Climate Change 2014: Impacts, Adaptation, and Vulnerability
TECHNICAL SUMMARY

Coordinating Lead Authors
Christopher Field (USA), Vicente Barros (Argentina), Katharine Mach (USA), Michael Mastrandrea (USA)

Lead Authors
Maarten van Aalst (Netherlands), Neil Adger (UK), Paulina Aldunce (Chile), Douglas Arent (USA), Jonathon Barnett (Australia), Richard Betts (UK), Eren Bilir (USA), Joern Birkmann (Germany), JoAnn Carmin (USA), Dave Chadee (Trinidad and Tobago), Andrew Challinor (UK), Monalisa Chatterjee (USA/India), Wolfgang Cramer (Germany), Yuka Estrada (USA/Japan), Jean-Pierre Gattuso (France), Yasuaki Hijioka (Japan), Ove Hoegh-Guldberg (Australia), He-Qing Huang (China), Gregory Insarov (Russian Federation), Roger Jones (Australia), Sari Kovats (UK), Patricia Romero Lankao (Mexico), Joan Nymand Larsen (Iceland), Iñigo Losada (Spain), Jose Marengo (Brazil), Roger McLean (Australia), Linda Mearns (USA), Reinhard Mechler (Austria), John Morton (UK), Isabelle Niang (Senegal), Taikan Oki (Japan), Jane Mukarugwiza Olwoch (South Africa), Maggie Opondo (Kenya), Elvira Poloczanska (Australia), Hans-O. Pörtner (Germany), Margaret Hiza Redsteer (USA), Andy Reisinger (New Zealand), Aromar Revi (India), Daniela Schmidt (UK), Rebecca Shaw (USA), William Solecki (USA), John Stone (Canada), Ken Strzepek (UNU/USA), Avelino Suarez (Cuba), Petra Tschakert (USA), Riccardo Valentini (Italy), Sebastian Vicuna (Chile), Alicia Villamizar (Venezuela), Katharine Vincent (South Africa), Rachel Warren (UK), Thomas Wilbanks (USA), Poh Poh Wong (Singapore), Gary Yohe (USA)

Review Editors
Paulina Aldunce (Chile), Jean Ometto (Brazil), Nirivololona Raholijao (Madagascar), Kazuya Yasuhara (Japan)

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INTRODUCTION

Climate change is shifting patterns of risks and opportunities in a complex and changing world. The Working Group II contribution to the IPCC's Fifth Assessment Report (AR5) acknowledges the complexity of climate change and of the world in which it is unfolding. It recognizes that impacts of climate change will vary across regions and populations, through space and time, dependent on myriad factors including the extent of mitigation and adaptation. It provides information on patterns of changing risks and on how they can be managed.

For the past two decades, Working Group II has developed assessments of climate change impacts, adaptation, and vulnerability. The Working Group II contribution to the IPCC's AR5 builds from the Fourth Assessment Report (AR4), published in 2007, and the Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX), published in 2012 (Box TS.1). Section A of this summary characterizes observed impacts, vulnerabilities, and responses to date. Section B, building from exposure, vulnerability, and physical hazards as determinants of risk, considers approaches for managing the risks of climate change. Section C examines the range of future risks across sectors and regions, highlighting where choices matter for reducing risks through mitigation and adaptation. Section D explores the broader interactions among mitigation, adaptation, and sustainable development.

Box TS.2 defines concepts central to the Working Group II contribution to the AR5. To accurately convey the degree of certainty in key findings, the report relies on the consistent use of calibrated uncertainty language, introduced in Box TS.3. Chapter sections in square brackets indicate the assessment supporting findings in this summary.

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Box TS.1. The Context of the Assessment

The literature available for assessing climate change impacts, adaptation, and vulnerability has more than doubled since 2005 (*very high confidence*). The diversity of the topics and regions covered by the literature has similarly expanded, as well as the geographic distribution of the authors contributing to the knowledge base for climate change assessments (Box TS.1 Figure 1). Production of climate change literature has increased in the developing countries, although their institutions lag those in developed countries regarding access to and production of climate change literature. The unequal distribution of literature, which is influenced by factors such as scientific funding and capacity building, presents a challenge to the development of a comprehensive and balanced assessment of the global impacts of climate change. [1.1.1, Fig. 1-1]

[INSERT BOX TS.1 FIGURE 1 HERE
Box TS.1 Figure 1: Results of English literature search using the Scopus bibliographic database from Reed Elsevier Publishers. (a) Annual global output of publications on climate change and related topics: impacts, adaptation, and costs (1970-2010). (b) Country affiliation of authors of climate change publications summed for IPCC regions for three time periods: 1981-1990, 1991-2000, and 2001-2010, with total number during the period 2001-2010. (c) Results of literature searches for climate change publications with individual countries mentioned in publication title, abstract, or key words, summed for all countries by geographic region. [Figure 1-1]]

The evolution of the IPCC assessments of impacts, adaptation, and vulnerability indicates an increasing emphasis on humans, their role in managing resources and natural systems, and the societal impacts of climate change (*very high confidence*). The expanded focus on societal impacts and responses is evident in the composition of the IPCC author teams, the literature assessed, and the content of the IPCC assessment reports. Three important characteristics in the evolution of the Working Group 2 assessment reports are an increasing attention to: (i) Adaptation limits and transformation in societal and natural systems; (ii) Synergies between multiple variables and factors that affect sustainable development, including risk management; and (iii) Institutional, social, cultural, and value-related issues. [1.1, 1.2]

Adaptation has emerged as a central area of work in climate change research, in country level planning, and in the implementation of climate change strategies (*high confidence*). The body of literature shows an increased focus on capitalizing upon adaptation opportunities and on the interrelations among adaptation, mitigation, and alternative sustainable pathways. In spite of the uncertainty of future impacts and adaptation, the literature shows an emergence of studies on transformative processes that take advantage of synergies between adaptation planning, development strategies, social protection, and disaster risk reduction and management. [1.1.4]

The treatment and communication of uncertainties in IPCC reports have evolved over time, reflecting iterative learning and more coherent guidance across all Working Groups (*high confidence*). An integral feature of IPCC reports is communicating the strength and uncertainties in the scientific understanding underlying assessment findings. In Working Group II, the use of calibrated language began in the Second Assessment Report, where most chapters used qualitative levels of confidence for their Executive Summary findings. Based on experience, guidance notes were developed for subsequent assessment reports. The AR5 Guidance Note continues to emphasize a theme from all three guidance documents to date: the importance of clearly linking each key finding and corresponding assignment of calibrated uncertainty language to associated chapter text, as part of the traceable account of the author team's evaluation of evidence and agreement supporting that finding (see Box TS.3). [1.1.2.2, Box 1-1]

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Box TS.2. Terms Critical for Understanding the Summary

Core concepts defined in the glossary and used throughout the report include:

Climate change: A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulation of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use. In contrast, the Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." The UNFCCC thus makes a distinction between climate change attributable to human activities that alter the atmospheric composition, and climate variability attributable to natural causes.

Exposure: The presence of people, livelihoods, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected.

Vulnerability: The propensity or predisposition to be adversely affected.

Impacts: Effects on natural and human systems. In this report, the term 'impacts' is used to refer to the effects on natural and human systems of physical events, of disasters, and of climate change.

Risk: The potential for consequences where something of human value (including humans themselves) is at stake and where the outcome is uncertain. Risk is often represented as probability of occurrence of a hazardous event(s) multiplied by the consequences if the event(s) occurs. This report assesses climate-related risks.

Adaptation: In human systems, the process of adjustment to actual or expected climate and its effects, which seeks to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate.

Incremental adaptation – Adaptation actions where the central aim is to maintain the essence and integrity of an incumbent system or process at a given scale.

Transformational adaptation – Adaptation that changes the fundamental attributes of a system in response to actual or expected climate and its effects.

Resilience: The ability of a social, ecological, or socio-ecological system and its components to anticipate, reduce, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner.

Transformation: A change in the fundamental attributes of a system, often based on altered paradigms, goals, or values. Transformations can occur in technological or biological systems, financial structures, and regulatory, legislative, or administrative regimes.

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Box TS.3. Communication of the Degree of Certainty in Assessment Findings

Based on the Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties, the Working Group II contribution to the Fifth Assessment Report relies on two metrics for communicating the degree of certainty in key findings:

- Confidence in the validity of a finding, based on the type, amount, quality, and consistency of evidence (e.g., mechanistic understanding, theory, data, models, expert judgment) and the degree of agreement. Confidence is expressed qualitatively.
- Quantified measures of uncertainty in a finding expressed probabilistically (based on statistical analysis of observations or model results, or expert judgment).

Each finding has its foundation in an author team's evaluation of associated evidence and agreement. The summary terms to describe available evidence are: *limited*, *medium*, or *robust*; and the degree of agreement: *low*, *medium*, or *high*. These terms are presented with some key findings. In many cases, author teams additionally evaluate their confidence about the validity of a finding, providing a synthesis of the evaluation of evidence and agreement. Levels of confidence include five qualifiers: *very low*, *low*, *medium*, *high*, and *very high*. Box TS.3 Figure 1 illustrates the flexible relationship between the summary terms for evidence and agreement and the confidence metric. For a given evidence and agreement statement, different confidence levels could be assigned, but increasing levels of evidence and degrees of agreement are correlated with increasing confidence.

[INSERT BOX TS.3 FIGURE 1 HERE
Box TS.3 Figure 1: Evidence and agreement statements and their relationship to confidence. The shading increasing towards the top right corner indicates increasing confidence. Generally, evidence is most robust when there are multiple, consistent independent lines of high-quality evidence. [Figure 1-4]]

When author teams evaluate the likelihood of some well-defined outcome having occurred or occurring in the future, a finding can include likelihood terms (see below) or a more precise presentation of probability. Use of likelihood is not an alternative to use of confidence: an author team will have a level of confidence about the validity of a probabilistic finding. Unless otherwise indicated, findings assigned a likelihood term are associated with *high* or *very high* confidence.

Term*	**Likelihood of the outcome**
Virtually certain	99–100% probability
Very likely	90–100% probability
Likely	66–100% probability
About as likely as not	33–66% probability
Unlikely	0–33% probability
Very unlikely	0–10% probability
Exceptionally unlikely	0–1% probability

* Additional terms used in limited circumstances are *extremely likely:* 95– 100% probability; *more likely than not:* >50–100% probability; and *extremely unlikely:* 0–5% probability.

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A) VULNERABILITIES, IMPACTS, AND ADAPTATION IN A COMPLEX AND CHANGING WORLD

This section presents observed effects of climate change, including detection and attribution of impacts on human and natural systems. It evaluates sensitivities to climate, factors determining vulnerability and exposure, and the role of non-climate stressors. It considers that the effects of climate variability, climate extremes, and climate change are determined through the interaction of vulnerability and exposure with physical hazards. The section also examines coping and adaptation responses to climate events and conditions to date. It identifies challenges and options based on adaptation experience, and it looks at what has motivated previous adaptation actions in the context of climate change and broader objectives.

A.i. Vulnerabilities and Observed Impacts across Sectors with Regional Examples

Impacts of recent observed climate change on physical, biological, and human systems have been detected on all continents and in most oceans (*high confidence*). This conclusion is strengthened by observations since the AR4 as well as through more extensive analyses of earlier observations. Most reported impacts of climate change are attributed to regional warming of the atmosphere and the ocean, with lower confidence in attribution of observed impacts to shifts in rainfall patterns. There is emerging evidence of impacts of ocean acidification. For many natural systems, new or stronger evidence for substantial and wide-ranging impacts of climate change exists, including the cryosphere, water resources, coastal systems, and ecosystems on land and in the ocean. For managed ecosystems and human systems, the effects of changing social and economic factors often dominate over any direct impact of climate change. Despite this, numerous impacts of climate change have been detected. See Table TS.1 for examples of observed impacts across regions. [18.3-18.6]

[INSERT TABLE TS.1 HERE
Table TS.1: Observed impacts attributed to climate change with *medium* (*) or *high* (**) confidence. Impacts for physical, biological, and human systems are characterized across eight major world regions. For each observed impact, confidence in detection is equal to or greater than confidence in attribution. [Table 18-6, 18-7, 18-8, 18-9]]

Confidence in attribution is assigned through assessment of the relative contribution to a system's behavior by all known drivers affecting the system's dynamics, using scientific methods and also involving an assessment of confidence in detection. Formal meta-analysis or aggregated assessments of many observations or studies can help to improve confidence. In most studies, the attribution of observed impacts and vulnerabilities is related to all changes in climate that represent deviations from historical means and/or historic variability. Only a smaller number of robust attribution studies link responses in physical and biological systems to *anthropogenic* climate change. Though evidence is improving, there is a persistent gap of knowledge regarding how large parts of the world are being affected by observed climate change. Research to improve the timeliness and knowledge about the detection and attribution is needed in particular for the risk of extreme events. [18.1, 18.2.1, Box 18-1, 18.7]

Factors determining vulnerability and exposure

Climatic and biophysical drivers interact with systemic non-climatic drivers of vulnerability and exposure to shape differential risks and impacts (*very high confidence*). Since AR4 the framing of adaptation has moved further from a focus on biophysical vulnerability to the wider social and economic drivers of vulnerability. Factors affecting vulnerability and exposure involve a complex mix of physical and socio-economic factors, including gender, age, health, social status and ethnicity, environmental degradation, technology gaps, conflict, and institutions, political systems, and governance structures. Uneven socio-economic development pathways at the national and global level create and perpetuate systemic vulnerabilities. This unevenness results from structural conditions of poverty, inequality, and marginalization, as well as differential levels of health and human security. See Box TS.4. [13.1, 14.1, 14.2, 19.6.1]

Vulnerability and exposure of communities or social-ecological systems to climatic hazards are dynamic and thus varying across temporal and spatial scales. Effective risk reduction and adaptation strategies consider these dynamics and the inter-linkages between socio-economic development pathways and the vulnerability and exposure of people. Changes in poverty or socio-economic status, race and ethnicity compositions, age structures, and governance have had a significant influence on the outcome of past crises associated with climatic hazards. [15.2.4, 19.6.1]

Understanding of future vulnerability of human and social-ecological systems to climate change remains limited due to incomplete consideration of socio-economic dimensions (*very high confidence*). Future vulnerability will depend on factors such as wealth and its distribution across society, patterns of aging, access to technology and information, labor force participation, societal values, and mechanisms and institutions to resolve conflicts (see also Box TS.4). These dimensions have received only limited attention and are rarely included in vulnerability assessments, and frameworks to integrate social and cultural dimensions of vulnerability with biophysical impacts and economic losses are lacking. [25.3, 25.4, 25.11]

Impacts from recent extreme climatic events show significant vulnerability of some ecosystems and many human systems to current climate variability (*very high confidence*). Impacts include the alteration of ecosystems, altered food production, damage to infrastructure and settlements, morbidity and mortality, and consequences for mental health and human well-being. These experiences are consistent with a significant adaptation deficit in developing and developed countries for some sectors and within some regions. See Table TS.2.

- Recent floods in Australia and New Zealand caused severe damage to infrastructure and settlements and 35 deaths in Queensland alone (2011); the Victorian heat wave (2009) increased heat-related morbidity and caused 374 excess deaths, and intense bushfires destroyed over 2,000 buildings and led to 173 deaths; widespread drought in south-east Australia (1997-2009) and many parts of New Zealand (2007-2009) resulted in economic losses (approximately A$7.4b in south-east Australia in 2002-03 and NZ$3.6b in direct and off-farm output in 2007-09) and mental health problems in some areas of Australia. [13.2.1, Table 25-1, 25.8.1, Box 25-5, Box 25-6, Box 25-8]
- The observed impacts of extreme weather events indicate the current vulnerability of Europe across multiple sectors. [Table 23-3]
- In North America, most economic sectors have been affected by and responded to extreme weather, including hurricanes, flooding, and intense rainfall (*high confidence*). Heat extremes currently result in increases in mortality and morbidity, with impacts that vary by age and socioeconomic factors (*very high confidence*). Coastal storm events periodically cause excess mortality and morbidity via a range of direct and indirect pathways in North America, particularly along the east coast of the US, and the gulf coast of both Mexico and the US (*high confidence*). Many infrastructural elements across North America are currently vulnerable to extreme weather events (*medium confidence*). Infrastructures, particularly in water resources and transportation, are in many cases deteriorating, and are thus more vulnerable to extremes than strengthened ones. Extreme events have caused significant damage to infrastructure in many parts of North America. [26.6, 26.7]
- Research to improve the timeliness and knowledge about detection and attribution is needed in particular for the risk of extreme events. [18.7]

[INSERT TABLE TS.2 HERE
Table TS.2: Illustrative selection of some recent extreme impact events for which the role of climate has been assessed in the literature. The table shows confidence assessments as to whether the associated meteorological events made a substantial contribution to the impact event, as well as confidence assessments of a contribution of anthropogenic emissions to the meteorological event. The assessment of confidence in the findings is not necessarily a conclusion of the listed literature but rather results from assessment of the literature. Assessment of the role of anthropogenic emissions in the impact event requires a multi-step evaluation. [Table 18-4]]

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Box TS.4. Multidimensional Vulnerability to Climate Change

People who are socially, economically, culturally, politically, or institutionally marginalized are typically most at risk from adverse impacts of climate change and climate change responses. However, such heightened vulnerability does not occur in isolation; rather, it is observed along intersecting and simultaneous axes of marginalization and privilege, including not only income and assets but also gender, class, race, ethnicity, age, and (dis)ability (Box TS.4

Figure 1). Other dimensions include resource access, location, legal systems, and voice. Understanding differential adaptive capacity for individuals, households, and communities requires attention to multidimensional inequality, deprivation, and power, as well as context-specific constellations in which certain dimensions drive differential vulnerability while others play a secondary role or are absent (e.g., class and gender in one case versus race, gender, and age in another case). Few studies depict the full spectrum of these differences and the ways in which they interact to shape resilience or vulnerability, and thus attribution remains a challenge. Since inequality is not just a consequence of climate change, but also a key cause and amplifier of its impacts, inequality-sensitive analyses are needed for effective and efficient adaptation.

[INSERT BOX TS.4 FIGURE 1 HERE

Box TS.4 Figure 1: Intersecting yet simultaneous and dynamic axes of privilege and marginalization, shaped by people's multiple identities and embedded in uneven power relations and development pathways. Together, they result in differential vulnerability to the same exposure to climate change and climate change responses. These intersecting dimensions ("intersectionality") illustrate systemic vulnerability and multidimensional deprivation that determine inequality and adaptive capacity while being transformed as a result of negative climate change impacts and risks as well as consequences of policy responses, often to the detriment of the poor and disadvantaged. [Figure 13-4]]

Example impacts and risks of climate change and climate change responses:

- Differential impacts on men and women arise from distinct roles in society, the way these roles are enhanced or constrained by other dimensions of privilege and marginalization, and the nature of response to hazards. [9.3.5, 13.2.1]
- Both male and female deaths are recorded after flooding, dependent on socio-economic disadvantage and culturally-imposed expectations to save lives. While women are generally more sensitive to heat stress, more male workers are reported to have died largely due to gender roles and responsibilities related to outdoor and indoor work [11.4.1, 13.2.1]
- Women often experience additional duties as laborers and caregivers as a result of weather events, climate, and extreme events, as well as responses (e.g., male outmigration), while facing more psychological and emotional distress, loss in food intake, and in some cases increasing incidences of domestic violence. [9.3.5, 9.4.1, 13.2.1]
- Privileged members of society can benefit from climate change impacts and response strategies, due to their flexibility in mobilizing and accessing resources and positions of power, often to the detriment of others. [13.2.1]
- Populations that presently experience high levels of ill-health are more seriously affected than those currently in relatively good health. [11.3]
- Children and the elderly are often at higher risk, due to narrow mobility, susceptibility to infectious diseases, reduced caloric intake, and social isolation. While adults and older children are more severely affected by some climate-sensitive vector borne diseases such as dengue, young children are more likely to die from or be severely compromised by diarrheal diseases. [11.5, 13.2.1]
- In most urban areas, low-income groups face larger climate change risks and impacts because of poor quality and insecure housing, inadequate infrastructure and lack of provision for health care, emergency services, and measures for disaster risk reduction. [8.1.4]
- Indigenous peoples' livelihoods and lifestyles, often dependent on natural resources, are highly sensitive to climate change and climate change policies, especially those that marginalize their knowledge and perspectives. [12.3]
- Pastoralists and artisanal fisher folk may be becoming more vulnerable to climate change, partly due to neglect, misunderstanding, or inappropriate policy toward them on the part of governments. [9.3.5]
- The ability of migrants to adapt to climate change may be declining in destination areas, particularly in urban centers in developing countries. One primary mechanism is the clustering of low income migrants in flood-prone and landslide-prone high density housing. [12.4.2]
- In areas where violent conflict has destabilized society and damaged natural and social capital people are particularly vulnerable to climate change. [12.5]
- One-dimensional narratives, particularly of women and other marginalized groups, deny agency and portray people's vulnerability as their intrinsic problem. [13.2.1]
- Disadvantaged groups without access to land and labor, including female-headed households, are disproportionately harmed by climate change response mechanisms (e.g., CDM, REDD+, large-scale land acquisition for biofuels, and planned agricultural adaptation projects). [9.3.5, 12.2, 12.5, 13.3.1]

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Freshwater resources

Glaciers worldwide continue to shrink (*very high confidence*). New glacier lakes have formed, and existing ones have changed. Seasonal ice in many lakes and rivers forms later and breaks up earlier. A major part of these changes can be attributed to climate change (*high confidence*). [3.2.3, 18.3.1.3, 18.5, Figure 18-3]

Widespread changes and degradation of permafrost of both high-latitude and high-elevation mountain regions have been observed over the past years and decade*s* *(high confidence).* The permafrost boundary has been moving polewards and to higher elevations, and the active layer thickness has increased at many sites (*medium confidence* in attribution to climate change). [18.3.1, 18.5]

Hydrological systems have changed in many regions due to changing rainfall or melting glaciers, affecting water resources, water quality, and sediment transport (*medium confidence*). In many river systems, the frequency of floods has been altered by climate change (*low* to *medium confidence*). The duration of droughts in some regions has been altered by climate change (*medium confidence*). In the last decades, warming has caused a shift towards earlier maximum spring discharge, decreased spring snowpack, and sometimes decreased magnitudes of snowmelt floods in regions with seasonal snow storage (*high confidence*, based on *high agreement*, *robust evidence*). Where more winter precipitation falls as rain than snow, winter low flows have increased significantly. Where the stream flow is lowest in summer, decreased snow storage has exacerbated summer low flows. [3.2.3, 18.3.1, 18.5]

Specific regional examples include the following. See also Table TS.1.

