,** 462, 939
- Water quality,** 205, 277–278, 457, 461–463, 582–583
 drinking water, 278, 558, 579, 582, 586, 616
 observed changes, 468, 558, 582–583
 projected changes, 61, 611–612
 water pollution in cities, 462, 939
- Water, Sanitation and Hygiene (WaSH),** 596–597, 616, 622, 627–628, 635, 640
 COVID-19 and, 628
- Water scarcity,** 11, 12, 46, 75, 555, 556, 560–563, 620, 765, 2464
 definitions of, 560
 human health and, 586–587
 observed impacts, 11, 12, 46, 49
 physical, 560
 populations experiencing, 49, 59, 555, 558, 561, 563, 620
 temperature and, 558
 in urban areas, 926
 Water Scarcity Index (WSI), 560
- Water security*,** 11, 49–50, 558–565, 560–563, 718, 2463–2464
 adaptation limits, 85
 centrality of, 557, 558–565
 definition of, 558
 enabling principles, 557, 654–659
 FAQs, 660, 666–667
 Global Water Security Index (GWSI), 562–563
 key risks, 2455, 2463–2464, 2503
 projected impacts, 61–62
 system transformations for, 654–659
 urban areas, 926
- Water stress,** 558
 Asia, 1459, 1485, 1515
 Small Islands, 623, 2046
- Water towers,** 1484, 2279–2280
- Water-use efficiency (WUE)*,** 568
- Water uses,** 50, 558
 agriculture, 50, 74–75, 613–614, 624–625, 664–666
 cultural uses, 565, 572, 594–596, 595–596, 619, 620, 2464
 food production, 50, 558
 handwashing (WaSH), 628
 irrigation, 16, 556, 613–614, 626–627, 806
 urban and peri-urban areas, 558
 wastewater management, 75, 586–587, 631, 655
- Waves,** 395, 463
 coastal systems, 395
 Small Islands, 2045–2046, 2055, 2056, 2070, 2078
 See also Storm surge
- Weather events, attribution of,** 152, 587
- Weather sensitivity, identification of,** 2423
- Weeds,** 57, 730, 1844
 Australasia, 1594, 1598, 1616, 1636, 1637
 Europe, 1844
- Well-being*,** 1041–1170
 about, 1044–1059
 climate change impacts on, 63, 1046
 definition of, 1049
 as evaluation metric, 163
 Indigenous Peoples, 1054–1058
 Indigenous Peoples' perspectives on, 1629
 measures of, 163
 observed impacts, 48, 1076–1077
 subjective, 1049
 See also Health and well-being; Mental health
- West Nile fever,** 51, 261, 1063, 1090, 1862, 1969, 2427
- Wetlands*,** 463, 592, 632
 coastal, 62, 421–424, 422, 423
 Global Wetland Outlook, 592
 restoration, 23, 465, 634–635
 sea level rise and, 62
 species range shifts, 423–424, 592
 urban, 309
- Whales,** 1947, 1952, 2332, 2336
- Wheat,** 584–585, 1716, 1844, 1956
 nutritional quality, 1046
 observed impacts, 728–729, 732
 projected yields, 736–737, 1352, 1492, 1848
- Wild foods,** 758–760, 761–763, 1353–1354, 2380
- Wildfires,** 20, 201, 202, 243–246, 247–248, 272, 280–281, 928
 adaptation/management, 289, 290, 310
 air pollution and diseases, 1045, 1054, 1071
 Amazonia, 244–245, 271–272, 1220–1221
 area burned, 11, 201, 202, 243–246, 247–248
 Asia, 1464, 1474, 1477, 1533
 attribution for, 1948
 Australasia, 589–590, 591, 1583, 1589, 1589–1590, 1594, 1599–1601
 cascading impacts, 83, 1600–1601
 Central and South America, 1704–1706, 1713–1715, 1718–1719, 1718
 Chile (mega-fires, 2017), 589, 591
 climate change and, 247–248
 compound risks, 67–68, 83
 costs (L&D), 245, 1583
 deforestation and, 201, 271–272
 displacement/migration and, 1085
 escalating impacts and risks, 1599–1601
 Europe, 272, 1835–1836, 1836
 extreme, 565
 FAQ, 247–248
 feedbacks, 275–276
 fire seasons, 201, 246, 250
 fire weather, 11, 62, 67, 1583, 1589, 1591, 1599–1600
 globally, 244
 indigenous responses, 1056–1057
 Mediterranean Region, 239, 245, 2235, 2237
 mental health effects, 1078
 mountain regions, 2281, 2284
 natural fire regimes, 310
 North America, 1948–1950, 1962, 1967, 1969
 observed changes, 11, 20–21, 201, 243–246, 281
 post-fire vegetation, 236, 2281
 projections, 22, 202, 271–272, 281, 1071, 1098
 regional changes, 244–246
 respiratory diseases and, 52
 risks, 50, 271–272, 280–281
 temperature and, 202, 272
 tropical forests, 2378, 2378
 water quality and, 582, 583
 See also Fires
- Wildlife**
 actions to protect, 222
 host-parasite combinations, 261
 human-wildlife interactions, 57, 1054, 1339, 1481
 wildlife diseases, 51–52, 200, 233–236, 261
- Win-win approaches,** 1240, 1528
- Wind,** 927
 wind speeds: Asia, 1465, 1471
 wind speeds: Australasia, 1589, 1590
- Wind power,** 461, 1246
- Wind towers,** 953
- Wind turbines,** 461
- Window of opportunity,** 31, 32–33, 35, 102–107, 204, 2543, 2556, 2597–2598, 2662
 for CRD and SDGs, 31, 32–33, 35, 102–107, 2662
 for emissions reductions, 32–33, 204, 2683, 2685, 2733
 in Europe, 1821
 rapidly narrowing, 31, 32–33, 35, 204, 2658
 for system transitions, 2658
- Wine,** 739, 1844
- Women.** See Gender
- Woody encroachment,** 47, 201, 238, 240, 275, 314
- Working Groups.** See IPCC Working Groups
- World Heritage Sites,** 1393
 Australasia, 300, 1595, 1625
 Mediterranean Region, 2235, 2248
- World Humanitarian Summit,** 919, 920
- Worldviews,** 31, 33, 108, 2711–2712, 2713
- ## Y
- Yap, livelihood strategies,** 1185–1186
- Youth**
 inclusion in solutions, 31
 innovation, 719, 820–821
- Youth-led social movements,** 911, 912, 946–947, 963, 2418, 2720–2721
- ## Z
- Zika,** 1063, 1093–1095, 1371, 1373, 1691, 1710
 in Europe, 1862, 1862
- Zoning,** 942–943
- Zoonoses (zoonotic diseases),** 13, 51–52, 57, 232–233, 233–235, 789–790
- Zooplankton,** 224, 429, 431, 451, 2329, 2330