- In Asia, the Altai-Sayan, Pamir, and Tien Shan glaciers have lost on average 10% of their area and 15% of their ice volume since 1960. Rates of further glacier degradation depend mainly on increases in summer air temperature and changes in precipitation. [24.9.3]
- In North America, changes in climate trends include reductions in spring snowpack along with an earlier peak runoff over many areas (*very high confidence*). Attribution of observed changes to anthropogenic climate change has been established for some physical systems (e.g., snowpack). In most areas, impacts of climate variability such as floods, decreased water availability, and increased salinity of coastal water supplies, which are exacerbated by other anthropogenic drivers, are observed (*high confidence*). Water supply deficits are conducive to adaptive response, with many hard and soft approaches to adaptation currently available. [26.2, 26.3]
- In Central and South America, there have been changes in geophysical variables (cryosphere and runoff) that affect streamflow and ultimately water availability (*high confidence*). Since AR4, there is growing evidence that glaciers (both tropical and extratropical) are retreating and the cryosphere in the Andes is changing according to the warming trends. These changes affect streamflow availability in different seasons of the year. Robust trends are apparent, associated with changes in precipitation such as increasing runoff in the Southeastern South America region (La Plata basin), and decreasing runoff in the Central Andes (Chile, Argentina) and Central America. In contrast to these findings, no robust trend in streamflow in the Amazon Basin has been detected. [27.3.1]
- In the Arctic, the decline of summer sea-ice is occurring at a rate that exceeds most model projections (*high confidence*). In some regions of Antarctica, evidence of similarly rapid rates of change is emerging, particularly for ice shelves. There is some evidence, for example in the reduction of sea-ice extent in the Arctic and in the west Antarctic Peninsula, that the changes are non-linear and may be accelerating. [WGI AR5 Chapter 14]

Terrestrial and inland water systems

The magnitude of future climate change could approach that of many of the largest climatic changes observed in Earth history (*high confidence*). The planet's biota, carbon cycle, and associated feedbacks and services have responded to climate change in Earth history even when the rates of past global climate change were slower than implied by higher warming scenarios (e.g., RCP 8.5). However, the impacts of climate change on terrestrial and freshwater ecosystems must also be considered in the context of non-climatic influences, both naturally-occurring and directly driven by humans. [4.2.2]

Plant and animal species have moved their ranges, altered their abundance, and shifted their seasonal activities in response to climate change in the past, and they are doing so now in many regions (*high confidence*). The broad patterns of species and biome movement towards the poles and higher in altitude in response to a warming climate are well established for the distant (*very high confidence*) and recent past (*medium confidence*). Seasonal activity of species has responded to warming over the last several decades based on extensive ground and satellite-based measurements (*high confidence*). Species have already started to migrate out of protected areas and towards mountaintops over the last several decades due to a warming climate. Observations and models of the seasonal activities of species indicate that climate warming disrupts species life cycles and interactions between species, as well as altering ecosystem function. At local scales, observed and modeled species responses sometimes differ from qualitative predictions based on global scale indices of warming; this can often be explained by large variation in local scale climate response to global warming, changes in climate factors other than average temperature, non-climatic determinants of species distributions, interactions between climate and other simultaneous global change factors such as nitrogen deposition, and species interactions. No past climate changes are a precise analog to the current and projected climatic changes, so species responses inferred from the past only give indications, especially at the local scale. [4.2.2, 4.3.2, 4.3.3, 4.4.1, 18.3.2, 18.5]

There is *very low confidence* that observed species extinctions can be attributed to recent climate warming given the very low fraction of species for which global extinction has been ascribed to climate change and the tenuous nature of most attributions. However, in the specific case of Central American amphibians, there is *medium confidence* that recent warming has played a role in their extinctions. [4.3.2, 18.3.2, 18.5]

Increases in the frequency or intensity of ecosystem disturbances due to fires, pest outbreaks, wind-storms, and droughts have been detected in many parts of the world (*medium confidence*). Such changes beyond the range of historical natural variability will alter the structure, composition, and functioning of ecosystems (*high confidence*). These changes will often be manifested as relatively abrupt and spatially-patchy transitions following disturbances, rather than gradual and spatially-uniform shifts in location or abundance (*medium confidence*). There is evidence of an increase in tree mortality in many regions over the last decade, but there is *low confidence* in the detection of a global trend in increased mortality or in the attribution of such a global trend to climate change. In some regions, increased tree mortality is sufficiently intense and widespread as to result in forest dieback, which constitutes a major risk because of its large impacts on biodiversity, wood production, water quality, amenity, economic activity, and the climate itself. In detailed regional studies, particularly in western and boreal North America, observed tree mortality is detectable and can be attributed to the direct effects of high temperatures and drought, or to changes in the distribution and abundance of insect pests and pathogens related, in part, to warming (*high confidence*). [4.2.4, 4.3.2, 4.3.3, 4.3.4, Box 4-2, Box 4-3, Box 4-4, Figure 4-12]

Several major terrestrial ecosystems are undergoing broad-scale changes that can be characterized as early warnings for coming regime shifts, in part due to climate change. Climate change is a driver of widespread shrub encroachment in the Arctic tundra (*high confidence*) and of boreal forest tree mortality (*low confidence*). Observed recession and degradation of the Amazon forest cannot be attributed to climate change. [18.3.2, 18.5.6, 18.5.7]

Specific regional examples include the following. See also Table TS.1.

- In Europe, climate change has already affected the distribution and abundance of some animals and plant species in Europe (*high confidence*). Observed climate change is affecting a wide range of flora and fauna in Europe, including plant pests and diseases and the vectors of animal diseases (*medium confidence*). Observed climate warming has increased forest productivity in northern Europe (*medium confidence*) and fire incidence in southern Europe (*high confidence*). [23.4.1, 23.4.3, 23.4.4, Table 23-4, Table 23.6, 23.6.4]
- In North America, climate change is already affecting many ecosystems (*high confidence*). Forests are being affected by fire, drought, pests, and other climate-related stresses. [26.4]
- In Central and South America, land cover change is a key driver of environmental change with significant impacts that may increase potential negative impacts from climate change. Deforestation and land degradation are mainly attributed to increased extensive and intensive agriculture, both from traditional

export activities such as beef and soy production, but more recently from biomass for biofuel production. Agricultural expansion has affected fragile ecosystems such as the edges of the Amazon forest and the tropical Andes, increasing the vulnerability of communities to extreme climate events, particularly floods, landslides, and droughts. Even though deforestation rates in the Amazon have decreased substantially in the last eight years to a current value of 0.29%, the lowest for all forest biomes in Brazil, other regions like the Cerrado and the Chaco forests still present high levels of deforestation with rates as high as 1.33%. [27.2.2]

- In Central and South America, conversion of natural ecosystems is the main proximate cause of biodiversity and ecosystem loss, and in parallel is a driver of anthropogenic climate change. Plant species are rapidly declining in Central and South America; the highest percentage of rapidly declining amphibian species occurs also in Central and South America, with Brazil being among the countries with the most threatened species of birds, mammals, and freshwater fishes. However, the region has still large extensions of natural vegetation cover for which the Amazon is the main example. [27.3.2]
- **Climate change is impacting terrestrial and freshwater ecosystems in some areas of the Arctic and Antarctica.** This is due to ecological effects resulting from reductions in the duration and extent of ice cover and enhanced permafrost thaw (*very high confidence*) and through changes in the precipitation-evaporation balance (*medium confidence*). [28.2] The abundance and biomass of deciduous shrubs and grasses has increased substantially over large – but not all – parts of the Arctic tundra in recent years (*very high confidence*). It is *very likely* that most of this increase in biomass can be attributed to longer growing seasons and higher summer temperatures. The tree line has moved northwards and upwards in many, but not all, Arctic areas, and significant increases in tall shrubs have been observed in many places (*high confidence*). Other factors such as changes in herbivore grazing, anthropogenic disturbances, and changes in precipitation and the snow/water regime also influence the tree line and structural vegetation changes in the northern boreal forest. [28.2]

Coastal systems and low-lying areas

On-going warming and acidification of coastal waters have direct and indirect impacts on natural ecosystems (*very high confidence*). More than 70% of the world's coastlines have significantly warmed during the past 30 years. The increase in the acidity of seawater is much greater in some coastal areas than in the open ocean due to the combined effects of atmospheric CO_2 uptake and eutrophication. Both changes have wide-ranging consequences on coastal organisms and ecosystems, such as species survival and shifts, coral bleaching, and decreased rates of calcification. Reducing regional stressors represents an opportunity to strengthen the ecological resilience of these ecosystems, which may help them survive projected changes in ocean temperature and chemistry. See also Box TS.9. [5.3.4, 6.1.1, 6.2.2, 6.3.2, 6.5.2, 30.4, 30.5, Box CC-CR, CC-OA]

Due to the increased frequency of stress events arising from elevated sea temperatures, coral reefs have experienced increased mass bleaching and mortality (*very high confidence*). These events have contributed to the loss of reef building corals in many parts of the world since the early 1980s. [18.3.3, 18.3.4, Box 18-3, 18.5, Table 18-8, Box CC-CR]

Despite the known sensitivity of coastal systems to sea-level rise, local perturbations from regional variability in the ocean and human activities preclude the confident detection of sea level-related impacts attributable to climate change outside of the Arctic. [18.3.3]

Specific regional examples include the following. See also Table TS.1.

- In North America, coastal zones are being affected by multiple and often interacting climate stresses including higher temperatures, ocean acidification, coral reef bleaching, sea level rise, storm surges, and storms (*high confidence*). [26.4]
- In north-eastern Australia (since the late 1970s) and more recently in western Australia, high sea surface temperatures have repeatedly bleached coral reefs. [25.6.2]
- In Central and South America, coastal and marine ecosystems have been undergoing significant transformations that pose threats to fish stocks, corals, mangroves, places for recreation and tourism, and controls of pests and pathogens. Frequent coral bleaching events have been recently reported for the Mesoamerican Coral Reef. Some of the main drivers of mangrove loss are deforestation and land

conversion, agriculture, and shrimp ponds to an extent that the mangroves of the Atlantic and Pacific coasts of Central America are some of the most endangered on the planet. [27.3.3.1]
- Arctic sea ice has been shrinking in extent, thickness, and composition, with observed impacts on marine biology and the livelihoods of indigenous people (*medium* to *high confidence*). [18.3.1, 18.3.4, 18.4.7, 18.5.7]

Marine systems

Climate change is manifesting itself in the alteration of abiotic and biotic properties of the ocean (*high confidence*). The physical and chemical properties of the ocean have changed significantly over the past 60 years due to anthropogenic climate change, including properties such as circulation intensity, temperature, oxygen (O_2) and nutrient inventories, carbon dioxide, ocean pH, salinity, and light regime. Changes to ocean conditions have resulted in fundamental and extensive changes to organisms and ecosystems in the ocean. [6.1.1, 6.2.2, 6.3.2, 6.5.2, 18.3.3, 18.3.4, 30.4, 30.5, Box CC-CR, CC-OA]

Marine ecosystems have been and are being exposed to and affected by climate changes of different rates, magnitude, and duration (*very high confidence*). In Earth history, natural climate change at rates slower than today's anthropogenic change has led to significant ecosystem shifts (*high confidence*). The fossil record and present field and laboratory observations confirm key environmental drivers and responses of ocean ecosystems to climate change including migration, altered ecosystem composition, changes in abundance, and extinctions. [6.1.2, 6.3]

Understanding of physiology combined with field observations demonstrates that vulnerability of most organisms is defined by their specialization on specific, limited temperature ranges and accordingly by their thermal sensitivity (*high confidence*). See Figure TS.1. Temperature defines the geographical distribution of species and their responses to climate change (*medium confidence*). Temperature extremes act through losses in abundance and habitat (e.g., sea ice and coastal), local extinction, and latitudinal shifts (*very high confidence*). Vulnerability is greatest in polar animals and in species living close to their upper thermal limits, for example in the tropics (*medium confidence*). [6.2.2, 6.2.3, 6.2.4, 6.2.5. 6.3.2, 6.5.2]

Warming is causing shifts in the geographical distribution, abundance, and migration patterns of species, paralleled by a reduction in their body size and a shift in the timing of seasonal activities. This results in altered interactions between species including changes in competition and predator-prey dynamics (*high confidence*). Increased temperatures have significantly altered the phenology or timing of key life-history events such as plankton blooms, migratory patterns, and spawning in fish and invertebrates over recent decades (*medium confidence*). There are many observations of poleward shifts in the distribution and abundance of fishes and invertebrates and/or of their shifts to deeper and cooler waters. Poleward shifts of plankton have occurred up to 250 km per decade, up to 30 times faster than terrestrial species. See Figure TS.1. [6.2.2, 6.2.5, 6.3, 6.5, 30.4, 30.5]

The combination and often amplification of climate change drivers acting globally and additional human-induced local drivers, such as overfishing, pollution, and eutrophication exacerbating hypoxia, result in enhanced vulnerability of natural and human systems to climate related forcings presently and into the future (*high confidence*). Observations include the progressive redistribution of species, changes in species' abundance, and the reduction in marine biodiversity in sensitive regions and habitats, putting the sustained provision of ecosystem services and fisheries productivity at risk. Socio-economic vulnerability is high particularly in tropical developing countries, progressively increasing the risk of reduced food supply, income, and employment. Key uncertainties include the upscaling of climate change effects from organism to ecosystem level, the adaptive capacity of marine organisms and human societies to these impacts, the interactions with other human drivers, the sustenance of biogeochemical functions and productivity in the global ocean, and the effectiveness of climate mitigation and adaptation measures. [6.3.5, 6.4, 6.6]

[INSERT FIGURE TS.1 HERE
Figure TS.1: Thermal specialization of species, sensitive to ocean acidification and hypoxia (A, left) causes warming induced distribution shifts (A, right). An example (B) is the northward expansion of warm-temperate species in the Northeast Atlantic. Differential distribution change across functional groups (C) will be influenced by species-specific impacts of future ocean acidification across phyla (D). Detailed introduction of each panel follows:

A) Mechanisms linking organism to ecosystem response explain the why, how, when, and where of climate sensitivity (blue to red color gradients illustrate transition from cold to warm temperatures). As all biota, animals specialize on limited temperature ranges, within which they grow, behave, reproduce, and defend themselves by immune responses (left). Optimum temperatures (T_{opt}) indicate performance maxima, pejus temperatures (T_p) the limits to long-term tolerance, critical temperatures (T_c) the transition to anaerobic metabolism, and denaturation temperatures (T_d) the onset of cell damage. These thresholds can shift by acclimatization (horizontal arrows). Under elevated CO_2 levels and in hypoxic waters performance levels can decrease and windows of performance be narrowed (dashed green arrows pointing to dashed black curves). Shifts in biogeography result during climate warming (right). The polygon delineates the range in space and time, the level of grey denotes abundance. Species display maximum productivity in southern spring, wide seasonal coverage in the center, and a later productivity maximum in the North. The impact of photoperiod increases with latitude (dashed arrow). During warming, the southern temperature and time window contracts while the northern one dilates (directions and shifts indicated by arrows). Control by water column characteristics or photoperiod may overrule temperature control in some organisms (e.g., diatoms), causing contraction of spatial distribution in the north. B) Long-term changes in the mean number of warm-temperate pseudo-oceanic species in the Northeast Atlantic from 1958 to 2005. C) Rates of change in distribution (km $decade^{-1}$) for marine taxonomic groups, measured at the leading edges (red), and trailing edges (brown). Average distribution shifts calculated using all data, regardless of range location, are in black. Distribution rates have been square-root transformed; standard errors may be asymmetric as a result. Positive distribution changes are consistent with warming (into previously cooler waters, generally poleward). Means ± standard error are shown, with number of observations and significance (*$p<0.1$, **$p<0.05$, ***$p<0.01$). D) % fraction of studied scleractinian coral, echinoderm, molluscan, crustacean, and fish species affected negatively, positively, or not at all by various levels of ambient CO_2. Effects considered include those on life stages and processes reflecting physiological performance (O_2 consumption, aerobic scope, behaviors, scope for behaviors, calcification, growth, immune response, acid-base balance, gene expression, fertilization, sperm motility, developmental time, production of viable offspring, morphology). Horizontal bars above columns represent frequency distributions significantly different from controls. [Figures 6-7, 6-10, 6-11, and 30-11]]

Rising atmospheric CO_2 not only causes ocean warming but also changes in carbonate chemistry termed ocean acidification. Ocean acidification has ramifications for processes ranging from physiology and behavior to population dynamics (*medium* to *high confidence*). A wide range of sensitivities to projected acidification exists within and across organism phyla (Figure TS.1). Across organisms, sensitivity decreases with increasing capacity to compensate for the elevated internal CO_2 concentration or falling pH (*medium confidence*). Most plants including algae respond positively to elevated CO_2 levels by increasing photosynthesis and growth (*high confidence*). Limits to adaptational capacity remain unexplored. See also Box TS.9. [6.2.2, 6.2.3, 6.2.4, 6.2.5, 6.2.6, 6.3.4, Box CC-OA]

Field observations attributed to anthropogenic ocean acidification are few due to limited changes in water chemistry between preindustrial times and today. Shell thinning in planktonic foraminifera from various regions and Southern Ocean pteropoda has been attributed fully or in part to acidification trends (*medium confidence*). Coastward shifts in upwelling regimes of the Northeast-Pacific and upwelled CO_2-rich waters presently causing larval oyster fatalities in aquacultures (*high confidence*) or shifts from mussels to fleshy algae and barnacles (*medium confidence*) provide an early perspective on future effects of ocean acidification. Ecosystems at risk of ocean acidification are warm and cold water coral reefs (*high* or *medium confidence*). [6.1.2, 6.2.2, 6.2.5, 6.3.4]

Climate change has influenced ocean primary productivity, with positive consequences for some fisheries and negative ones for others (*medium confidence*). The catch potential of fisheries has increased in some regions and decreased in others with consequences for the food and livelihood of involved human communities (*high confidence*). Fisheries at high latitudes are showing increased productivity due to sea ice retreats and increases in net primary productivity. In other regions, stratification of the water column driven by warming has reduced net primary productivity of the ocean. [18.3.4, 18.4.1, 18.5.7]

The ongoing expansion of hypoxic regions termed Oxygen Minimum Zones or anoxic "dead" zones constrains the habitat of oxygen-dependent animals, plants, and microbes while it benefits anaerobic microbial life (*high confidence*). Warming-induced stratification, reduced intensity of ocean circulation, and the decomposition of organic matter by heterotrophic organisms create an expansion of these specialized, microbially dominated ecosystems. The removal of fixed nitrogen (denitrification) via the metabolism of selected bacteria and archaea can reduce nutrient inventories and alter the nitrogen-phosphorus balance. Hypoxia tolerance varies among species and is influenced by temperature, elevated CO_2, food consumption, and oxygen demand. [6.2.2, 6.2.3, 6.2.4, 6.2.5, 6.2.6, 6.3.3, 6.3.5, 18.3.4]

Specific regional examples include the following. See also Table TS.1.

- In Europe, observed warming has shifted the ranges of marine fishes to higher latitudes (*high confidence*) and reduced body size (*low confidence*). Observed higher water temperatures have adversely affected both wild and farmed freshwater salmon production (*high confidence*). [23.4.6]
- In the Northeastern Atlantic, High Latitude Spring Bloom systems are responding to rapid warming with the greatest changes being observed since the late 1970s in the phenology, distribution, and abundance of plankton assemblages and the reorganization of fish assemblages (*high agreement, medium evidence*). The abundance of boreal species has decreased along the southern fringe and increased along the northern fringe. However, substantial natural variability over the past 30 years has occurred in the entire Northeast Atlantic region as part of the Atlantic Multidecadal Oscillation. These changes have both positive and negative implications for the future of the fisheries within the High Latitude Spring Bloom systems. [6.3.2, 30.5.1, 30.8.3, WGI AR5 Chapter 14]
- The upper layers of the world's Semi-Enclosed Seas show significant warming since 1982, although this warming signal is strongly influenced by long-term variability (e.g., Atlantic Multidecadal Oscillation) (*medium confidence*). Further warming will *very likely* cause greater thermal stratification, reducing oxygen levels at depth and extending hypoxic zones, especially in the Baltic and Black Seas. These changes are *likely* to impact regional ecosystems and fisheries, tourism, and other human activities, although the understanding of the potential impacts is relatively undeveloped. [30.3, 30.5.6]
- An increased nutrient supply through intensified upwelling in some regions (through intensified upwelling) threatens deep sea ecosystems with hypoxia by increasing the rate of metabolism (and hence oxygen use) (*medium agreement, medium evidence*). Similarly, a decrease in primary productivity in some areas (e.g., subtropical gyres) may reduce the availability of organic carbon to deep sea ecosystems. These changes are *virtually certain* to increase due to the amplifying influence of rising deep water temperatures on microbial metabolism. [30.5.7, 6.1.1]

Food production systems and food security

The effects of climate change on food production are already evident in several regions of the world (*high agreement, medium evidence*). Negative impacts of climate trends have been more common than positive ones, although the latter predominate at high latitudes (*high confidence*). Yields have increased in some (mid to high latitude) regions, due to warming and higher CO_2 (*low confidence*), and decreased in other (mainly low latitude) regions due to water shortages and higher temperatures (*medium confidence*). Since AR4, there have been several periods of rapid food price increases, demonstrating the partial sensitivity of current markets to climate variability. These recent price changes cannot presently be attributed to climate change, due to the presence of other drivers. Social and economic issues such as energy policy and changes in household income will remain the main drivers of changes in food security in the near-term, regionally and locally. [7.2, Figures 7-2, 7-3, 7-4, Table 7-1, 18.4.1, Table 18-9]

There is new understanding since AR4 of the sensitivity of crops to extreme heat, which reinforces the importance of temperature changes for determining impacts of climate change on regional crop yields (*medium agreement, medium evidence*). Extreme heat also has a negative effect on food quality in terms of nutrition and processing (*high agreement, robust evidence*). Evidence since AR4 confirms the positive effects of CO_2 and negative effects of elevated tropospheric ozone on crop yields (*high confidence*). There is emerging experimental and modeling evidence that interactions among production factors such as CO_2 and ozone, mean temperature, extremes, water, and nitrogen can alter primary food production in complex ways (*high agreement, medium evidence*). [7.2, 7.3, 7.3.2, 7.4, Figures 7-2, 7-5, 7-6, and 7-7]

Specific regional examples include the following. See also Table TS.1.

- In Africa, livelihood-based approaches for managing risks to food production from multiple stressors, including rainfall variability, have increased substantially since 2007 (*high confidence*). Collaborative, participatory research including scientists and farmers, strengthened communication systems for

anticipating and responding to climate risks, and increased flexibility in livelihood options strengthen agricultural coping strategies for near-term climate variability and provide potential pathways for increasing capacities to adapt to climate change. [22.4.5, 22.4.6, 22.6.1]
- In Europe, yields of some arable crop species such as wheat have been negatively affected by observed warming in some countries since the 1980s (*medium confidence*). [23.4.1]
- Food security of many indigenous and rural residents in the Arctic is being impacted by climate change, for example affecting indigenous people's access to traditional foods that have provided sustenance, cultural, religious, economic, and community well-being for many generations (*high confidence*). [28.2.4, 28.2.7, 28.4.1]

Urban areas

Many urban areas have long been exposed to a range of hazards and disaster risks that could be exacerbated by climate change (*high confidence*). These include water shortages and droughts in urban regions, geo-hydrological hazards, inland and coastal flooding, windstorms and storm surges, high levels of air pollution, extremes in urban heat and cold and urban heat islands, and novel compound and slow onset hazards that impact ecosystem resilience. Reducing basic service deficits and building resilient infrastructure systems could significantly reduce global climate risk (*very high confidence*). [8.2, 8.3]

Around one billion people live in informal settlements in urban areas with inadequate or no provision for infrastructure and services that provides a foundation for adaptation (*high confidence*). Here, poverty and social inequality may be aggravated by climate change and the lack of adaptive capacity. The adaptive capacity of an urban center is much influenced by the quality and coverage of infrastructure (piped water supplies, sewers and drains, all-weather roads, and electricity provision) and services that include solid waste collection, policing, health care, emergency services, and measures to reduce disaster risk. The extent to which urban and higher levels of governments are able to mobilize resources and choose the most appropriate technical and institutional systems for service delivery influences adaptive capacity and deepens climate resilience. The rate and magnitude of urban development in some low- and middle-income countries also bring great challenges that many high-income nations do not have to deal with. [8.2, 8.3]

Specific regional examples include:
- In North America, several social and economic impacts observed in human settlements have been attributed, with different degrees of certainty, to climate-related processes (*high confidence*), including but not limited to sea-level rise, changes in temperature and precipitation, and occurrences of extreme events such as droughts and storms. Differences in the severity of climate impacts on human settlements are strongly influenced by context-specific social and environmental factors and processes, with some (e.g., the legacy of previous and current stresses) common to urban and rural settlements. In cities, concentrations of populations, economic activities, cultural amenities, and built environments in highly-exposed urban locations such as coastal and dry areas create higher hazard risks. For example, Mexico City is vulnerable due to the high density of population combined with several socio-economic and environmental sources of vulnerability. [26.8]

Rural areas

Rural areas still account for almost half the world's population and about 75% of the developing world's poor people. There is a lack of clear definition of what constitutes rural areas, and definitions that do exist depend on definitions of the urban. Across the world, the importance of peri-urban areas and new forms of rural-urban interactions are increasing. However, rural areas, seen as a dynamic spatial category, remain important for assessing the impacts of climate change and the prospects of adaptation. [9.1.1, 9.1.2, 9.1.3]

Cases in the literature of observed impacts on rural areas often suffer from methodological problems of attribution, with regard to the difficulties of attributing extreme events to climate change, the status of local knowledge, and the action of non-climate shocks and trends, but evidence for observed impacts, both of extreme events and other categories, is increasing (*medium confidence*). Impacts attributable to climate change include declining yields of major crops, extreme events such as droughts and storms, and geographically-specific impacts such as glacier melt in the Andes. [9.3.2]

Climate change in rural areas will take place in the context of many important economic, social, and land-use trends (*very high confidence*). In different regions, rural populations have peaked or will peak in the next few decades. The proportion of the rural population depending on agriculture is extremely varied across regions, but declining everywhere. Poverty rates in rural areas are falling more sharply than overall poverty rates, and proportions of the total poor accounted for by rural people are also falling: in both cases with the exception of sub-Saharan Africa, where these rates are rising. [9.3.1]

In developing countries, rural people are subject to multiple non-climate stressors, including under-investment in agriculture (though there are signs this is improving), problems with land policy, and processes of environmental degradation (*high* to *very high confidence*). Hunger and malnutrition remain prevalent among rural children in South Asia and Sub-Saharan Africa. In developing countries, the levels and distribution of rural poverty are affected in complex and interacting ways by processes of commercialization and diversification, food policies, and policies on land tenure. In industrialized countries, there are important shifts towards multiple uses of rural areas, especially leisure uses, and new rural policies based on the collaboration of multiple stakeholders, the targeting of multiple sectors, and a change from subsidy-based to investment-based policy. [9.3.1, Table 9-1]

Prevailing development constraints, such as low levels of educational attainment, environmental degradation, gender inequality, and remoteness from decisionmakers, create additional vulnerabilities to climate change (*high confidence*). There are low levels of agreement on some of the key factors associated with vulnerability or resilience in rural areas, including rainfed as opposed to irrigated agriculture, small-scale and family-managed farms, and integration into world markets. There is greater agreement on the importance for resilience of access to land and natural resources, flexible local institutions, and knowledge and information, and on the association of gender inequalities with vulnerability. Specific livelihood niches such as pastoralism and artisanal fisheries are vulnerable and at high risk of adverse impacts (*medium* to *high confidence*), partly due to neglect, misunderstanding, or inappropriate policy towards them on the part of governments. Lack of supportive policies in rural areas can reinforce existing vulnerability. [9.2, 9.3.5, 9.4.4]

Specific regional examples include:

- In North America, geographic isolation and institutional deficits are key sources of vulnerability for many small rural areas. [26.8]

Key economic sectors and services

Extreme climate events have impacted natural and physical livelihood assets, incomes, public health, and social institutions. For example, flooding can have major economic costs, both in term of impacts (capital destruction, disruption) and adaptation (construction, defensive investment). Economic losses due to extreme weather events have increased globally, mostly due to increase in wealth and exposure, but with a documented contribution of climate change and variability in some cases. [10.3.1, 10.7.3, 18.4.4, 18.4.7]

Climate change strongly affects insurance systems (*high agreement, robust evidence*). More frequent and/or intensive weather disasters increase losses and loss variability in various regions and challenge insurance systems to offer affordable coverage while raising more risk-based capital, particularly in low- and middle-income countries. Economic-vulnerability reduction through insurance has proven effective. [10.7]

Specific regional examples include the following. See also Tables TS.1 and TS.2.

- In Europe, direct economic river flood damages have increased over recent decades (*high confidence*), but this increase is due to development in flood zones and not observed climate change. Some areas show changes in river flood occurrence related to observed changes in extreme river discharge (*medium confidence*). [23.2.3, 23.3.1, SREX 4.5]
- In North America, slow-onset perils such as sea level rise, drought, and permafrost melt are an emerging concern for some economic sectors, with large regional variation in awareness (*medium confidence*). [26.7]

Human health

The health of human populations is sensitive to shifts in weather patterns and other aspects of climate change (*very high confidence*). These effects occur directly, due to changing incidence in temperature and humidity extremes and occurrence of floods, storms, droughts, and fires. Indirectly, health may be damaged by ecological disruptions brought on by climate change (crop failures, shifting patterns of disease vectors), or social responses to climate change (such as displacement of populations following prolonged drought). Variability is a risk factor in its own right – it is more difficult to protect human health in a highly variable climate than one that is more stable. There is emerging evidence of non-linearities in response (such as greater-than-expected mortality due to heat waves) as climates become more extreme. [11.3, 11.5]

In recent decades, climate change has contributed to levels of ill-health (*likely*) though the present world-wide burden of ill-health from climate change is relatively small compared with other stressors on health and is not well quantified. Changes in temperature, rainfall, and sea-level have altered distribution of some disease vectors, increased heat wave casualties, and reduced food production for vulnerable populations (*medium confidence*). Dengue fever and malaria have increased in several regions of the world over the past few decades, but there is *very low confidence* in attribution of these trends to climate change. Although new infections and other conditions may emerge under climate change (*low confidence*), the largest risks by far will apply in populations already most affected by climate-related diseases. [11.3, 11.4, 18.4.5]

In addition to their implications for climate change, essentially all the important climate altering pollutants aside from CO_2 have other health implications (*very high confidence*). In 2010, more than 7% of the global burden of disease was due to inhalation of these air pollutants (*high confidence*), accounting potentially for an economic impact of 1-2 US$ trillion, depending on the economic valuation method used (*low confidence*). [Box 11.4]

Specific regional examples include the following. See also Table TS.1.

- In Africa, climate change is a multiplier of existing vulnerabilities affecting health outcomes, including water and sanitation coverage, food security, and access to health care and education (*high confidence*). [22.3.5]
- In Europe, climate warming has adversely affected trends in ground level tropospheric ozone (*low confidence*). [23.6.1]
- In Central and South America, climate variability and climate change are negatively affecting human health, either by increasing morbidity, mortality, and disabilities (*very high confidence*), through the emergence of diseases in regions previously non-endemic, or through the re-emergence of diseases in areas where they have previously been eradicated or controlled (*high confidence*). Climate-related drivers have been recognized for respiratory and cardiovascular diseases, vector- and water-borne diseases (malaria, dengue, yellow fever, leishmaniasis, cholera, and other diarrheal diseases), Hantaviruses and Rotaviruses, pregnancy-related outcomes, diabetes, chronic kidney diseases, and psychological trauma. [27.3.7]

Human security

Mobility is a widely used and often effective strategy to maintain livelihoods in response to social and environmental changes (*high agreement, medium evidence*). There is *robust evidence* that migration and mobility are adaptation strategies to climate variability. People who lack the ability to move will face higher exposure to weather-related extremes in both rural and urban areas in the developing world. There is some evidence to suggest that expanding opportunities for mobility reduce vulnerability and enhance human security. Observations of implementation of planned resettlement show that legitimate and inclusive planning processes help alleviate the conflict and insecurity that individuals and communities may experience. [12.4.3]

Some of the factors that increase the risk of violent conflict including civil wars are sensitive to climate change (*medium agreement, medium evidence*). The evidence on the direct effect of climate change and variability on violence is contested. [12.5] Though there is little agreement about causality, there is *robust evidence* that shows that low per capita incomes, economic contraction, and inconsistent state institutions are associated with the incidence of civil wars. These factors are sensitive to climate change. Climate change policy responses, particularly those associated with changing property rights to land, water, and resources, can increase the risk of violent conflict. A range of policies and institutions at multiple scales has been demonstrated to reduce the effects of environmental change on the risk of violent conflict. Economic growth, high per capita incomes, strong democratic institutions, social protection during economic and climate shocks, and robust institutional structures that protect property rights and manage conflict all reduce the risk that climate variability and extremes will lead to violence. [12.5]

Challenges for vulnerability reduction and adaptation are particularly high in regions that have shown severe difficulties in governance (*high confidence*). People living in places affected by violent conflict are particularly vulnerable to climate change (*high agreement, limited evidence*). Large-scale violent conflict harms infrastructure, institutions, natural capital, social capital, and livelihood opportunities. Since these assets facilitate adaptation to climate change, there are strong grounds to infer that conflict drives vulnerability to climate change impacts. [12.5.2, 19.6.1]

Currently many indigenous peoples are politically and economically marginalized and live in regions or depend on natural resources that are highly sensitive to climate changes (*high agreement, robust evidence*). Indigenous peoples have adapted to highly variable and changing social and ecological conditions. The current rate and magnitude of change will increasingly constrain the efficacy of indigenous and traditional knowledge in adaptive responses. [12.3]

Specific regional examples include the following. See also Table TS.1.

- In Europe, climate change has already affected cultural heritage (*low confidence*). [23.5.4, Table 23.6]
- In both Australia and New Zealand, indigenous peoples have higher than average exposure to climate change due to a heavy reliance on climate-sensitive primary industries and strong income and social connections to the natural environment, and face particular constraints to adaptation (*medium confidence*). Social status and representation, health, infrastructure and economic issues, and engagement with natural resource industries constrain adaptation and are only partly offset by intrinsic adaptive capacity (*high confidence*). Some proposed responses to climate change may provide economic opportunities, particularly in New Zealand related to forestry. Torres Strait communities are vulnerable even to small sea level rises (*high confidence*). [25.3, 25.8.2]
- For North America, indigenous peoples are vulnerable, due to their unique history and relationship to the land (*high confidence*). [26.8]
- Climate impacts on Arctic indigenous groups have been detected and attributed to climate change. These include changes in seasonal migration and hunting patterns, health, and cultural identity (*medium confidence*). [18.4.7, Box 18-5, 18.5.7, Table 18-9]

Livelihoods and poverty

Climate change constitutes an additional burden to the rural and urban poor. It acts as a threat multiplier, often with negative outcomes for livelihoods (*very high confidence,* based on *high agreement, robust evidence*). Weather events and climate, ranging from subtle shifts in trends to extreme events, affect poor people's lives directly through impacts on livelihood assets, such as losses in crop yields, destroyed homes, food insecurity, and loss of sense of place, and indirectly through increased food prices and climate policies. Changing climate trends provoke shifts in rural livelihoods such as from crop-based to mixed livestock- and forest-based livelihoods or to wage-based labor in agricultural and urban employment. Urban and rural transient poor who face multiple deprivations slide into chronic poverty as a result of weather events or extreme events, or a series of events, when they are unable to rebuild their eroded assets (*high agreement, limited evidence*). Many weather events that affect poor people remain unrecognized, such as short periods of extreme temperature or minor changes in the distribution of rainfall, due to short time series and geographically sparse, aggregated, or partial data, inhibiting detection and attribution in many low-income countries. [13.2.1, 13.3]

Climate change worsens existing poverty, exacerbates inequalities, and triggers new vulnerabilities and some opportunities. Poor people are poor for different reasons and thus are not all equally affected, and not all vulnerable people are poor. Climate change interacts with non-climatic stressors and entrenched structural inequalities to shape vulnerabilities (*very high confidence,* based on *high agreement, robust evidence*). Socially and geographically marginalized people exposed to persistent inequalities at the intersection of gender, age, race, class, caste, indigeneity, and (dis)ability are particularly negatively affected by weather events and climate (see Box TS.4). Context-specific conditions of marginalization shape differential vulnerability. Preexisting gender inequalities are increased or highlighted by weather events and climate. Gendered impacts depend on customary and new roles in society, often entailing higher workloads, occupational hazards indoors and outdoors, psychological and emotional distress, and mortality in climate-induced disasters. Very scarce evidence exists that demonstrates positive impacts of climate change on the poor, including flood preparedness, collective action, institutional change, and social asset accumulation. Often, the more affluent can better take advantage of shocks and crises, given their flexible assets and power status. [13.1.2, 13.1.3, 13.2.1]

Despite known vulnerabilities and increasing exposure to climatic stressors, impacts of climate change on human livelihoods have rarely been detected with confidence. Such detection is complicated by the effects of other economic and social factors. There is emerging literature on the impact of climate on poverty, working conditions, violent conflict, migration, and economic growth, but evidence for detection or attribution remains *limited*. [18.4.3, 18.4.6, 18.4.7]

Information needs and methods

Significant improvements have been made in the amount and quality of climate data available for establishing baseline reference states of climate-sensitive systems. These include new and improved observational datasets, rescue and digitization of historical datasets, and a range of improved global reconstructions of weather sequences. The uncertainties inherent in climate model projections of regional climate changes have not decreased from AR4; in some cases, the addition of regional forcings (e.g., topography) have increased some uncertainties. [21.3.3, 21.5.3]

Specific regional examples include:

- **In Asia, there are regions that are not sufficiently represented in studies of observed climate change, in particular Central and West Asia.** Numerical data on trends in precipitation are hard to find compared to trends in temperature. Furthermore, research data on changes in extreme climate events do not cover most Asian regions. Studies of both observed and projected impacts on biodiversity, boreal forest dynamics, CO_2 fertilization of crops and plants, and urban settlements are limited. More trans-disciplinary research is needed on direct and indirect health effects from climate change impacts on air and water quality and water quantity in different parts of Asia. The vulnerability, impacts, and adaptation of aggregated household welfare, livelihoods, and poverty need to be adequately studied. [24.8]

A.ii. Adaptation Experience

Human and natural systems respond to climate and its effects. Natural systems have some potential to adapt, and are adapting, through ecological and evolutionary processes, and humans may intervene to promote particular adjustments. Responses in human systems include coping with climate variability and extremes and managing risks through planned adaptation to climate change impacts. Adaptation can be motivated by broader vulnerability-reduction and development objectives, such as reducing existing adaptation deficits to current climate. [14.1]

Adaptation activity is increasing and becoming more integrated within wider policy frameworks (*high confidence*). Adaptation planning is transitioning from a phase of awareness and promotion to the construction of concrete responses in societies (*high agreement, robust evidence*). National-level plans and adaptation strategies for developed countries are mentioned in the literature more than for developing countries, whereas more implementation cases are documented at the local level in developing countries. [14.3.4, 14.4.2, 15.2, 15.3.1]

The social dimensions of adaptation have attracted more attention, including the relationship between adaptation, development, and disaster risk management (*high agreement, robust evidence*). Attention to climate change impacts and disaster risk management, which are key elements of adaptation planning, appears to have a more prominent role in developed countries. Risk reduction, especially for developed countries, has been planned by a top-down approach including engineered infrastructure-based solutions such as dikes to prevent flooding and coastal inundation and dams to improve water supplies. In contrast, there is a trend to link adaptation planning to development needs and stresses in developing countries. Strategies adopted in developing countries, e.g., those in NAPAs, are almost identical with standard development projects. [15.2, 15.3.1]

Adaptation assessments continue to evolve, and most include both top-down assessments of biophysical climate change risks and bottom-up assessments of what makes people vulnerable to those risks (*high confidence*). Most of the assessments of adaptation done so far have been restricted to impacts, vulnerability, and adaptation planning, with very few assessing the processes of implementation and evaluation of actual adaptation actions. The numerous assessments have led to a general awareness among decisionmakers and stakeholders of climate risks and adaptation needs and options, but this is often not translated into the implementation of even simple adaptation measures within ongoing activities or risk management planning. To overcome this "adaptation bottleneck," assessments may need to be linked more directly to particular decisions and the information tailored to facilitate the decision making process. [14.5.3, 14.5.4]

Evaluation of adaptation effectiveness is still in its infancy (*high confidence*). The demand for metrics to measure adaptation needs and effectiveness is increasing as more resources are directed to adaptation. But the search for metrics for adaptation will remain contentious with multiple alternatives competing for attention as governments, institutions, communities, and individuals value needs and outcomes differently and many of those values cannot be captured in a comparable way by metrics. These indicators need to track not just process and implementation, but also the extent to which targeted changes are occurring. [14.6.2, 14.6.3, 14.6.4]

A variety of tools are being employed in adaptation planning and implementation depending on social and management context (*high agreement, robust evidence*). Multidisciplinary efforts have been engaged to develop, assess, and communicate climate information and risk assessments across timescales. These efforts use a mixed portfolio of products from simple agroclimate calendars to computerized decision-support tools. Monitoring and early warning systems play an important role in helping to adjust adaptation implementation, especially on the local scale. [15.2.4]

The national level plays a key role in adaptation planning and implementation, while adaptation responses have diverse processes and outcomes at national, subnational, and local levels (*high agreement, robust evidence*). National governments assume a coordinating role of adaptation actions in subnational and local levels of government, including the provision of information and policy frameworks, creating legal frameworks, actions to protect vulnerable groups, and financial support to other levels of government. The number of adaptation responses has increased at the local level in developed and developing countries. However, there is a common trend that local governments are hindered by the absence of applicable guides to adaptation decision-making. Local councils and planners are often confronted by the complexity of adaptation, and even when information is available, they are left with a portfolio of options to prepare for future climatic changes and the potential unanticipated consequences of their decisions. Therefore, linkages with national and subnational levels of government, as well as the collaboration and participation of a broad range of stakeholders, are important. [15.2.2]

The diversity of adaptation experience, including corresponding constraints and opportunities, can be seen in specific geographic contexts:

- **The scale and concentration of urban climate risk and hence the imperative for adaptation are being acknowledged, but responses are weak except for a handful of cities largely in high-income countries (*medium confidence*, based on *high agreement, medium evidence*).** City governments are slowly learning from adaptation implementation experience. Most current adaptation action focuses on low-cost interventions such as infrastructure and asset-creation as a co-benefit of existing development interventions. Examples of adaptation actions have often included the designation of a unit within city government with responsibility for adaptation, measures to involve key sectors so they understand why they need to engage with adaptation, the importance of local champions to initiate measures and ensure continuity, and the importance of dialogue and discussion with all key stakeholders. [8.3, 8.4, 8.5]
- **There is also recognition of the need to review building codes, infrastructure standards, and land-use management thereby developing scalable approaches to local adaptation planning (*medium confidence*, based on *high agreement, medium evidence*).** The weak emphasis on human, institutional, and ecological adaptation with long-term resilience building potential is a matter of concern. [8.3, 8.4, 8.5]

- **City-based disaster risk reduction is a strong foundation around which to build urban climate resilience (*high confidence*, based on *high agreement*, *medium evidence*).** The capacity to integrate climate risk, disaster risk reduction, and urban infrastructure and planning is being slowly built in some parts of the world. Locally-relevant adaptation plans, data, and feedback mechanisms are important for building urban resilience (*high agreement, medium evidence*). Improved feedback, monitoring, and reporting capacity supported by new generation risk screening, vulnerability mapping, and integrated urban climate assessment tools are helping catalyze social-learning to help mainstreaming. [8.2, 8.3, 8.4]
- **There is a growing body of literature on successful adaptation in rural areas, including documentation of practical experience (*high confidence*).** Gender, the supply of information for decision-making, and the role of social capital in building resilience are all key issues. Constraints to adaptation come from lack of access to credit, land, water, technology, markets, and information, and constraints are particularly pronounced in developing countries. [9.4.1, 9.4.3, 9.4.4]
- **In all regions of Africa, national governments are initiating governance systems for adaptation and responding to climate change (*high agreement, medium evidence*).** While a wide range of adaptation options, approaches, and decision tools are being tested and implemented at different scales across Africa, these have not yet been taken to a scale that would address the complex vulnerabilities and needs identified. Institutional frameworks cannot yet effectively coordinate the range of adaptation initiatives being implemented, resulting in a largely ad hoc and project-level approach, which is often donor-driven and may not result in local or national ownership (*medium agreement, medium evidence*). Efforts such as disaster risk reduction, social protection, adaptation technologies, climate-resilient infrastructure, ecosystem restoration, and livelihood diversification are reducing vulnerability and enhancing resilience, but this is still largely confined to local scales and isolated initiatives (*high agreement, medium evidence*). Institutional capacities and governance mechanisms need to be strengthened with respect to the ability of national governments and scientific institutions in Africa to absorb and effectively manage funds allocated for adaptation (*medium confidence*). [22.4.4, 22.4.5, 22.6.2]
- **In Europe, adaptation policy has been developed at international (EU), national, and local government level, but so far evidence relates to studies of the prioritization of options, and there is limited systematic information on current implementation (or effectiveness).** Some adaptation planning has been integrated into coastal and water management, as well as disaster risk management. There is little evidence of adaptation planning in rural development or land-use planning. Conservation policies and selection of protected areas have not considered so far impact of climate changes. [23.6.4, 23.7, Box 23-2]
- **In Australasia, adaptation is already occurring and adaptation planning is becoming embedded in planning processes, albeit mostly at the conceptual rather than implementation level (*high agreement, robust evidence*).** Many solutions for reducing energy and water consumption in urban areas with co-benefits for climate change adaptation (e.g., greening cities and recycling water) are already being implemented. Planning for sea-level rise and, in Australia, for reduced water availability is becoming widely adopted, although implementation of specific policies remains piecemeal, subject to political changes, and open to legal challenges. Adaptive capacity is generally high in many human systems, but implementation faces major constraints especially for transformative responses at local and community levels (*high confidence*). Constraints on implementation arise from: uncertainty of projected impacts; limited financial and human resources to develop and implement effective policies and rules; limited integration of different levels of governance; lack of binding guidance on principles and priorities; different values and beliefs relating to the existence of climate change and to objects and places at risk; and attitudes towards risk. [25.4, 25.10.3, Boxes 25-1, 25-2, and 25-9]
- **In North America, while different tiers of government are assessing their climate vulnerabilities and designing adaptation actions and programs, there has been more leadership in adaptation planning at the local level (*high confidence*).** Many governmental responses are in the diagnosis and planning stage and have not yet moved into implementation. Important barriers exist to effective adaptation such as path dependency, lack of assets and options, lack of funding and staff, lack of horizontal and vertical coordination, asymmetries in access to information, lack of social capital, and top-down decision making. There are few examples of proactive adaptation anticipating future climate impacts, and these are largely found in sectors with longer-term decision-making, including energy and public infrastructure. [26.7, 26.8, 26.9]

- **In the Arctic, indigenous people have a high adaptive capacity and have begun to develop novel solutions to adapt to climate changes combining traditional and scientific knowledge and co-producing climate studies with scientific partners.** [28.2.4, 28.2.7, 28.4.1]
- **Since AR4, the analysis and implementation of coastal adaptation has progressed significantly, but much more effort is needed for a transition towards climate resilient and sustainable coasts (*very high confidence*).** The analysis of adaptation has progressed towards novel approaches such as robust decision making and adaptation pathways that recognize that deep uncertainty in projections of drivers does not have to be a barrier to adaptation (*high confidence*). Adaptation analysis and implementation have also progressed towards considering the institutional context and governance of adaptation, albeit many governance challenges related to vertical and horizontal policy integration, political will, and power relations remain (*very high confidence*). Many countries, states/provinces, cities, and communities are now carrying out adaptation activities including the mainstreaming of coastal adaptation into relevant strategies and management plans. [5.5.2, 5.5.4]

Adaptation actions and approaches to reducing vulnerability and enhancing resilience can be influenced by climate variability, extremes, and change, and by exposure and vulnerability at the scale of risk management (see Table TS.3).

[INSERT TABLE TS.3 HERE
Table TS.3: Illustrative examples of adaptation experience, as well as approaches to reduce vulnerability and enhance resilience. Adaptation actions can be influenced by climate variability, extremes, and change, and by exposure and vulnerability at the scale of risk management. Many examples and case studies demonstrate complexity at the level of communities or specific regions within a country. It is at this spatial scale that complex interactions between vulnerabilities, inequalities, and climate change come to the fore. At the same time, place-based examples illustrate how larger-level drivers and stressors shape differential risks and livelihood trajectories, often mediated by institutions.]

B) DECISIONMAKING IN A COMPLEX WORLD: UNDERSTANDING APPROACHES TO MANAGING RISKS THROUGH ADAPTATION

Managing the risks of climate change involves decisions with implications for future society, economies, environment, and climate. Some risks will emerge in the next few decades before substantial mitigation benefits can emerge, an era of climate responsibility. Other risks will emerge over a longer-term era of climate options; these risks vary across alternative climate change and development futures and depend on mitigation choices. The state of the future world cannot be known or projected with certainty (see Box TS.5), but robust decisions can be effective across a range of possible futures, especially if they build on existing knowledge. Fundamentally, responding to climate change can be considered an iterative process with continuing learning about risks and the effectiveness of risk management actions. Societies may need to transform in response to limits, for example by shifting goals or paradigms.

B.i. Determinants of risk

All decisions involving uncertainty and valued outcomes are risk assessments. Risk in the context of climate change is produced through the interaction of changing physical characteristics of the climate system with evolving characteristics of human, socioeconomic, and biological systems (exposure and vulnerability). See Figure TS.2. Alternative development paths influence risk both by changing the likelihood of physical impacts (through their effects on greenhouse gas emissions) and by altering vulnerability and exposure. [2.1.1, 19.1, 19.2, 19.2.4, Fig.19-1]

[INSERT FIGURE TS.2 HERE
Figure TS.2: Schematic of the interaction among the physical climate system, exposure, and vulnerability producing risk. Risks are a product of a complex interaction between physical hazards associated with climate change and climate variability on the one hand, and the vulnerability of a society or a social-ecological system and its exposure to climate-related hazards on the other. The definition and use of "key" and "emergent" are indicated in Section C.ii. Vulnerability and exposure are, as the figure shows, largely the result of socio-economic development pathways and societal conditions. Changes in both the climate system (left side) and development processes (right side) are key drivers of the different core components (vulnerability, exposure, and physical hazards) that constitute risk. [19.1, Figure 19-1]]

B.ii. Principles for Effective Adaptation

Experience in the practice of adaptation serves to clarify the opportunities for, and the most significant barriers to, adaptation and the synergies and tradeoffs with other societal goals.

Among the many actors and roles associated with adaptation, those associated with local governance and with the private sector are increasingly recognized as critical to progress (*high confidence*). These two groups will bear the main responsibility for translating the top-down flow of risk information and financing, and for scaling up the efforts of communities and households in identifying and implementing their selected adaptation actions. Local institutions, including local governments, NGOs, and civil society organizations, are often limited by lack of resources and capacity. Private entities, from individual farmers and small to medium enterprises (SMEs) to large corporations, will seek to protect their production systems, supply lines, and markets, by pursuing adaptation-related opportunities. These goals will help expand adaptation activities, but they may not align with government or community priorities without coordination and incentives. [14.4.2, 14.4.3, 14.4.8]

In the presence of limited resources and a range of goals, adaptation implies trade-offs between alternative policy goals (*high confidence*). Economics provides important inputs to the evaluation and ranking of adaptation options in the face of uncertainty. Approximate approaches are often necessary because of the lack of data or because of uncertainties about the nature of climate change or the efficacy of adaptation actions. A range of economic tools helps to address these uncertainties and helps design policies that are acceptable with a range of preferences and robust to existing uncertainties. There are methodologies that are able to capture non-monetary effects and distributional impacts, and to reflect ethical considerations. The resulting ranking depends on the "value system," i.e. on the weights attributed to different objectives. [17.2.6, 17.3, 17.5.4]

A range of factors constrains the planning and implementation of adaptation actions and potentially reduces their effectiveness (*high agreement, robust evidence*). The availability of resources for adaptation continues to feature strongly in the adaptation literature as a significant constraint on adaptation, as does uncertainty regarding future climate and disaster risk at national and regional scales. However, there is increasing awareness within the literature of the dynamics of social processes and governance that mediate the entitlements of actors to resources and promote social learning regarding adaptation. The manner in which these constraints manifest and their implications for the capacity of an actor to achieve adaptation objectives vary significantly across different regions and sectors as well as across different social and temporal scales. Some constraints to adaptation are a consequence of inherent trade-offs among different perceptions of risk and the allocation of finite resources, and therefore, adaptation efficiency and effectiveness may often be less than optimal. See Figure TS.3. Climate change policy at regional scales is constrained by the dual challenge in achieving integration at multiple administrative scales from global through national to local (multi-level governance), and across different sectors (policy coherence). The scales at which political decisions about climate change need to be made are frequently at odds with the definitions of regions. Climate change transcends political boundaries and is highly variable from region to region in terms of impacts and vulnerability. Likewise adaptation policies, options, and mitigation strategies are strongly region dependent and tied to local and regional development issues. [16.2, 16.3, 21.3]

[INSERT FIGURE TS.3 HERE
Figure TS.3: Key adaptation constraints assessed, categorized into two groups. One group reflects constantly evolving biophysical and socio-economic processes that influence the societal context for adaptation. These processes subsequently influence the second group of constraints affecting the implementation of specific adaptation policies and measures that could be deployed to achieve a particular objective. [Figure 16-2]]

Maladaptation is a cause of increasing concern to adaptation planners, where intervention in one location or sector could increase the vulnerability of another location or sector, or increase the vulnerability of the target group to future climate change (*medium confidence*). Such maladaptation can result from decisions where greater emphasis is placed on short-term outcomes ahead of longer-term threats, or from decisions that discount, or fail to consider, the full range of interactions arising from planned actions. [14.7.1, 14.7.2]

Cities are complex inter-dependent systems with potential synergies that could be leveraged to support adaptation (*high agreement, limited evidence*). Urban enterprises developed within globalized systems of production depend on reliable supply chains that may face particular difficulties. There are potential urban agglomeration economies around cost-effective adaptation and resilience building via improved built and ecological infrastructure and services and bringing together people, communities, and institutions to respond collectively (*medium confidence*, based on *medium agreement, limited evidence*). Thus, raising urban adaptive capacity requires effective multi-level governance with institutions that facilitate coordination across multiple, nested, and poly-centric authorities and have the capacity to mainstream adaptation measures. This is yet to be built in most parts of the world. [8.3, 8.4, 8.5]

Building human and institutional capacity for urban climate resilience will accelerate implementation and improve outcomes (*high confidence*). A binding constraint to effective and timely urban adaptation and building resilience is effective institutions and leadership across government, communities, civil society, knowledge institutions, and the media. There is evidence of expanding urban adaptation leadership, but building a wide support base for adaptation across many sectors, in and outside of government, to de-risk the impact of slow institutional development and leadership change is an important priority. This can be addressed by a number of structural interventions to enable city-wide alliances and frameworks to be built, institutionalization of processes, building a culture of exchange between learning organizations, and a strong emphasis on capacity building. Networking and sharing experiences among adaptation practitioners and between cities is also an important vehicle to improve city-level outcomes. [8.4, 8.5]

B.iii. Approaches for Managing Risks and Building Resilience in a Complex and Changing World

The report assesses a wide variety of approaches for managing risks and building resilience. Mitigation is assessed in WGIII AR5. Strategies and approaches to climate change adaptation include efforts to decrease vulnerability or exposure and/or increase resilience or adaptive capacity. Types of responses are given in Table TS.4.

[INSERT TABLE TS.4 HERE
Table TS.4: Entry points, strategies, measures, and options for managing the risks of climate change. These approaches should be considered overlapping rather than discrete, and they are often pursued simultaneously. Examples given can be relevant to more than one category.]

Low-regrets actions to increase resilience

Strategies and actions can be pursued now that increase climate resilience while at the same time helping to improve human livelihoods, social and economic well-being, and responsible environmental management (*high confidence*). Adaptation actions can provide significant co-benefits such as alleviating poverty and enhancing development especially in developing countries. Climate change adaptation efforts can improve ecosystem resilience by implementing sustainable forestry quotas, expanding floodplain setbacks, implementing coastal afforestation and coral reef propagation, restoring degraded lands, maintaining healthy vegetation on slopes, incentivizing development away from coastal areas and bluffs, and removing barriers to the migration of plants and animals. [15.3.1, 17.2.7, 17.4.4, 20.6.2, 29.6.1, 29.6.2, Figure 29-5]

A low-regrets co-benefits approach of improving resilience through an emphasis on disaster risk reduction has become increasingly common (*high agreement, medium evidence*). Climate change adaptation and disaster risk reduction share similar objectives and challenges, although disaster risk management strategies by themselves often fail to account for a wide spectrum of threats and scales needed for climate change adaptation. There are many synergies between adaptation, development, and disaster risk reduction, and steps are being taken to achieve better integration (*high confidence*). [14.3.4, 14.4.2, 15.2.1, 15.2.3]

Building climate resilience in cities can be well-served by ecosystem-based adaptation with water and food systems as foci (*medium confidence*). Ecosystem-based adaptation is regarded as one of the more cost effective and sustainable approaches to urban adaptation, although the costs of needed land acquisition can be high. This is even though climate change will impact ecosystem services by altering ecosystem functions such as temperature and precipitation regimes, evaporation, humidity, and soil moisture levels. Ecosystem-based adaptation is closely linked to sustainable water management that ensures sufficient supplies, increases capacities to manage reduced freshwater availability, enables flood risk reduction and mitigation, manages waste water flows, and ensures water quality. [8.3, 8.5]

Integration and mainstreaming

Integration streamlines the planning and decisionmaking process and embeds climate sensitive thinking in existing and new institutions and organizations (*high confidence*). Integration helps avoid mismatches with development planning, facilitates the blending of multiple funding streams, and reduces the possibility of maladaptive actions. Development and adaptation can be complementary or competitive and development can yield adaptation co-benefits, provided it takes into account climate change in its design. Many aspects of economic development also facilitate adaptation to a changing climate, such as better education and health, and there are adaptation strategies that can yield welfare benefits even in the event of a constant climate, such as more efficient use of water and more robust crop varieties. Maximizing these synergies requires a close integration of adaptation actions with existing policies, referred to as mainstreaming. Mainstreaming adaptation into planning and decision-making, including official development assistance, is an opportunity for enhancing the effectiveness and efficiency of adaptation investments. [14.3.4, 14.4.2, 16.6, 17.2.7, 17.4.4]

Iterative approaches and learning

Due to the uncertainty, dynamic complexity, and short-to-long timeframes associated with climate change, robust adaptation efforts require iterative risk management strategies (*high agreement, medium evidence*). See Figure TS.4. Iterative risk management involves an ongoing process of assessment, action, reassessment, and response that may need to be applied under climate change, for decades, if not longer. [2.1.2, 2.2.1, 2.3.1, 15.2.3]

Adaptation planning and implementation is considered as a social learning process to formulate efficient plans, which allows periodical adjustments in order to reduce the uncertainty of the impacts of climate change and societal needs to cope with them (*high agreement, medium evidence*). Social learning is a relevant but under-investigated feature of planning and a critical part in the innovations for adaptation. Understanding of why and how learning takes place is needed to improve the impact and efficiency of plans, improve the transferability of best practices, increase public support, and translate learning into new plans. Monitoring and evaluation are two important learning tools in promoting this process. Although the importance of evaluation in adaptation is recognized, this topic is under-researched and requires significant work. [15.3.3]

[INSERT FIGURE TS.4 HERE
Figure TS.4: Schematic illustration of adaptation as an iterative risk management process. Each individual adaptation decision comprises well known aspects of risk assessment and management (top left panel). Each such decision occurs within and exerts its own sphere of influence, determined by the lead and consequence time of the decision, and the broader regulatory and societal influences on the decision (top right panel). A sequence of adaptation decisions creates an adaptation pathway (bottom panel). There is no single correct adaptation pathway, although some decisions, and sequences of decisions, are more likely to result in long-term maladaptive outcomes than others, but the judgment of outcomes depends strongly on societal values, expectations, and goals. [Figure 25-6]]

Working across scales

Opportunities exist for actors at all geographical and institutional levels and in different development contexts to facilitate, initiate, and implement effective adaptation action (*medium agreement, medium evidence*). Adaptation action at all levels—from households, firms, or municipalities to national government agencies and regional economic integration organizations—is influenced by resources made available by third parties, including the sharing of knowledge and information, the transfer of technologies, and the provision of financial resources. In addition, national and international public policy can encourage the preparation and implementation of national adaptation strategies. [16.6]

Adaptation governance plays a key role in promoting the transition from planning to implementation of adaptation (*high agreement, medium evidence*). The role of governance is highlighted in building adaptive capacity to climate change, in providing the connections among individuals, communities, organizations, agencies, and institutions at multiple levels, and in articulating top-down or bottom-up perspectives. Bottom-up approaches are particularly useful in efforts seeking to reduce social vulnerability and addressing adaptation to climate change as a process. However, adaptation to climate change also requires complementary top-down strategies through different levels of governments to realize mainstreaming adaptation. Adaptation planning also highlights the importance of intergovernmental and multidisciplinary approaches integrating science and planning. Because adaptation is a multidimensional issue involving many state and non-state actors functioning on varying scales of global, national, and local levels, a coordination of roles and responsibilities enhances institutional networking for effective implementation. Multilevel governance offers the chance to identify options for switching from reactive to proactive adaptation processes that are essential in safeguarding investments and infrastructures especially in urban adaptation. See Figure TS.5. [15.2.3, 15.4]

[INSERT FIGURE TS.5 HERE
Figure TS.5: Four main phases of adaptation planning and implementation: needs, planning, implementation, and evaluation. This is a cyclic, iterative process. Building capacity to respond to change, whether expected or unexpected, creates resilience in societies to cope in the face of uncertainties in climate change projections. Efforts in adaptation can be linked with development or disaster risk management. Adaptation governance underlies

capacity, and governance takes place at multiple scales: international, national, sub-national, and local. [Figure 15-1]]

Knowledge transfer

Information and knowledge on climate change risks from various stakeholders and organizations are essential resources for adaptation planning (*high agreement, robust evidence*). Although a wide range of adaptations are possible with current technologies and management practices, development and diffusion of technologies can expand the range of adaptation possibilities by expanding opportunities or reducing costs. [15.2.4]

Decision support situated at the intersection of data provision, expert knowledge and human decision-making across scales is most effective when it is context-sensitive, taking account of the diversity of different types of decisions, decision processes, and constituencies. [2.2, 2.3]

Traditional and indigenous forms of knowledge are a major resource for adapting to climate change except when the changes exceed the knowledge repertoire (*high agreement, robust evidence*). Culture and local and traditional forms of knowledge are highly dynamic and context dependent, reflecting and reasserting values and shaping both adaptive and maladaptive responses. Local and traditional knowledge is often neglected in policy and research, and mutual recognition and integration of local and traditional knowledge with scientific knowledge will increase the effectiveness of adaptation responses. [12.3]

Risk sharing mechanisms and economic instruments

Economic instruments have high potential in fostering adaptation as they directly and indirectly provide incentives for anticipating and reducing impacts (*high confidence*). Instruments comprise risk sharing and transfer mechanisms (insurance), loans including public private finance partnerships, payment for environmental services, improved resource pricing (water markets), charges and subsidies including land taxes, direct investment, norms and regulations, behavioral approaches, and institutional innovations. Innovative fiscal instruments, measures to attract “climate-proof” public and private investment and micro-insurance coverage of poorer households, risk transfer mechanisms, and innovative market-based insurance coverage will be necessary to address the large climate adaptation finance needs. Markets provide an additional mechanism for adaptation (*high agreement, medium evidence*). [8.4, 10.7.4, 10.7.5, 10.7.6, 10.9, 17.4, 17.5]

Risk financing mechanisms at local, national, regional, and global scales contribute to increasing resilience to climate extremes (*medium confidence*). Applicable mechanisms comprise informal and traditional risk sharing, such as relying on kinship networks, as well as market-based instruments including microinsurance, insurance, reinsurance, and national, regional, and global risk pools. Large-scale public-private risk prevention initiatives and government insurance of the non-diversifiable portion of risk offer example mechanisms for adaptation. Commercial reinsurance and risk-linked securitization markets also have a role in ensuring financially resilient insurance systems. With considerable disaster insurance market failure, public-private partnerships are the norm rather than the exception with the public sector acting as regulator, provider, or insurer of last resort (*high confidence*). Price signals associated with risk financing can provide incentives for reducing risk, yet the evidence of effectiveness is *limited* and the presence of many counteracting factors actually often leads to disincentives, also known as moral hazard. [10.7, 17.3.4, 17.3.6, 17.4, 17.5.1]

Transformation, including transformational adaptation

Adaptation options have focused mostly on cautious, incremental changes, but there is increasing recognition that transformative changes may be necessary as a response to projected climate changes (*medium confidence*). While no-regret, low-regret, and win-win strategies have attracted most attention in the past, there is increasing recognition that an adequate adaptive response will mean acting in the face of continuing uncertainty about the extent of climate change and the nature of its impacts and, thus, of adaptation needs. A focus on flexibility and adaptive management is becoming more common in selecting adaptation options. However, many see the need for more transformative changes in perception and paradigms about the nature of climate change, adaptation, and their relationship to other natural and human systems. [14.1, 14.3.4]

Transformation in wider political, economic, and social systems can either open up or close policy spaces for more resilient and sustainable forms of climate responses, particularly where contemporary development pathways are identified and addressed as part of the root causes of vulnerability. While transformations may be reactive, forced, or induced by random, stochastic factors, they may also be deliberately created. Deliberate transformations can take place across interacting spheres, the practical, political, and personal spheres of transformation (See Figure TS.6). Whether in relation to transformational adaptation, transformation to low-carbon societies, or transformations to global sustainability, attention to all three spheres is relevant in responding to the observed and anticipated impacts of climate change. Climate-resilient pathways may involve conflicting goals and visions for the future, and not every transformation is considered equally ethical, equitable, or sustainable. [20.5.2]

[INSERT FIGURE TS.6 HERE
Figure TS.6: The practical, political, and personal spheres of transformation. [20.5.2, Figure 20-2]]

B.iv. Understanding of Limits to Adaptation

Limits to adaptation emerge as a result of the interaction between climate change and other biophysical and socioeconomic constraints (*high agreement, robust evidence*). While biophysical thresholds represent an important determinant of limits to adaptation, particularly for natural systems, socioeconomic conditions and trends also contribute to the definition of limits in social systems. In particular, demographic change as well as economic development will influence future human vulnerability and adaptive capacity, but the externalities of these processes may reduce the resilience of natural systems to adapt to a changing climate. [16.2, 16.3, 16.4]

Evidence from both natural and human-managed systems demonstrates the existence of limits to adaptation to climatic and other related environmental and socio-economic risks (*high agreement, robust evidence*). Archeological and historical evidence is providing growing insights into periods of societal change, including catastrophic societal failures, in which climate change or variability may have been a contributory factor. Such evidence indicates that socioeconomic and cultural factors mediate societal responses to emergent risks such as changes in climate and influence the likelihood of limits to adaptation being reached and exceeded. [16.3, 16.5, 16.5.1, 16.5.2, 16.8, Box 16-3]

Social limits to adaptation are dynamic over space and time due to normative judgments and values of actors, technological change, and emergent properties of complex systems (*high agreement, limited evidence*). Limits to adaptation are expected to be exceeded locally before being exceeded regionally and at larger spatial scales. This should provide regional, national, and international actors with an early warning of possible future adaptation constraints and limits. Some adaptation limits may be removed over time either due to changing normative judgments and values of actors that lead to the abandonment of previously held objectives, or through technological advancement. However, some actors may find that transformational changes are required that necessitate trade-offs in some values in order to preserve others. [16.4.1, 16.4.2]

The greater the magnitude of climate change, the greater the likelihood that adaptation will encounter limits (*high agreement, limited evidence*). Mitigation and adaptation are complementary strategies. Greater adaptation efforts will be required to achieve the objectives of actors if mitigation efforts are not successful in avoiding high magnitudes of climate change. There are, however, limits to the extent to which adaptation could reduce the impacts not avoided by mitigation, and residual loss and damage may occur despite adaptive action. Knowledge about limits to adaptation could therefore inform the level and timing of mitigation and might justify early mitigation action. However, as the future capacity of actors in different sectoral and regional contexts to adapt to climate change remains uncertain, the implications of adaptation for mitigation demand will be contingent upon economic development pathways and investments made to enhance the adaptive capacity of vulnerable actors. [16.3.1, 16.5, 19.6, 19.7, 20.5.3]

Much of the literature identifying limits to adaptation for specific systems and/or management objectives is associated with biophysical systems, particularly ecosystems and/or individual species that are dependent

upon specific biophysical regimes (*high agreement, robust evidence*). Those species that already persist at the edge of their thermal and/or hydrological limits may be most vulnerable to a changing climate. Species do have capacity to adapt through phenotypic and genetic responses. The physiological and/or ecological thresholds imposed by climate effectively represent "hard" limits in that no adaptation options can be implemented to enable sustainability once thresholds are exceeded. As a broad range of human values and managed systems are dependent upon ecosystems goods and services, "hard" limits in ecological systems have the potential to constrain or limit adaptation in socioeconomic systems.
[16.4.1]

The capacity to describe and predict limits to adaptation is significantly impaired by the complexity of socio-ecological systems (*high agreement, limited evidence*). While there is *high agreement* that limits to adaptation exist, detailed understanding of the level at which climate change impacts may impose an intolerable risk to social objectives (the definition of adaptation limits adopted here) is available only for a small number of ecosystems and crop species. Any assessment of limits to adaptation in human systems is preliminary because of uncertainty about the existence and level of adaptation limits, and whether these limits are hard or soft. Furthermore, social, economic, and cultural trends and conditions, including uncertainty regarding actors' objectives and values and how they evolve over time, further confound explicit definitions of limits. Thus, while climate change raises "reasons for concern" regarding the sustainability of various natural and human systems, there is little evidence to support climate thresholds, such as a 2°C increase in global mean temperature, as being robust definitions of limits to adaptation. [16.4.2]

Specific regional examples of limits to adaptation have been assessed:

- In Africa, growing understanding of the multiple inter-linked constraints on increasing adaptive capacity is beginning to indicate potential limits to adaptation (*high agreement, limited evidence*). Climate change combined with other external changes (environmental, social, political, technological) may overwhelm the ability of people to cope and adapt, especially if the root causes of poverty and vulnerability are not addressed. Risks of maladaptation are increased by development interventions that often fail to consider how different types of change interact and undermine the ability of people to cope with multiple stressors. Evidence is growing for the effectiveness of flexible and diverse development systems designed for reducing vulnerability, spreading risk, and building adaptive capacity, and for the benefits of new development trajectories that place climate resilience, ecosystem stability, equity, and justice at the center of development efforts. [22.4.6]
- For Europe, synthesis of evidence across sectors and subregions confirms that there are limits to adaptation from social, economic, and technological factors. Adaptation is further impeded because climate change affects multiple sectors. [23.5, 23.10]

_____ START BOX TS.5 HERE _____

Box TS.5: Characterizing the Future

While there are many possible scenarios for future climate change and societal development, current decisions narrow future options. New risks will emerge in the coming decades as a result of past emissions and current socioeconomic trends. Societal responses, particularly adaptations, will influence outcomes during this era of climate responsibility. In contrast, benefits of current mitigation efforts will emerge over a longer period. Future risks during this longer-term era of climate options are thus linked to current mitigation and development choices.

Trends in vulnerability, exposure, and climate, as well as weather and seasonal forecasting of climate variability, can inform decisions in the era of climate responsibility. Climate and impact model projections become increasingly relevant for climate-affected decisions playing out over the longer term, recognizing that uncertainties about future vulnerability and exposure also increase over time. [21.3.3, 21.5.1, 21.5.3]

Scenarios are a vital part of managing uncertainty. [2.2.1] Scenarios provide a mechanism for characterizing possible socioeconomic futures and climate change outcomes. Socioeconomic factors influence not only greenhouse gas emissions but also the size and location of populations at risk from various climate change impacts, the differential vulnerability of these populations, and their capacities to adapt.

Modeled future impacts assessed in this report draw on a combination of climate model simulations (CMIP3) using SRES scenarios and new climate model simulations (CMIP5, completed in 2011-12) using the new Representative Concentration Pathway (RCP) scenarios. The RCPs span the range of SRES scenarios for long-lived greenhouse gases, but they have a narrow range and fall at or below the lowest SRES in terms of emissions of ozone and aerosol precursors and related pollutants (*high confidence*). The IPCC has created and used emission scenarios to project future climate since the First Assessment Report, and most recently the SRES scenarios were used in the Third Assessment Report, AR4, and SREX. With AR5, the new RCP scenarios present both emissions and greenhouse gas concentration pathways, and corresponding socio-economic pathways have also been developed. The 4 RCPs assume different levels of mitigation, leading to 21st century radiative forcing levels of 2.6, 4.5, 6.0, and 8.5 W m^{-2} (see WGI AR5 Chapters 1, 6, 11, and 12). All RCPs project a rapid decline in short-lived pollutants and land-use change by 2050, almost independent of fossil-fuel use and population, while other published scenarios indicate a less rapid decline in aerosol precursors**.** A process (shared socioeconomic pathways, SSP's) has been initiated to identify shared assumptions and global scenarios for use in both mitigation and adaptation research. But although progress has been made, the vast majority of the impacts, adaptation, and vulnerability literature since AR4 continues to be based on the SRES. [1.1.3, 21.5.3]

Future climate depends on future climate forcing from emissions and concentrations, the climate system response to forcing, and the natural internal variability of the climate system (see Box TS.5 Figure 1). Climate models continue to produce a range of projected futures where for some variables and locations the sign of projected change may differ from one model to another. However, in many instances this indicates a lack of significant change compared to the natural variability for that region. The degree to which the model uncertainty can be reduced remains an open question. [21.5.3]

Box TS.5 Figure 1 illustrates alternative climate futures, under RCPs 4.5 and 8.5, along with observed temperature and precipitation changes. Future climate change interacts with vulnerability and exposure to determine future risks.

[INSERT BOX TS.5 FIGURE 1 HERE

Box TS.5 Figure 1: Changes in annual average temperature (A) and precipitation (B). For observations (top map, A and B; CRU), differences are shown over land between the 1986-2005 and 1906-1925 periods, with white indicating areas where the difference between the 1986-2005 and 1906-1925 periods is less than twice the standard deviation of the 20 20-year periods beginning in the years 1906 through 1925. For projections (bottom four maps, A and B; CMIP5), four classes of results are displayed. (1) White indicates areas where for >66% of models the annual average change is less than twice the baseline standard deviation of the respective model's 20 20-year periods ending in years 1986 through 2005. Thus in these regions, more than 2/3 of models show no significant change in the annual average using this measure of significance, although this does not imply no significant change at seasonal or shorter time-scales such as months to days. (2) Gray indicates areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation, but <66% of models agree on the sign of change. In these regions, more than 2/3 of models show a significant change in annual average, but less than 2/3 agree on whether it will increase or decrease. (3) Colors with white circles indicate the change averaged over all models where >66% of models exhibit a change greater than twice the respective model baseline standard deviation and >66% of models agree on whether the annual average will increase or decrease. In these regions, more than 2/3 of models show a significant change in annual average and more than 2/3 (but less than 90%) agree on whether it will increase or decrease. (4) Colors without circles indicate areas where >90% of models exhibit a change greater than twice the respective model baseline standard deviation and >90% of models agree on whether the annual average will increase or decrease. For models that have provided multiple realizations for the climate of the recent past and the future, results from each realization were first averaged to create the baseline-period and future-period mean and standard deviation for each model, from which the multi-model mean and the individual model signal-to-noise ratios were calculated. The baseline period is 1986-2005. The late-21st century period is 2081-2100. The mid-21st century period is 2046-2065. See also Annex I of WGI AR5. [Box CC-RC]]

_____ END BOX TS.5 HERE _____

C) FUTURE RISKS AND CHOICES: RISKS AND POTENTIAL FOR ADAPTATION

Assessment of the full range of potential future impacts, not only the most likely outcomes, provides a basis for understanding future risks. In some cases, the probability of an impact occurring may be relatively low, but consideration is warranted because the potential consequences are significant. This section covers future risks across sectors and regions, and their sensitivity to the magnitude and rate of climate change, to the characteristics of development that affect vulnerability, and to policy choices. It emphasizes the importance of societal development in determining impacts at a given magnitude of climate change. It also recognizes that individuals vary in what they hold most dear, in how they value assets that are not typically monetized, and in how much they discount the future. The section examines the distribution of risks across populations with contrasting vulnerability and adaptive capacity, across sectors where metrics for quantifying impacts may be quite different, and across regions with widely varying traditions and resources. The assessment features interactions across sectors and regions and among climate change and other stressors. It elucidates how and when choices matter in reducing future risks and highlights the differing eras for mitigation and adaptation benefits.

C.i. Sectoral Risks with Regional Examples

For the era of climate responsibility (the next few decades) and the era of climate options (the longer term), risks will emerge across sectors and regions, dependent on the magnitude and rate of climate change and on the vulnerability of exposed social and natural systems.

Freshwater resources

Projected climate changes would change hydrological regimes substantially (*high agreement, robust evidence*). Runoff and groundwater recharge are projected to increase at high latitudes and in the wet tropics, and to decrease in most dry tropical regions, controlled mainly by changes in precipitation. Changes in runoff are typically one to three times greater than changes in precipitation. Except in very cold regions, warming brings forward the snowmelt season, altering the seasonal regime. Figure TS.7 depicts projected decreases in groundwater resources and associated vulnerability. [3.4.5, 3.4.6]

Hydrological impacts of climate change increase with increasing greenhouse-gas emissions (*high agreement, robust evidence*). A low-emissions pathway reduces damage costs and costs of adaptation. Impacts of climate change on water resources are expected to reduce economic growth, particularly in developing countries (*high agreement, limited evidence*). [Table 3-2, 3.4, 3.5, 3.6.5]

Glaciers will continue to lose mass, with meltwater yields from stored glacier ice eventually diminishing as the glaciers shrink (*high agreement, robust evidence*). The rate of loss per unit of glacierized area will accelerate. The accumulation season will become shorter and the melting season longer, and in almost all regions total accumulation will decrease. In many regions meltwater production will increase during the next several decades but decrease thereafter. Glaciers have long response times and would continue to lose mass even if the climate were to cease to change. [3.4.4]

[INSERT FIGURE TS.7 HERE
Figure TS.7: Human vulnerability to climate-change-induced decreases of renewable groundwater resources by the 2050s for lower (B2) and higher (A2) emissions pathways and two global climate models. The higher the vulnerability index (percent decrease of groundwater recharge multiplied by a sensitivity index), the higher the vulnerability. The index is computed for areas where groundwater recharge is projected to decrease by at least 10%, as compared to the reference period 1961-90. [Figure 3-9]]

Climate change is projected to reduce renewable water resources in most semi-arid and arid regions, potentially affecting food security (*high agreement, robust evidence*). Drying of soils is projected in most dry regions (*medium confidence*). Projected changes in droughts depend partly on the definition of drought. [3.4.9, 3.5, WGI AR5 12.4.5]

Projected climate changes imply large changes in the frequency of floods (*high agreement, robust evidence*). More frequent intense rainfall events [WGI AR5 12.4.5] would increase the frequency of flooding in small catchments, but the implications for larger catchments are more uncertain because of the limited extent of the intense events. In some areas, reduced snowfall will reduce spring flood peaks. More people will be exposed to floods, notably in Asia, Africa, and Central and South America, and economic losses will increase due to both increased exposure and anthropogenic climate change (*high confidence,* based on *high agreement, limited evidence*). Vulnerability can be reduced by adaptation. [3.4.9]

Water quality changes are linked to warming, changes in rainfall, and climate-related erosion and deforestation (*high agreement, limited evidence*). Projections under climate change scenarios show a risk of deteriorating water quality for municipal supply, even with conventional treatment. Possible positive impacts include reduced risks of eutrophication and algal blooms when nutrients are flushed from lakes and estuaries by more frequent storms and hurricanes (*high agreement, limited evidence*). [3.2.5, 3.5.2]

Climate change increases investment costs for water and wastewater treatment, while operating costs could rise or fall. Improved or even new water-treatment infrastructure may be needed to address variations in the quantity and quality of water (*high agreement, medium evidence*), but under warmer conditions water and wastewater treatment processes may perform better (*low* to *medium agreement, limited evidence*). [3.5.2, 3.6]

Adaptive water management techniques offer an opportunity to address uncertainty due to climate change (*high agreement, limited evidence*). Such techniques include scenario planning, employing experimental approaches that involve learning from experience, and developing flexible solutions that are resilient to uncertainty. However, there are barriers such as lack of technical capacity, financial resources, awareness, and communication. [3.6.2, 3.6.6]

Adaptation to climate change in the water sector provides many opportunities for low-regrets improvements (*high agreement, limited evidence*). Of the global cost of adaptation, 85% is required in developing countries (*medium agreement, medium evidence*), in amounts similar to those estimated for the Millennium Development Goals. Annual global adaptation costs to maintain baseline levels of water-supply and sanitation services will be 50 to 70% of baseline investment in the sector (*high agreement, limited evidence*). Some adaptive water-management measures also mitigate climate change (*medium agreement, limited evidence*). For example, wetland conservation increases carbon storage. [3.6.1, 3.6.5, 3.7.2]

Specific regional examples include:

- In Africa, the impact of climate change on water availability is uncertain (*high confidence*). Water resources are subject to high hydro-climatic variability over space and time, and are a key constraint on the continent's continued economic development. Water is the primary medium through which early and subsequent climate change impacts will be felt by people, ecosystems, and economies. Many of the fragile terrestrial and aquatic ecosystems in Africa are implicitly or explicitly water dependent. Impacts of climate change will be superimposed onto already water-stressed catchments with complex land uses, engineered water systems, and a strong historical socio-political and economic footprint. Strategies and plans of action to adapt to climate change through an integrated approach to land and water management benefit establishment of effective resilience to the projected impacts of climate change. [22.3.2, 22.3.3]
- In Europe, climate change will decrease surface water quality due to higher temperatures (*medium confidence*). [23.6.3]
- In Asia, water scarcity is expected to be a major challenge for most of the region due to increased water demand and lack of good management (*medium confidence*). Water resources are important in Asia given the massive population. However, there is *low confidence* in future precipitation projections at a regional scale and thus in freshwater availability in most parts of Asia. Shrinking of glaciers in Central Asia and the Himalayas is projected to affect water resources in downstream river catchments. Population growth and increasing demand arising from higher standards of living could worsen water security in many parts of Asia and affect many people in the future. Better water management strategies are needed to ease water scarcity. Water saving technologies and changing to drought tolerant crops have been found to be successful adaptation options in the region. [24.4.3, Box 3-1]
- In Australasia, freshwater resources are projected to decline in far south-west and far south-east mainland Australia (*high confidence*) and for rivers originating in the eastern and northern parts of New Zealand

(*medium confidence*). Systematic constraints on water resource use in southern Australia, driven by rising temperatures and reduced cool-season rainfall, have the potential to be severe but can be moderated or delayed significantly by globally effective mitigation combined with adaptation, with an increasing need for transformative adaptation for greater rates and magnitude of change (*high confidence*). Integrated responses encompassing management of supply, recycling, water conservation, and increased efficiency across all sectors are available but face implementation constraints. [25.2, 25.5.1, Box 25-2]

- Throughout North America, it is *very likely* that the 21st century will witness decreases in water quality, and increases in flooding and droughts under climate change, with these impacts exacerbated by other anthropogenic drivers. It will also witness decreases in water supplies for urban areas and irrigation in some areas of North America, with confounding effects of development, except in general for southern Mexico, the northwest and northeast coastal USA, and west and east Canada. [26.3, 26.8]
- In Central and South America, although there is high uncertainty in terms of climate change projections for regions with high vulnerability in terms of current water availability, this vulnerability is expected to increase in the future due to climate change impacts (*high confidence*). Already vulnerable regions in terms of water supply, like the semi-arid zones in Chile-Argentina, North Eastern Brazil, and Central America and the tropical Andes, are expected to increase even further their vulnerability due to climate change. Glacier retreat is expected to continue, and a reduction in water availability due to expected precipitation reduction and increased evapotranspiration demands is expected in the semi-arid regions of Central and South America. These scenarios would affect water supply for large cities, small communities, hydropower generation, and the agriculture sector. Current practices to reduce the mismatch between water supply and demand could be used to reduce future vulnerability. Constitutional and legal reforms towards more efficient and effective water resources management and coordination among relevant actors in many countries in the region (e.g., Honduras, Nicaragua, Ecuador, Peru, Uruguay, Bolivia, and Mexico) also represent an adaptation strategy to climate variability and change. [27.3.1, 27.6.1]

Terrestrial and inland water systems

There is *high confidence* for freshwater ecosystems and *medium confidence* for terrestrial ecosystems that direct human impacts such as land-use change, pollution, and water resource development will continue to dominate the threats to ecosystems, with climate change becoming an increasing additional stress through the century, especially for high-warming scenarios such as RCP 6.0 and 8.5. Model-based projections imply that direct land cover change will continue to dominate over climate-induced change for low to moderate warming scenarios at global scales (e.g., RCP2.6 to RCP6.0). However, in many areas not subject to intensive human disturbance, even lower levels of projected future climate changes will result in changes in large-scale ecosystem character depending on the nature of regional climate changes (*high confidence*). Such changes may not be fully apparent for several decades after reaching the critical regional climate state, due to long response times in ecological systems (*medium confidence*). For higher warming scenarios, some model projections imply climate-driven large-scale ecosystem changes that become comparable with direct human impacts at the global scale. [Box CC-RF, 4.3.3]

Significant feedbacks exist between terrestrial ecosystems and the climate (*medium confidence*). Thus local, regional, and global climate may be affected as ecosystems are altered, through climate change itself or other mechanisms, such as conversion to agriculture or human settlement. These climate feedbacks are driven by changes in surface albedo, evapotranspiration, and greenhouse gas emissions. The regions where the climate is affected may be different from the location of the ecosystem change. [4.3.3]

The capacity of many species to respond to climate change will continue to be constrained by non-climate factors (*high confidence*), including but not limited to the simultaneous presence of land-use changes, habitat fragmentation and loss, competition with alien species, exposure to novel pests and diseases, nitrogen loading, and increasing carbon dioxide and tropospheric ozone. [Figure 4-1, 4.2.4, 4.3.3]

A changing climate exacerbates other threats to biodiversity (*high confidence*). In some systems, such as high altitude and latitude freshwater and terrestrial ecosystems, climate changes exceeding those projected under RCP2.6 will lead to major changes in species distributions and ecosystem function. Since the specific changes in individual regions depend on the nature of the projected regional climate change, the confidence in specific future ecosystem changes is limited by the confidence assigned to regional climate change projections by Working Group I. [4.3.2, 4.3.3, 4.4.1]

Terrestrial plant and animal species will continue to move their ranges, alter their abundance, and shift their seasonal activities in response to projected future climate change (*high confidence*). *High confidence* in past responses, coupled with projections from a diversity of models and studies, provides *high confidence* that such responses will be the norm with continued warming. These shifts in species ranges will cause large changes in local abundance under all climate change scenarios: abundance declining in areas where climate becomes unfavorable and potentially increasing in areas where climate becomes more favorable. Such changes in species abundance lead to changes in community composition and ecosystem function. [4.2.1, 4.2.2, 4.3.2, 4.3.3]

Climate change is increasing the likelihood of the establishment, growth, spread, and survival of some invasive alien species populations in some regions (*high confidence*). Invasive species are more likely than native species to have traits that favor their survival and reproduction under changing climates. Species movement into areas where they were not present historically will be driven both by climate change and by increased dispersal opportunities associated with human activities. [4.2.4]

Even for mid-range rates of climate change (i.e., RCP 4.5 and 6.0 scenarios) many species will be unable to move fast enough to track suitable climates (*medium confidence*). See Figure TS.8. Over the last several decades many, but not all, species have tracked changes in climate. Populations of species that cannot track future climate change by migrating will find themselves in unfavorable climates and are unable to expand into newly climatically suitable areas. Species in large flat areas are particularly vulnerable because they must migrate over longer distances to keep up with climate change than will species in mountainous regions. Species with low migration capacity will also be especially vulnerable: examples include most trees, many plants, and some small mammals. Combinations of low migration capacity and large flat areas are projected to pose the most serious problems for tracking climate; for example, even the maximum observed and modeled migration rates for mid- and late-successional tree species will be insufficient to track climate change in flat areas even at moderate rates of climate change (*medium confidence*). Barriers to migration such as mountain ranges, dams, habitat fragmentation, and occupation of habitat by competing species substantially reduce the ability of species to migrate to more suitable climates (*high confidence*). Outlier populations (e.g., collections in botanical gardens or parks), as well as intentional and accidental anthropogenic transport, will speed migration (*high confidence*). [4.3.2, 4.3.3]

[INSERT FIGURE TS.8 HERE
Figure TS.8: Rate of climate change (A), corresponding climate velocities (B), and rates of displacement of several terrestrial and freshwater species groups in the absence of human intervention (C). The thin red arrows give an example of interpretation. Rates of climate change of 0.03 °C/yr correspond to ca. 1.1 km/yr global average climate velocity. When compared to rates of displacement, this would exceed rates for most plants, many primates, and some rodents. (A) Observed rates of climate change for global land areas are derived from CRUTEM4 climate data reanalysis; all other rates are calculated based on the average of the CMIP5 climate model ensembles for the historical period and for the future based on the four RCP emissions scenarios. The lower bound (17% of model projections are outside this bound) is given for the lowest emissions scenario and the upper bound for the highest emissions scenario. Data were smoothed using a 20-year sliding window, and rates are based on means of between 17 and 30 models using one member per model. Global average temperatures at the end of the 21st century are given for each RCP scenario. Colors in the background synthesize the ability of species to track climate through displacement. (B) Estimates of climate velocity were semi-quantitatively synthesized from seven studies using a diversity of analytical approaches and spatial resolutions. The three axes represent estimated climate velocities for mountainous areas (left), for global land area (center), and for regions that are flat or have high rates of climate change (right). (C) Rates of displacement for terrestrial plants, trees, mammals, birds, phytophagous insects, and freshwater mollusks. Each box represents ~95% of the estimates, and the bar is a qualitative estimate of the median. [Figure 4-6]]

Large magnitudes of climate change will negatively impact species with populations that are primarily restricted to protected areas, mountaintops, or mountain streams, even those that potentially migrate fast enough to track suitable climates (*high confidence*). Climate change is projected to either create unsuitable climates for species that remain in these areas, or force species out of protected areas and off mountaintops. These effects are foreseen to be modest for low magnitudes of climate change (e.g., RCP 2.6) and very high for the highest magnitudes of projected climate change (e.g., RCP 8.5). Species have already started to migrate out of protected areas and towards mountaintops over the last several decades due to a warming climate. [4.3.2, 4.3.4]

Projected climate changes imply increased extinction risk for a substantial fraction of species during and beyond the 21st century, especially as climate change interacts with other pressures, such as habitat modification, over-exploitation, and invasive species (*very high confidence*). Uncertainties in regional climate projections, highly variable estimates from comparisons of paleontological extinctions in response to past climate changes, different methods of estimating present and future extinction risk, and the variable adaptive capacity of wild species all contribute to an extremely broad range of estimates of future extinction risk due to climate change. There is *low confidence* that global extinction risks due to climate change can be accurately quantified. There is, however, a strong consensus that current climate change pressures and their interactions with other global changes will increase extinction risk for many terrestrial and freshwater species. [4.3.2]

It is *virtually certain* that the carbon stored in land and freshwater ecosystems in the form of plant biomass and soil organic matter has increased over the past two decades in what is known as the terrestrial carbon sink. There is *low confidence* that the transfer of carbon dioxide from the atmosphere to the land will continue at a similar rate for the remainder of the century. The terrestrial carbon sink is offset to a large degree by carbon released to the atmosphere through forest conversion to farm and grazing land and through forest degradation (*high confidence*). The carbon stored thus far in terrestrial ecosystems is vulnerable to loss back to the atmosphere as a result of climate change (including indirect effects such as increased risk of fires and pest outbreaks) and land-use change (*medium confidence*). Terrestrial and freshwater ecosystems have been responsible for the uptake of about a quarter of all anthropogenic CO_2 emissions in the past half century. The net fluxes out of the atmosphere and into plant biomass and soils show large year-to-year variability. As a result there is *low confidence* in the ability to determine whether the net fluxes into or out of terrestrial ecosystems at the global scale have increased or decreased over the past two decades. The factors causing the current increase in land carbon include the positive effects of rising CO_2 on plant productivity, a warming climate, and recovery from past disturbances (*high confidence*), but there is *low confidence* in the relative contribution by each of these and other factors. Experiments and modeling studies provide *medium confidence* that increases in CO_2 up to about 600 ppm will continue to enhance photosynthesis and plant water-use efficiency, but at a diminishing rate. Other factors associated with global change, including high temperatures, rising ozone concentrations, and in some places drought, decrease plant productivity by comparable amounts (*medium confidence*). Models provide *high confidence* that nitrogen availability will limit the response of many natural ecosystems to rising CO_2. There are few field-scale experiments on ecosystems at the highest CO_2 concentrations projected by RCP 8.5 for late in the century, and none of these includes the effects of other potential confounding factors. [4.2.2, 4.2.4, 4.3.2, 4.3.3, Box 4-4]

Recent experimental, observational, and modeling studies provide *medium confidence* that forests may be more sensitive to future climate change than reported in the IPCC AR4, and that tree mortality and forest dieback could become a problem in many regions much sooner than previously anticipated. Future climate change impacts on tree mortality and tree ranges could be large (*high confidence*), but experimental, observational, and modeling studies also indicate that there is *low confidence* associated with model-based projections of the details of these impacts. As such, projections of increased tree growth and enhanced forest carbon sequestration mediated by increasing growing season length, rising CO_2 concentrations, and atmospheric nitrogen deposition are being viewed with increasingly greater caution due to the counter-balancing effects of mortality and dieback. The consequences for the provision of timber and other wood products are projected to be highly variable between regions and products depending on the balance of the positive vs. negative effects of global change. [4.3.3, 4.3.4]

Terrestrial and freshwater ecosystems can, when pushed by climate change, cross “tipping points” and abruptly change in composition, structure, and function (*high confidence*). The crossing of these tipping points will result in significant increases in carbon emissions to the atmosphere (*medium confidence*). This has happened many times in Earth history. There are plausible mechanisms, supported by experimental evidence and model results, for the existence of ecosystem tipping points in both boreal-arctic systems and the rainforests of the Amazon basin; others may exist. Continued climate change could push the boreal-arctic system across such a tipping point in this century, and cause an abrupt transformation of the ecology and albedo of this region, as well as the release of greenhouse gases from the thawing permafrost and burning forests (*low confidence*). Adaption measures will be unable to prevent substantial change in the boreal-arctic system (*high confidence*). Continued climate change together with land use change and fire activity could also cause much of the Amazon forest to transform abruptly to more open, dry-adapted ecosystems, and in doing so, put a large stock of biodiversity at elevated risk and create a large new net greenhouse gas source to the atmosphere (*low confidence*). The combination of climate change and land-use change in the Amazon will cause accelerated drying and drought frequency in the region (*medium confidence*), and there is *low confidence* that these Amazon changes will affect rainfall in agricultural regions elsewhere on the planet. Rigorously applied adaptation measures could lower the risk of abrupt change in the Amazon, as well as the impacts of that change (*medium confidence*). Policy and market-driven interventions have caused a steep decline in deforestation in the Amazon since 2005 that has decreased anthropogenic carbon emissions to the atmosphere by 1.5% (*very high confidence*). [4.2.2, 4.2.4, 4.3.3, Box 4-3, Box 4-4, Figure 4-10]

Management actions can reduce, but not eliminate, exposure to climate-driven ecosystem impacts, and can increase ecosystem adaptability (*high confidence*). The capacity for natural adaptation by ecosystems and their constituent organisms is substantial, but for many ecosystems and species this is insufficient to cope without substantial loss of species and ecosystem services, given the rate and magnitude of climate change projected under medium-range warming (e.g., RCP 6.0) or high–range warming scenarios (e.g., RCP 8.5) (*medium confidence*). The capacity for ecosystems to adapt to climate change can be increased by reducing the other stresses operating on them; reducing the rate and magnitude of change; reducing habitat fragmentation and increasing connectivity; maintaining a large pool of genetic diversity and functional evolutionary processes; assisted translocation of slow moving organisms or those whose migration is impeded, along with the species on which they depend; and manipulation of disturbance regimes to keep them within the ranges necessary for species persistence and sustained ecosystem functioning. [4.4.1, 4.4.3]

Specific regional examples include:

- In Europe, climate change will cause changes in habitats and species, with local extinction (*high confidence*) and continental scale shifts (*low/medium confidence*). The habitat of alpine plants will be significantly reduced (*high confidence*). Phenological mismatch will constrain both terrestrial and marine ecosystem functioning under climate change (*high confidence*), with a reduction in some ecosystem services (*low confidence*). The introduction and expansion of invasive species, especially those with high migration rates, from outside Europe will increase with climate change (*medium confidence*). Biodiversity is affected in unprotected areas more than in protected areas, but Natura 2000 areas retain climate suitability for species no better and sometimes less effectively than unprotected areas (*low confidence*). All ecosystem services, particularly provisioning, regulating, and cultural services, will be degraded by climate change in at least one European sub-region. [23.6.4, 23.6.5, 23.10, Table 23.2]
- In Europe, climate change will increase damage to forests from pests and diseases in all sub-regions (*high confidence*), from wildfires in Southern Europe (*high confidence*), and from storms (*low confidence*). Climate change will cause ecological and socio-economic damages from shifts in forest tree species range, with a general trend of south-west to north-east (*medium confidence*), and in pest species distributions (*low confidence*). Short-term and long-term strategies in forest management may be an adequate measure to enhance ecosystem resistance and resilience (*medium confidence*). [23.4.4]
- In Asia, terrestrial systems are under increasing pressure from both climatic and non-climatic drivers. The projected changes in climate will impact vegetation and increase permafrost degradation during the 21st Century (*high confidence*). The largest changes are expected in cold northern and high-altitude areas, where boreal and subalpine trees will *likely* invade treeless arctic and alpine vegetation, and evergreen conifers will *likely* invade deciduous larch forest. Large changes may also occur in arid and semi-arid areas, but uncertainties in precipitation projections make these difficult to predict. Vegetation change in the more densely populated parts of Asia will be constrained by the impact of vegetation fragmentation on seed dispersal. The impacts of projected climate changes on the vegetation of the lowland tropics are currently poorly understood. Trends in phenological timing consistent with the impacts of regional warming are widespread in eastern Asia, particularly for plants. Permafrost degradation will spread during the 21st century from the southern and low-altitude margins, advancing northwards and upwards. Many models agree on the direction of change, but rates of change vary greatly between different projections. [24.2.2, 24.4.2, 24.4.3, 24.9.3]
- In Australia, loss of montane ecosystems and some endemic species, driven by rising temperatures, increased fire risk, and drying trends, can be delayed but now appears very difficult to avoid entirely, even with combined globally effective mitigation and planned adaptation (*high confidence*). Fragmentation of landscapes, limited dispersal, and evolutionary capacity limit adaptation options. Many endemic species will suffer from range contractions, and some may face local or even global extinction. [25.6.1]

- In Australasia, projected changes in climate and increasing atmospheric CO_2 have the potential to benefit forest growth in cooler regions except where soil nutrients or rainfall are limiting (*high confidence*). Spring pasture growth in cooler regions would also increase and be beneficial for animal production if it can be utilized. [25.7.1, 25.7.2]
- In North America, a global increase of 2°C would have widespread adverse impacts on many ecosystems, *likely* reducing biodiversity and ecosystem services (*high confidence*). [26.4]
- In Antarctica, warming in combination with increased water availability is expected to lead to increased productivity and biomass, and the development of community complexity in native terrestrial biota (*high confidence*). However, these responses are potentially confounded by multiple stressors, including human activities (research stations, tourism, etc.). Climate change will increase the vulnerability of terrestrial ecosystems to invasions by non-indigenous taxa, the majority expected to arrive through direct human assistance, which poses the greatest threat to terrestrial plant and animal communities in the future (*high confidence*). [28.3.3]

Coastal systems and low-lying areas

Coastal systems and low-lying areas will increasingly experience adverse impacts associated with submergence and extreme sea level flooding due to relative sea level rise (*high confidence*). Large spatial variations in the projected sea level rise, together with local factors such as subsidence, suggest that relative sea level rise can be considerably larger than projected global mean sea level rise and therefore is an important consideration in impact assessments (*very high confidence*). Changes in storms and associated storm surges may further contribute to changes in sea level extremes, but the small number of regional storm surge studies, limited spatial coverage, and different modeling approaches used means that there is *low confidence* in projections of storm surge. [5.3.1, 5.3.3]

Acidification and warming of coastal waters will continue with significant consequences for coastal ecosystems (***high confidence***). The increase in acidity will be higher in areas where eutrophication is an issue, with negative consequences for many calcifying organisms. The interaction of acidification and warming exacerbates coral bleaching and mortality (*very high confidence*). Some warm water corals and their reefs will continue to respond to warming with species replacement, bleaching from loss of associated algae, and a decreased coral cover resulting in habitat loss. Warming will cause a decline of vegetated coastal habitats across the temperate zone. Temperate seagrass and kelp ecosystems will decline with increased frequency of heat waves and sea temperature extremes as well as through the impact of invasive subtropical species (*high confidence*).The decline of seagrass and kelp habitats will affect food webs, biodiversity, and biogeochemical cycling in these ecosystems (*very high confidence*). The projected degradation of some marine ecosystems such as coral reefs and Mediterranean intertidal communities is *very likely* to pose substantial challenges for coastal societies where livelihoods and food security may depend on ecosystem health. In the absence of adaptation, beaches, sand dunes, and cliffs currently eroding will continue to do so under increasing sea levels (*high confidence*). Increased human-induced drivers have been the primary drivers of change in coastal aquifers, lagoons, estuaries, deltas, and wetlands (*very high confidence*). Climate-change-related drivers will exacerbate currently existing problems in these natural systems. [5.4.2, 6.2, 6.3.2, 6.3.5, 6.5.2, 30.4, 30.5.3, 30.5.6, Box CC-CR, Box CC-OA]

The population and assets exposed to coastal risk as well as human pressures on coastal ecosystems will increase significantly in the coming decades due to population growth, economic development, urbanization, and coastward migration of people (*high confidence*). Under medium population projections, the population exposed to the 1 in 100 year coastal flood is expected to increase from 271 million in 2010 to 345 million in 2050 due to socio-economic development only. This increase in coastal population is expected to further exacerbate human pressures on coastal systems resulting from excess nutrient input, reduced run-off, and sediment delivery. [5.3.4]

The costs of inaction are larger than the sum of adaptation and residual damage costs for the 21st century at the global scale (*high agreement*). Without adaptation, hundreds of millions of people will be affected by coastal flooding and be displaced due to land loss through submergence and erosion by 2100; the majority of those affected are from East, Southeast, and South Asia (*high confidence*). Even with global mean sea-level rise of 1.3m by 2100, protection is considered economically rational for most developed coastlines in most countries (*high agreement*).

Under medium socio-economic development assumptions, the expected direct global annual cost of coastal flooding (adaptation and residual damage costs) may reach 300 US$ billion per year in 2100 without adaptation and 90 US$ billion per year with adaptation under a 1.26 m sea-level rise scenario. [5.4.3, 5.5.3]

The impacts of climate change on coasts and the required level of adaptation vary strongly between regions and countries (*high confidence*). While developed countries are expected to be able to adapt to even high levels of sea-level rise, small island states and some low-lying developing countries are expected to face very high impacts and associated annual damage and adaptation costs of several percentage points of GDP (*high agreement*). Developing countries and small island states within the tropics relying on coastal tourism are impacted not only directly by future sea-level rise and associated extremes but also by the impacts of coral bleaching and ocean acidification and reductions in tourist flows from other-regions **(***very high confidence*). [5.4.3, 5.5.3]

Specific regional examples include:

- In Africa, the impacts of climate change, mainly through sea level rise, combined with other extreme events (such as high tide levels and high storm swells) have the potential to threaten coastal zones, particularly coastal towns (*high confidence*). The example of the Kwa Zulu Natal coast (South Africa), where Durban is located, which was affected by a combination of high water level and high storm swell in March 2007, is indicative of what could happen. There is growing evidence that the costs of these impacts will increase for economic sectors and people living in these zones (*medium confidence*). [22.3.2, 22.3.7]
- In Africa, ocean ecosystems, in particular coral reefs, will be affected by climate-change-induced ocean acidification. Ocean ecosystems are also affected by changes in upwelling, with ramifications for crucial economic activities, mainly fisheries (*medium confidence*). [22.3.2, 22.3.4]
- In Europe, the costs of adapting dwellings or upgrading coast defence will increase under all scenarios (*high confidence*). Climate change will entail the loss or movement of coastal wetlands. [23.3.2, 23.6.5, 23.7.6]
- In Asia, coastal and marine systems are under increasing pressure from both climatic and non-climatic drivers (*high confidence*). Mean sea level rise will *very likely* contribute to upward trends in extreme coastal high water levels, and in the Asian Arctic, rising sea levels will interact with projected changes in permafrost and the length of the ice-free season to cause increased rates of coastal erosion (*high agreement, medium evidence*). Coastal freshwater swamps and marshes will be vulnerable to saltwater intrusion with rising sea levels. Widespread damage to coral reefs correlated with episodes of high sea-surface temperature has been reported in recent decades, and such damage will increase during the 21st century as a result of both warming and ocean acidification (*high confidence*). [24.4.3]
- In Australia, significant change in community structure of coral reef systems, driven by increasing sea-surface temperatures and ocean acidification, can be delayed but now appears very difficult to avoid entirely, even with combined globally effective mitigation and planned adaptation (*high confidence*). The natural ability of reefs to adapt to projected changes is limited. [Box CC-CR, 25.6.2, 30.5]
- In Australia and New Zealand, rising sea levels and increasing heavy rainfall are projected to increase erosion and inundation, with consequent damages to many low-lying ecosystems, infrastructure, and housing (*high confidence*). Widespread damages to coastal infrastructure and low-lying ecosystems would present major challenges <u>if</u> sea level rise exceeds 1m. Managed retreat is a long-term adaptation strategy for human systems, but options for some natural ecosystems are limited due to the rapidity of change and lack of suitable space for inland migration. Risks from sea level rise are *very likely* continue to increase beyond 2100 even if temperatures are stabilized. [WGI AR5 13.ES, Box 25-1, Table 25-1, 25.4.2, 25.6.1-2]
- In Brazil, fisheries' co-management—a participatory process involving local fishermen communities, government, academia, and NGOs—favors a balance between conservation of marine fisheries, coral reefs, and mangroves, and the improvement of livelihoods, as well as the cultural survival of traditional populations. [27.3.3]
- In the Arctic, the primary conservation concern for polar bears over the foreseeable future is the recent and projected loss of annual ice over continental shelves and decreased ice duration and thickness (*high confidence*). [28.2.2]

Marine systems

Physical effects of climate change on marine ecosystems may act, under some circumstances, as an additional pressure that cannot be ameliorated by local conservation measures or a reduction in human activities like fishing (*high confidence*). Effects of climate change will thus complicate management regimes, e.g. presenting direct challenges to the objectives of spatial management once species undergo large-scale distributional shifts. This increases the vulnerabilities of marine ecosystems and fisheries. [6.4]

Ocean acidification resulting from the increased flux of atmospheric CO_2 into the ocean represents a fundamental challenge to marine organisms and ecosystems, although the extent of its influence varies with the taxa and process involved (*high confidence*). Evidence from controlled laboratory experiments and mesocosm studies indicate that ocean acidification significantly impacts a large range of organisms (e.g., corals, fish, pteropods, coccolithophores, and macroalgae), physiological (e.g., skeleton formation, gas exchange, reproduction, growth, and neural function), and ecosystem processes (e.g., productivity, reef building, and erosion), but there are fewer field studies that have shown (or not shown) direct ecosystem changes. Ocean acidification and its effects are characterized in Box TS.9. [30.3.1, 30.3.2, 30.4, Box CC-OA, 6.2, 6.3, 6.5, Box 5-1, Box 6-2]

Several environmental drivers act simultaneously on ocean biota, often leading to interactive effects and complex responses (*high confidence*). Ocean acidification and hypoxia narrow thermal ranges and enhance sensitivity to temperature extremes in organisms such as corals, coralline algae, molluscs, crustaceans, and fishes. Genetic adaptation may occur; the capacity to compensate for or keep up with the rate of ongoing thermal change is limited (*low confidence*). [6.2, 6.3.2, 6.3.5, 6.5.2, 30.4, 30.5.3, 30.5.6, Box CC-CR]

The oceans currently provide about half of global net primary production (NPP). Environmental controls on NPP include temperature, CO_2, nutrient supply, and irradiance, all of which are projected to be altered (WGI AR5). The direction, magnitude, and regional differences of a change of NPP in the open ocean as well as in coastal waters have *limited evidence* and *low agreement* for a global decrease projected by 2100. At high (polar) latitude an increase in NPP is also projected with *low confidence*. [6.3.1, 6.5.1]

Modeling projects that, through species gains and losses in response to warming, the diversity of marine animals and plants will increase at mid and high latitudes (*high confidence*) and fall at tropical latitudes (*low confidence*), leading to a large-scale redistribution of global catch potential for fishes and invertebrates (*medium confidence*). If a decrease in global ocean net primary production or a shift downwards in the size spectrum of primary producers occurs, the overall fisheries catch potential will decrease. Animal displacements are projected to lead to a 30–70% increase in the fisheries yield of high-latitude regions but a drop of 40–60% in the tropics by 2055 relative to 2005 under the SRES A1B scenario (*medium confidence* for the general trend of shifting fisheries yields, *low confidence* for the magnitude of change). See Figure TS.9. Climate change impacts on the abundance and distribution of harvested aquatic species, both freshwater and marine, and aquaculture production systems in different parts of the world, are expected to continue with negative impacts on nutrition and food security for especially vulnerable people in some regions but with benefits in other regions that become more favorable for aquatic food production (*high agreement, medium evidence*). [6.2.5, 6.3.2, 6.4, 6.5, 6.5.2, 7.2.1, 7.3.2, 7.4.2, 7.5.1]

[INSERT FIGURE TS.9 HERE
Figure TS.9: A) Multi-model mean changes of projected vertically-integrated net primary production (small and large phytoplankton). To indicate consistency in the sign of change, regions are stippled where all models (four in total) agree on the sign of change. Changes are annual means under the SRES A2 scenario (between RCP 6.0 and 8.5) for the period 2080 to 2099 relative to 1870 to 1889. B) A projection of maximum fisheries catch potential of 1000 species of exploited fishes and invertebrates from 2000 to 2050 under the SRES A1B scenario. C) Example of changes occurring within fisheries across the ocean. [Figures 6-14, 6-15, and 30-15]]

The observed and projected impacts on ocean ecosystems and processes reveal significant regional differences that will benefit from differing policy responses and adaptation approaches (*medium agreement, medium evidence*). Changing distribution and abundance of fish species as waters warm and acidify suggest the need for flexible and informed decision-making. For example, tuna, a key fisheries species, are highly sensitive to changes in sea temperature, and changes in their distribution and abundance will provoke new technological and policy challenges. The cross-boundary migration of fish stocks (from the waters of one nation to another) will benefit from international cooperation and evidence-based decision making. [30.5.5, 30.6.3]

Building dynamic fisheries management and sustainable aquaculture represent opportunities for adaptation to changes in the distribution and productivity of fish stocks (*high agreement, medium evidence*). The application of ecosystem-based management that includes climate change to manage the development and maintenance of fish stocks represents a key tool for adapting to changes resulting from climate change. Reducing non-sustainable fishing (e.g., bottom trawling, "ghost" fishing) provides an avenue for adapting to climate impacts by reducing the impact of additional stressors. Changes to coastal fishing due to the loss of coastal ecosystems will require adaptation strategies such as marine protected areas, alternative livelihoods, and/or the movement of people and industry sectors. Key adaptations for fisheries are for policy and management to maintain ecosystems in a state that is resilient to change, to enable occupational flexibility, and to develop early warning systems for extreme events (*high agreement, medium evidence*). Industries such as nature-based tourism will require similar strategies for decision-making. [30.6.3, 6.5, 7.5.1]

Projected change to ocean ecosystems as a result of ocean warming and acidification will reduce access to food, and increase poverty and disease in many countries (*medium agreement, limited evidence*). Reduced access to food in some coastal regions as a result of declining fisheries will affect an increasing number of already vulnerable people and will result in associated health impacts. [30.6.3, 30.6.5, 6.4]

Climate change, by increasing temperatures and altering surface winds, has influenced ocean mixing, nutrient levels, and primary productivity. These changes are *very likely* to have positive consequences for some fisheries and negative ones for others through the de-oxygenation of deep water environments and associated spread of hypoxic zones (*medium agreement, medium evidence*). In regions where primary production has increased (or is predicted to increase), such as in the High Latitude Spring Bloom Systems, Eastern Boundary Upwelling Ecosystems, and Equatorial Upwelling, energy transfer to higher trophic levels is *likely* to increase along with microbial activity. Increased primary productivity is *likely* to lead to an increased transfer of organic carbon to deep sea habitats stimulating respiration and drawing down oxygen levels in some areas. These changes are further influenced by the contribution of nutrients from coastal pollution, leading to the expansion of hypoxic (low in oxygen) zones in areas such as the Gulf of Mexico, North Sea, Arabian Sea, and coastal areas of many countries. Increasing temperatures will also reduce the solubility of oxygen, adding to oxygen stress (*very high confidence*). [30.5.2, 30.5.4, 30.5.6, 6.2, 6.3, 6.5]

Changes to surface winds, sea level, wave height, and storm intensity will increase the risks associated with coastal and ocean based industries such as shipping, oil, gas, and mineral extraction (*medium agreement, medium evidence*). Storm impacts on coastal areas will increase with sea level rise through greater storm surge impacts. [WGI AR5 3.7.4] Strategies will require consideration of these changes in the design and use of ocean-based infrastructure together with the evolution of policy for reducing risks to equipment and people. New opportunities for shipping, oil, gas, and mineral extraction, as well as international issues over access and vulnerability, are expected to evolve as waters warm, particular in high latitude regions. [30.6, 6.5]

Ocean ecosystems and associated sub-regions offer a large potential for carbon dioxide mitigation strategies (*medium agreement, limited evidence*). Ecosystems such as mangroves, seagrass, and salt marsh represent potentially significant carbon sequestration strategies (e.g., "blue carbon"). Reducing highly anoxic habitats through coastal restoration (and hence the emission of methane) also represents significant mitigation opportunities, although an understanding of these opportunities is limited. Sequestration of anthropogenic CO_2 into deep ocean areas has been explored, although studies indicate significant hurdles with respect to expense and to the vulnerability of deep water marine ecosystems. [30.7]

Geoengineering approaches involving manipulation of the ocean to ameliorate climate change (e.g., purposeful nutrient fertilization, binding of CO_2 by enhanced alkalinity, and direct CO_2 injection into the deep ocean) have very large associated environmental footprints (*high confidence*), with some requiring purposeful alteration of ocean ecosystems for implementation. Alternative methods focusing on solar radiation management leave ocean acidification unabated. [6.4.2]

Specific regional examples include:

- In Europe, climate change will not decrease net fisheries economic turnover in some parts of Europe (e.g. Bay of Biscay) (*low confidence*) due to introduction of new (high temperature tolerant) species. Climate change will not entail relocation of fishing fleets (*high confidence*). High temperatures will increase frequency of harmful algal blooms (*medium confidence*). [23.4.6]
- In the polar regions, shifts in the timing of seasonal biomass production could disrupt matched phenologies in food webs, leading to decreased abundance of high latitude marine organisms (*medium confidence*). Ocean acidification has the potential to inhibit egg development and shell formation of some zooplankton and krill with potentially far-reaching consequences to food webs. Loss of sea ice in summer is expected to enhance secondary pelagic production in the Arctic with associated changes in the energy pathways within the marine ecosystem. [28.2.2, 28.3.2]

Food production systems and food security

Without adaptation, moderate warming of up to 2^{o}C local temperatures is expected to reduce yields on average for the major cereals (wheat, rice, and maize) in temperate regions, although many individual locations may benefit (*medium confidence*). There is confirmation that even modest warming up to 2°C will decrease yields in low-latitude tropical regions (*medium agreement, robust evidence*). Reductions of more than 5% are *more likely than not* beyond 2050 and *likely* by the end of the century. From the 2070s onwards, all of the positive yield changes are in temperate regions, suggesting that yield reduction in the tropics are *very likely* by this time and substantial, particularly for wheat (*high agreement, robust evidence*). [7.4, Figures 7-5, 7-6, and 7-7]

Changes in climate and CO_2 levels will enhance the distribution and increase the competiveness of agronomically important and invasive weeds (*high agreement, robust evidence*). Rising CO_2 reduces the effectiveness of herbicides (*high agreement, medium evidence*). The effects of climate change on disease pressure on food crops is uncertain, with evidence pointing to changed geographical ranges of diseases but less certain changes in disease intensity (*low agreement, medium evidence*). [7.3.2]

Impacts of increased heat stress and more frequent extreme events will be negative in all regions for livestock (*high agreement, robust evidence*). Changes in animal diseases and vectors are less certain (*medium agreement, medium evidence*). Livestock systems' adaptations center around adjusting management to the available resources, using breeds better adapted to the prevailing climate, and removing barriers to adaptation such as improving credit access (*medium evidence, medium agreement*). [7.3.2, 7.5]

Adaptation possibilities of food systems to climate change show a very wide range in effectiveness, with *medium confidence* that adaptation will increase in effectiveness with increasing local mean temperature up to ca. 3°C local warming above pre-industrial, after which the net benefits no longer increase (*medium agreement, medium evidence*). Most studies, however, have focused on food production rather than on adapting food systems. Generally, adaptation leads to lower reductions in food production than in its absence with an overall crop yield difference in adaptation cases of about 15-20% over non-adaptation cases (*high agreement, medium evidence*), with more effective adaptation at higher latitudes (*medium agreement, limited evidence*), but with some adaptation options more effective than others. Thus, benefits of adaptation are greater for wheat, rice, and maize in temperate rather than tropical regions (see Figure TS.10). A range of potential adaptation options exists across all food system activities, not just in food production, but benefits from potential innovations in food processing, packaging, transport, storage, and trade are insufficiently researched. [7.1, 7.3.2, 7.5, 7.6, Figure 7-5, Figure 7-9] Urban food-adaptation is linked to progressive public policy on food security and livelihood development, addressing constraints in agricultural production and food supply chains, and limiting the impact of food price shocks caused by extreme events on the food and nutrition security of the poor. [8.3]

[INSERT FIGURE TS.10 HERE
Figure TS.10: Projected changes in crop yield as a function of time. The y-axis indicates degree of consensus and the colors denote percentage change in crop yield. Data are plotted according to the 20-year period in which the center point of the projection period falls. [Figure 7-6]]

Specific regional examples include:

- In Africa, recent evidence further strengthens a key finding from the AR4 that "agricultural production and food security (including access to food) in many African countries and regions are *likely* to be severely compromised by climate change and climate variability" (*high confidence*). Temperature rise and a reduction in growing season length by mid-century are expected to significantly reduce crop productivity with strong adverse effects on food security. New evidence is also emerging that fisheries and high-value perennial crops could also be adversely affected by temperature rise, and that the pressure of pest and diseases on crops and livestock is expected to increase as a result of climate change and other factors. Moreover, new challenges to food security are emerging as a result of strong urbanization trends on the continent and increasingly globalized food chains, which require better understanding of the multi-stressor context of food and livelihood security in Africa. [22.3.4]
- In Europe, climate change will increase yields in Northern Europe (*medium confidence*) but decrease cereal yields in Southern Europe (*high confidence*). Compared to AR4, new evidence regarding future yields in Northern Europe is less consistent regarding the magnitude and sign of change. In Northern Europe, climate change will increase the seasonal activity of pests and plant diseases (*high confidence*). Climate change will adversely affect dairy production in Southern Europe because of heat stress in lactating cows (*medium confidence*). Climate warming has caused the spread of blue tongue disease in ruminants in Europe (*high confidence*) and northward expansion of tick vectors (*medium confidence*). [23.4.1, 23.4.2, 23.5.1]
- In Europe, climate change will increase irrigation needs (*high confidence*), but future irrigation will be constrained by reduced runoff, demand from other sectors, and economic costs. By 2050s, irrigation will not be sufficient to prevent damage from heat waves to crops (*medium confidence*). System costs will increase under all climate scenarios (*high confidence*). Integrated management of water can address future competing demands among agriculture, conservation, and human settlements. [23.4.1, 23.4.3, 23.7.2]
- In Europe, shifts in agriculture production across sub-regions will occur (*medium confidence*). Climate change will alter the productivity of bioenergy crops by shifting their distribution northward (*high confidence*). Elevated atmospheric CO_2 can improve drought tolerance of bioenergy crop species due to improved plant water use, maintaining high yields in future climate scenarios (*medium confidence*). [23.4.5] Climate change will change the geographic distribution of wine grape varieties (*high confidence*). This will reduce the economic value of wine products and the livelihoods of local wine communities in Southern and Continental Europe (*medium/low confidence*). Some adaptation is possible through technologies and good practice. [23.3.5, 23.4.1, 23.4.5, 23.5.4, Box 23-1]
- In Asia, the impacts of climate change on food production and food security will vary by region with many regions experiencing a decline in productivity (*medium confidence*). This is evident in the case of rice production. Most models using a range of GCMs and SRES scenarios show that higher temperatures will lead to lower rice yields as a result of shorter growing periods and heat-induced sterility. There are a number of regions that are already near the critical temperature threshold. However, CO_2 fertilization may at least in part offset yield losses in rice and other crops. In Central Asia, some areas could be winners (cereal production in northern and eastern Kazakhstan could benefit from the longer growing season, warmer winters, and slight increase in winter precipitation), while others could be losers (western Turkmenistan and Uzbekistan, where frequent droughts could negatively affect cotton production, increase water demands for irrigation, and exacerbate desertification). In the Indo-Gangetic Plains of South Asia, there could be up to 50% decrease in the most favorable and high yielding wheat area due to heat stress at 2x CO_2. There are many potential adaptation strategies such as crop breeding, but research on their effectiveness is limited. [24.4.4]
- In Australia and New Zealand, rainfall changes and rising temperatures will shift agricultural production zones (*high confidence*). Significant reduction in food production in the Murray-Darling Basin, far south-eastern Australia, and some eastern and northern areas of New Zealand would present major challenges if scenarios of severe drying are realized. More efficient water use, allocation, and trading would increase the resilience of systems in the near term but cannot prevent significant reductions in agricultural production and severe consequences for ecosystems and some rural communities at the dry end of the projected range. [25.2, 25.5.1, 25.7.2, Box 25-5]
- In North America, without adaptation, projected changes in temperature, precipitation, and extreme events would result in notable productivity declines in major crops by the end of the 21st Century (*very high confidence*). Given that North America is a significant source of global food supplies, there will *likely* be a

negative effect on global food security if projected productivity declines are not addressed with substantial investments in adaptation (*medium confidence*). Adaptation may ameliorate many climate impacts to North American agriculture, but the institutional support mechanisms currently in place are insufficient to ensure effective, equitable, and sustainable adaptation strategies. [26.5]

- In Central and South America, changes in agricultural productivity in response to climate change are expected to have a great spatial variability. In Southeastern South America, where projections indicate more rainfall, average productivity could be sustained or increased until the mid-century (SRES: A2, B2) (*medium confidence*). In Central America, northeast of Brazil, and parts of the Andean region, increases in temperature and decreases in rainfall could decrease the productivity in the short-term (before 2025), threatening the food security of the poorest population (*medium confidence*). The great challenge for Central and South America will be to increase food and bioenergy production and at the same time sustain environmental quality in a scenario of climate change. [27.3.4]
- In the Arctic, significant impacts on the availability of key subsistence marine and terrestrial species are projected as climate continues to change with the ability to maintain economic livelihoods being affected (*high confidence*). Changing sea-ice conditions will result in more difficult access for hunting marine mammals. [28.2.6]

Urban areas

Increasing concentration of populations, assets, and economic activities in the urban areas of almost all countries, irrespective of income level, will increase the concentration of climate-related risks for a large and growing proportion of the world's population (*medium confidence*, based on *high agreement, medium evidence*). This could threaten economic and development processes, poverty reduction, and ecological sustainability. Furthermore, projections for the next few decades suggest that it is in and around urban areas that almost all the increase in the world's population and much of the increment in capital formation, economic activity, infrastructure development, ecosystem degradation, and emissions will take place. [8.1, 8.3, 8.4]

Adapting urban centers' economic base can enhance comparative advantage, deepen climate resilience, and limit disadvantage (*high agreement, medium evidence*). Climate change will shift the comparative advantages of cities and regions and differentially threaten or enhance the resource, asset, and economic base and so lead to significant structural changes and impacts on local, national, and potentially the global economy. Effective adaptation can protect a city's economic base via a mix of strategies. These include extreme weather exposure reduction via effective land-use planning, selective relocation and structural measures, reduction in the vulnerability of lifeline infrastructure and services, and measures to assist vulnerable sectors and households, mitigation of business interruption and capital stock losses, and support to the "waste economy" and the "green economy." These adaptation actions may be easier and cheaper to implement in new and peri-urban development. [8.3]

Good quality, affordable, and well-located housing provides one of the bases for city-wide adaptation (*high confidence*), by conforming to appropriate health and safety and climate-resilient building standards and having sufficient residual structural integrity over its service life to protect its occupants against extreme weather, especially heat waves and storms. It is particularly important for vulnerable groups, especially children and older residents with chronic health conditions. This can be enabled via a range of structural interventions, interventions that reduce risks to housing and support access to quality housing for low-income groups, non-structural interventions (like insurance), and disaster risk reduction measures. Well-coordinated strategies are required to address a multiplicity of agencies working at various levels, overlapping regulations, and lack of committed resources. [8.3]

Rural areas

Future impacts of climate change on the rural economic base and livelihoods, land-use, and regional interconnections are at the latter stages of complex causal chains (*high confidence*). These flow through changing patterns of extreme events and/or effects of climate change on biophysical processes in agriculture and less-managed ecosystems. This increases the uncertainty associated with any particular projected impact. [9.3.3]

Major impacts of climate change in rural areas will be felt through impacts on water supply, food security, and agricultural incomes (*high confidence*). In certain countries shifts in agricultural production, of food and non-food crops, could take place. Areas suitable for cultivation of coffee, tea and cocoa, which support millions of smallholders in over 60 countries, will be significantly reduced. Price rises, which may be induced by extreme weather events apart from other factors, have a disproportionate impact on the welfare of the poor in rural areas, such as female-headed households and those with limited access to modern agricultural inputs, infrastructure, and education. Adaptation can build on current responses to climate variability, in production of food crops, cash crops and livestock and in water management, but these may not be sufficient to deal with the range of projected climate change. [9.3.3, 9.3.4, 9.4.1, 9.4.3]

Climate change will lead to higher prices and increased volatility in agricultural markets, which might undermine global food supply security while affecting rural households depending on whether they are net buyers or net sellers of food (*medium* to *high confidence*). Deepening agricultural markets through reforming trade and making institutional efforts to improve the predictability and the reliability of the world trading system, as well as by investing in additional supply capacity of small-scale farms in developing countries, could help reduce market volatility and manage food supply shortages that might be caused by climate change (*medium agreement*). [9.3.3]

Most studies on valuation highlight that climate change impacts will be significant especially for the developing regions, due to their economic dependence on agriculture and natural resources, low adaptive capacities, and geographical locations (*high confidence*). Valuation of climate impacts needs to draw upon both monetary and non-monetary indicators. The valuation of non-marketed ecosystem services and the limitations of economic valuation models which aggregate across multiple contexts pose challenges for valuing impacts in rural areas. [9.3.4]

Specific regional examples include:

- In parts of Asia, increases in flood and drought will exacerbate rural poverty due to negative impacts on rice crops and increases in food prices and the cost of living (*high confidence*). [24.4.6]

Key economic sectors and services

Climate change would reduce energy demand for heating and increase energy demand for cooling in the residential and commercial sectors (*high agreement, robust evidence*). The balance of the two depends on the geographic, socioeconomic, and technological conditions. Increasing income will allow people to regulate indoor temperatures to a comfort level that leads to fast growing energy demand for air conditioning even in the absence of climate change in warm regions with low income levels at present. Energy demand will be influenced by changes in demographics (upwards by increasing population and decreasing average household size), lifestyles (upwards by larger floor area of dwellings), the design and heat insulation properties of the housing stock, the energy efficiency of heating/cooling devices, and the abundance and energy efficiency of other electric household appliances. The relative importance of these drivers varies across regions and will change over time. [10.2]

Climate change would affect different energy sources and technologies differently, depending on the resources (water flow, wind, insolation), the technological processes (cooling), or the locations (coastal regions, floodplains) involved (*high agreement, robust evidence*). Gradual changes in various climate attributes (temperature, precipitation, windiness, cloudiness, etc.) and possible changes in the frequency and intensity of extreme weather events will progressively affect operation over time. Climate-induced changes in the availability and temperature of water for cooling are the main concern for thermal and nuclear power plants, but several options are available to cope with reduced water availability. Similarly, already available or newly developed technological solutions allow firms to reduce the vulnerability of new structures and enhance the climate suitability of existing energy installations. [10.2]

Climate change would influence the integrity and reliability of pipelines and electricity grids (*medium agreement, medium evidence*). Pipelines and electric transmission lines have been operated for over a century in diverse climatic conditions on land from hot deserts to permafrost areas and increasingly at sea. Climate change is *about as likely as not* to require the adoption of technological solutions for the construction and operation of pipelines and power transmission and distribution lines from other geographical and climatic conditions, adjustments in existing pipelines, and improvements in the design and deployment of new ones in response to the changing climate and weather conditions. [10.2]

Climate change would negatively affect transport infrastructure (*high agreement, limited evidence*). Transport infrastructure malfunctions if the weather is outside the design range, which would happen more frequently should climate change. All transportation infrastructure is vulnerable to freeze-thaw cycles; paved roads are particularly vulnerable to temperature extremes and unpaved roads to precipitation extremes. Transport infrastructure on ice or permafrost is especially vulnerable. [10.4]

Climate change would affect tourism resorts, particularly ski resorts, beach resorts, and nature resorts (*high agreement, robust evidence*), and tourists would be inclined to spend their holidays at higher altitudes and latitudes (*high agreement, medium evidence*). The economic implications of climate-change-induced changes in tourism demand and supply may be substantial, with gains for countries closer to the poles and higher up the mountains and losses for other countries. The demand for outdoor recreation is affected by weather and climate, and impacts will vary geographically and seasonally. [10.6]

Climate change would affect the health sector (*high agreement, medium evidence*) through increases in the frequency, intensity, and extent of extreme weather events adversely affecting infrastructure and increase the demands for services due to the human health impacts of climate change, placing additional burdens on public health, disease burden, and health care personnel and supplies; these have economic consequences. [10.8]

Climate change would have impacts, heterogeneous in both sign and size, on water resources and water use (*high agreement, robust evidence*), but the economic implications are not well understood. Economic impacts include flooding, scarcity, and cross-sectoral competition. Water scarcity and competition for water, driven by institutional, economic, or social factors, may mean that water assumed to be available for a sector is not. [10.3]

The impacts of climate change would decrease productivity and economic growth, but the magnitude of this effect is not well understood (*high agreement, limited evidence*). Climate could be one of the causes why some countries are trapped in poverty, and climate change may make it harder to escape poverty traps. [10.9]

Not all key sectors have been subject to detailed research based on a comprehensive assessment across economic sectors. Few studies have evaluated the possible impacts of climate change on mining, manufacturing, or services (apart from health, insurance, and tourism). Further research, collection, and access to more detailed economic data and the advancement of analytic methods and tools will be required to further assess the potential impacts of climate on key economic systems and sectors. [10.5, 10.8, 10.10]

Specific regional examples include:

- In Europe, climate warming will decrease space heating demand and increase cooling demand (*high confidence*), with income growth driving the largest part of this increase from 2000-2050 (especially in eastern regions) (*medium confidence*). Energy efficient buildings and cooling systems as well as demand-side management will reduce future energy demands. Climate change will increase the problems associated with overheating in domestic housing. [23.3.2, 23.3.4]
- In Europe, climate change will decrease hydropower production from reductions in rainfall in all sub-regions except Scandinavia (*high confidence*). Climate change will have no impact on wind energy production before 2050 (*medium confidence*) and only a small impact after 2050 (*low confidence*). Climate change will inhibit thermal power production during summer (*medium confidence*). Plant modifications and operational changes can reduce adverse impacts. [23.3.4]
- In Europe, climate change is *likely* to further increase coastal and river flood risk and, if unabated, will substantially increase flood damages (monetary losses and people affected). Adaptation can prevent most of the projected damages (*high confidence*, based on *high agreement*, *medium evidence*). [23.3.1, 23.5.1, 23.7.1, 23.8.3]
- In Europe, climate change will affect the impacts of hot and cold weather extremes on transport leading to economic damage and/or adaptation costs, as well as some benefits during winter (e.g., reduction of maintenance costs) (*medium confidence*). Climate change will reduce severe accidents in road transport and adversely affect inland water transport particularly the Rhine in summer after 2050. Damages to rail

infrastructure from high temperatures will increase. Adaptation through maintenance and operational measures can reduce adverse impacts to some extent. [23.3.3]
- In Europe, no significant impacts are projected before 2050 in winter or summer tourism except for ski tourism in low altitude and mid altitude sites and under limited adaptation (*medium confidence*). After 2050, tourism activity will decrease in southern Europe (*low confidence*) and increase in northern/continental Europe (*medium confidence*). Artificial snowmaking will prolong the activity of some ski resorts (*medium confidence*). [23.3.6]
- In Europe, the capacity to adapt will be higher than for other world regions, but there are important differences in impacts and the capacity to respond within the European sub-regions. Climate change will affect economic activity in southern Europe more than other sub-regions (*medium confidence*), [Table 23.4, 23.9.1] and increase future intra-regional disparity (*low confidence*). [23.9] The Mediterranean (part of Southern region) is particularly vulnerable to climate change as multiple sectors will be adversely affected (tourism, agriculture, forestry, infrastructure, energy, population health) (*high confidence*). [23.9, 23.9.1, Box 23-3, Table 23.4]
- In Australia and New Zealand, increased frequency and intensity of flood damage to settlements and infrastructure are projected, driven by increasing extreme rainfall although the amount of change remains uncertain (*high confidence*). In many locations, continued reliance on increased protection alone would become progressively less feasible. Increased damages to ecosystems and settlements, economic losses, and risks to human life from wildfires in most of southern Australia and many parts of New Zealand are projected, driven by drying trends and rising temperatures (*high confidence*). Building codes, design standards, local planning mechanisms, and public education can assist with adaptation and are being implemented in regions that have experienced major events. These impacts have the potential to be severe but can be moderated or delayed significantly by globally effective mitigation combined with adaptation, with an increasing need for transformative adaptation for greater rates and magnitude of change. [25.2, Table 25-1, 25.4.2, 25.6.1, 25.7.1, Box 25-6, 25.10.3, Box 25-8]
- In New Zealand and southern parts of Australia, projected changes in climate have the potential to reduce energy demand for winter heating (*high confidence*). [25.7.4]
- In North America, there is an emerging concern that dislocation in one sector of the economy may have an adverse impact on other sectors due to supply chain interdependency (*medium confidence*). [26.7]
- In the Arctic, climatic and other large-scale changes can have potentially large effects on communities where relatively small and narrowly based economies leave a narrower range of adaptive choices (*high confidence*). Increased economic opportunities and challenges for culture, security, and environment are expected with the increased navigability of Arctic marine waters and the expansion of land- and fresh water-based transportation networks. Rising temperatures, leading to the further thawing of permafrost and changing precipitation patterns, have the potential to affect all infrastructure types and related services in the Arctic. [28.2.6, 28.4.2]

Human health

If climate change continues as projected in scenarios in the next few decades, the major increases of ill-health compared to no climate change will occur with *high confidence* through:
- Greater incidence of injury, disease, and death due to more intense heat waves, storms, floods, and fires.
- Increased risk of under-nutrition resulting from diminished food production in poor regions.
- Loss of work capacity and reduced labor productivity in vulnerable populations.
- Increased risks of food- and water-borne diseases and vector-borne infections.
- Modest improvements in some areas due to lower impacts of cold, shifts in food production, and reduction of disease-carrying vectors. These positive effects will be out-weighed, world-wide, by the magnitude and severity of the negative effects of climate change.

Impacts on health will be reduced, but not eliminated, in populations that benefit from rapid social and economic development, particularly among the poorest and least healthy groups. [11.4, 11.5, 11.6, 11.7]

For RCP 8.5 by 2100, most of the world land area will be experiencing annual mean temperatures at least 4°C above those of 1986-2005. This means that important limits to adaptation for health impacts may have been exceeded in many areas of the world during this century (*high confidence*). These relate to sea level rise, storms, loss of agricultural productivity, and daily temperature/humidity conditions that exceed coping mechanisms, making potentially large areas seasonally unsuitable for normal human activities, including growing food or working outdoors. [11.8]

Climate change is expected to substantially affect regional air quality, for example near surface ozone concentrations; however, this effect also depends strongly on future emissions. [21.3.3, 21.5.3]

The most effective adaptation measures for health in the immediate term are programs that extend basic public health measures and essential health services, increase capacity for disaster preparedness and response, and alleviate poverty (*very high confidence*). [11.6]

Specific regional examples include:

- In Africa, climate change is expected to increase the burden of a wider range of health outcomes (*medium confidence*). Findings on malaria are similar to AR4, emphasizing the spatial and temporal spread of malaria in the East Africa Highlands and increased transmission intensity in South Africa. Indirectly, climate change could increase the burden of malnutrition, which will have the highest toll on children and women. Adaptation in the health sector will build on existing public health interventions as well as specific adaptation measures such as early warning systems. [22.3.5, 22.4.5]
- In Europe, climate change will increase the frequency tropospheric ozone events (exceedences) in the future (*low confidence*), even assuming future emissions reductions. [23.6.1]
- In Europe, particularly in Southern Europe, climate change will increase the frequency and intensity of heat waves (*high confidence*) with adverse implications for health, agriculture, energy production, transport, tourism, labour productivity, and built environment, and heat-related deaths and injuries will increase (*medium confidence*). Climate change will change the distribution and seasonal pattern of some human infections, including those transmitted by arthropods. [23.2.2, 23.5.1, Table 23.4]
- In Asia, more frequent and intense heat-waves will increase mortality and morbidity in vulnerable groups. Increases in heavy rain and temperature will increase the risk of diarrheal diseases and malaria (*high confidence*). [24.4.6]
- In Australia, increasing morbidity, mortality, and infrastructure damages during heat waves, resulting from increased frequency and magnitude of extreme temperatures, have the potential to be severe but can be moderated or delayed significantly by globally effective mitigation combined with adaptation (*high confidence*). Vulnerable populations include the elderly, children, and those with existing chronic diseases; aging trends and prevailing social dynamics constrain effectiveness of adaptation responses, with an increasing need for transformative adaptation for greater rates and magnitude of change. [25.8.1]
- In New Zealand and southern parts of Australia, projected changes in climate have the potential to reduce morbidity from winter illnesses (*high confidence*). [25.8.1]
- In North America, the effect of increasing heat extremes on health will depend on the pace of adaptation (*high confidence*). Given current levels of adaptation, there are *likely* to be increased health impacts from heat extremes among vulnerable communities, populations, and individuals. Conditional on an increase in storm severity under a changing climate, there are *likely* to be continued human health risks in the absence of specific adaptation planning. [26.6]
- In Central and South America, climate variability and change may exacerbate current and future risks to health, given the region's vulnerabilities in existing health, water, sanitation and waste collection systems, nutrition, and pollution. [27.3.7]

Human security

Climate change threatens human security, because it a) undermines livelihoods, b) compromises culture and identity, c) increases migration that people would rather have avoided, and d) undermines the ability of states to provide the conditions necessary for human security (*high agreement, robust evidence*). Human security breakdowns almost never have single causes, but instead emerge from the interaction of multiple factors. For populations that are already socially marginalized, are resource dependent, and have limited capital assets, human security will be progressively undermined as the climate changes. Increases in the rate and magnitude of climate change increase the risk to human security by exacerbating negative feedbacks between cultural processes, migration, and violent conflict. See Figure TS.11. [12.1.2, 12.2, 12.7]

[INSERT FIGURE TS.11 HERE
Figure TS.11: Synthesis of evidence on the impacts of climate change on elements of human security and the interactions between elements. Examples of positive and negative changes in security associated with interventions indicated by arrows. [Figure 12-3]]

Climate change will have significant impacts on forms of migration that compromise human security (*medium agreement, medium evidence*). Some migration flows are sensitive to changes in resource availability and ecosystem services. Major extreme weather events have in the past led to significant population displacement, and changes in the incidence of extreme events will amplify the challenges and risks of such displacement. There is evidence that many vulnerable groups do not have the resources to be able to migrate to avoid the impacts of floods, storms, and droughts. There is evidence from models, scenarios, and observations that coastal inundation and loss of permafrost can lead to migration and resettlement. Migrants themselves may be vulnerable to climate change impacts in destination areas, particularly in urban centers in developing countries. [9.3.3, 12.3.2, 12.4.2]

Climate change will lead to new challenges to states and will shape both conditions of security and national security policies (*medium agreement, medium evidence*). Physical aspects of climate change, such as sea level rise, extreme events, and hydrologic disruptions, pose major challenges to vital transportation, water, and energy infrastructure. Some states are experiencing major challenges to their territorial integrity, including Arctic countries, small island states, and other states highly vulnerable to sea level rise. Some impacts of climate change, such as changes in sea ice, transboundary and shared water resources, and the migration of pelagic fish stocks, have the potential to increase rivalry among states. There is evidence that the presence of robust institutions can manage many of these rivalries such that human security is not severely eroded. These threats to national security will affect the capacity of states and communities to provide human security. [12.5.4, 12.6]

Climate change affects cultures and the cultural expressions important for maintaining identity and traditional and local forms of knowledge (*high agreement, medium evidence*). Climate change impacts will lead to significant changes in environmental and societal conditions throughout the natural world, and in human settlements. These changes will compromise dimensions of the cultural core and assets that are highly valued by societies. The magnitude of the perceived loss depends on the robustness of cultural identity and the mechanisms for maintaining and transferring knowledge. [12.3]

Specific regional examples include:

- In Europe, climate change and sea level rise will damage European cultural heritage, including buildings, local industries, landscapes, and iconic places such as Venice (*medium confidence*), and some cultural landscapes will be lost forever (*low/medium confidence*). [23.5.4, Table 23-5]
- In the Arctic, impacts on human health and well-being from climate change are significant and projected to increase, especially for many indigenous peoples (*high confidence*). Impacts include injury and risk from changes in extreme weather and ice and snow conditions; decreased access to local foods and compromised freshwater sources; permafrost and erosion damage to infrastructure; and loss of traditional livelihood, language, culture, and relocation of communities. These impacts are expected to vary among diverse settlements, and are often related to the large percentage of northern settlements along coastlines or beside rivers and lakes. [28.2.4]

Livelihoods and poverty

Climate change will create new poor, in low-income countries and middle- to high-income countries, and will jeopardize sustainable development. Most severe impacts are projected for urban areas and some regions in sub-Saharan Africa and Southeast Asia (*medium confidence*, based on *medium agreement, medium evidence*). Future impacts of weather events and climate will slow down economic growth and poverty reduction, further erode food security, and trigger new poverty traps, the latter particularly in urban areas. Climate change will exacerbate multidimensional poverty in low and lower middle-income countries, including high mountain states and countries with indigenous people threatened by sea level rise and relocation, and create new poverty pockets in upper middle-to high-income countries. Urban and wage-labor dependent poor households, as well as regions with high food insecurity, above all in Africa, and high inequality, will be particularly affected due to food price increases. [13.2.2, 13.4]

Social protection programs can help the chronically poor reduce risk and protect assets during crises, through transfers of income or assets to the poor, protection against livelihood risks, and enhancement of the social status and rights of the marginalized (*medium confidence*). However, existing projects have offered few concrete suggestions on how to address underlying social and political vulnerabilities and inequalities that inhibit adaptation. Also, there is *limited evidence* that such programs strengthen local collective capacity to act, for instance to install or modify risk-reducing infrastructure and services, or address the incapacity in local governments in provision for water, sanitation, drainage, health care, and emergency services. Existing examples underscore the need to explicitly address livelihood security and resilience in the long-term, rather than focusing on short-term disaster relief. [13.4]

Specific regional examples include:

- In North America, climate change impacts can hamper progress towards sustainability and have the potential to exacerbate existing challenges such as deficits in infrastructure or in institutional capacity to promote the health and wellbeing of human populations (*high confidence*). [26.7, 26.9]

Regional risks

Figure TS.12 provides a synthesis of sectoral risks for several regions, based on the expert judgment of assessment authors. Risks are estimated for the era of climate responsibility (here, for 2030-2040) and for the era of climate options (here, for 2080-2100) under different levels of global average warming dependent on mitigation outcomes (about +2 or +4°C global average warming above preindustrial in 2080-2100). Risks are summarized sector by sector, reflecting the overall structure of the WGII report (Part A). Risks, indicated by colored shading, are estimated for low to high adaptation to indicate opportunities for reducing risks through adaptation. Distance of this shading from the center of each diagram indicates the level of risk, with greater distance corresponding to higher risk. Examples of specific risks are presented in Table TS.5.

Assessed impacts across Europe are summarized in Table TS.6. Key regional risks for Australia and New Zealand are presented for the era of climate options in Table TS.7. Observed changes in climate and other environmental factors are shown for Central and South America in Figure TS.13. Key risks and vulnerabilities for the ocean's regions are depicted in Figure TS.14.

[INSERT FIGURE TS.12 HERE
Figure TS.12: Estimated risk from climate change to selected sectors and systems in Africa (A), Europe (B), and North America (C), for different time frames (2030-2040 and 2080-2100), under two levels of global average warming above preindustrial (2°C and 4°C) and different assumptions about adaptation to manage these risks. Levels of risk and of adaptation are differentiated by colored shading, ranging from high adaptation to low adaptation. Estimated risks rely on expert judgments. The risk categories reflect the overall structure of Part A of the WGII AR5. [Figures 22-7 and 26-6]]

[INSERT TABLE TS.5 HERE
Table TS.5: Examples of risks that increase with increasing level of climate change. Examples of potential positive impacts are also given. Risks increasing moderately or severely from now until the 2040s, which can be considered an era of climate responsibility, are described, in addition to risks increasing from ~2050 through the end of the 21st century, which can be considered to represent an era of climate options. For risks increasing in both the era of climate responsibility and the era of climate options, the potential for proactive adaptation to reduce the risks is characterized as low or high, with detail provided on adaptation issues and prospects. Risks increasing in the era of climate options can generally be reduced through globally effective mitigation occurring during the era of climate responsibility and the era of climate options. Increasing risks in the era of climate responsibility are generally difficult to reduce substantially through mitigation, even with globally effective mitigation. They can be managed through vulnerability reduction, adaptation, and transformations that promote climate-resilient development pathways.]

[INSERT TABLE TS.6 HERE
Table TS.6: Assessment of climate change impacts by European sub-region and sector (by 2050, medium emissions) With economic development, with land use change. No further planned adaptation. [Table 23-4]]

[INSERT TABLE TS.7 HERE
Table TS.7: Key regional risks during the 21st century from climate change for Australia and New Zealand. Color bars indicate risk as a function of global mean temperature relative to pre-industrial, based on the studies assessed and expert judgement, for the current (top bar) and a hypothetical fully adapted state (bottom bar). For each risk, relevant climate variables and trends are indicated by symbols, in approximate order of priority. Where relevant climate projections span a particularly wide range even for a given amount of global mean temperature change, risks are shown in two pairs for high and low end projections, each without and with effective adaptation. [Table 25-8]]

[INSERT FIGURE TS.13 HERE
Figure TS.13: Summary of observed changes in climate and other environmental factors in representative regions of Central and South America. The boundaries of the regions in the map are conceptual (not precise geographic nor political) and follow those developed in SREX Figure 3-1. [Figure 27-7]]

[INSERT FIGURE TS.14 HERE
Figure TS.14: Summary of key risks and vulnerabilities associated with climate change on the world's ocean regions. [Figure 30-15]]

C.ii. Key and Emergent Risks

Key risks are potential adverse consequences for humans and social-ecological systems due to the interaction of climate-related physical hazards with vulnerabilities of societies and systems exposed. Risks are considered "key" due to high physical hazard or high vulnerability of societies and systems exposed, or both. [Box 19-2]

Key risks resulting from the interaction of hazardous climate changes and physical impacts with the vulnerability of societies and exposed systems, identified with *high confidence* [19.6.2], include the following:

- The risk for increased food insecurity can result from both local conditions like adverse changes in rainfall patterns and a lack of alternative sources of income for some affected households, as well as regional and national conditions like a breakdown of food distribution and storage processes.
- The risks of dispossession of land—including the alteration of rural inhabitants' coping and adaptation processes—result from shifts in energy policies and global markets.
- The risk of loss of livelihoods due to changes in climatic conditions and socioeconomic structures affects people living in low-lying coastal zones and people engaged in rain-fed agriculture in developing countries and countries with economies in transition.
- The risks of increasing morbidity, mortality, and infrastructure failure as well as new systemic risks (such as the risk of heat stress as a result of power shortages during extreme events) affect urban areas in both developed and developing countries.
- The risk of increase in disease burden results from the interaction of changes in physical climate conditions like increasing temperatures with the vulnerability of people due to, for example, an aging population.

Consequences of global temperature rise in excess of 4°C relative to preindustrial levels can now be assessed. See Box TS.6. Key risks associated with large temperature rise include exceedance of human physiological limits in some locations and nonlinear earth system responses (*high confidence*). There may also be key risks in other sectors and regions that have not been studied in this context. [19.5.1]

Interactions among climate change impacts in various sectors and regions, and human vulnerability and adaptation in other sectors and regions, as well as interactions between adaptation and mitigation actions, are generally not included, or not well integrated, into projections of climate change impacts. Their consideration leads to the identification of a variety of emergent risks (*high confidence*). [19.3] Several such complex-system interactions that increase vulnerability and risk are identified with *high confidence*, for example:

- The risk of severe harm and loss due to climate change-related hazards and various vulnerabilities is particularly high in large urban and rural areas in low-lying coastal zones. These areas, many characterized by increasing populations, are exposed to multiple hazards and potential failures of critical infrastructure, generating new systemic risk. [19.3.2]
- The risk of climate change to human systems is increased by the loss of ecosystem services (e.g., water and air purification, protection from extreme weather events, preservation of soils, recycling of nutrients, and pollination of crops), which are supported by biodiversity. [19.3.2]
- In some water stressed regions, groundwater stores that have historically acted as buffers against climate change impacts are being depleted, with adverse consequences for human systems and ecosystems, whilst at the same time climate change may directly increase or decrease regional groundwater resources. [19.3.2]
- Climate change adversely affects human health, increasing exposure and vulnerability to a variety of other stresses, for example by altering the prevalence and distribution of diseases that are weather and climate sensitive, increasing injuries and fatalities resulting from extreme weather events, and eroding mental health in response to population displacement. [19.3.2]
- Spatial convergence of impacts in different sectors creates impact "hotspots" involving new interactions (Figure TS.15). Examples include the Arctic (where sea ice loss and thawing disrupts transportation, buildings, other infrastructure, and potentially disrupts Inuit culture); the environs of Micronesia, Mariana Island, and Papua New Guinea (where coral reefs are highly threatened due to exposure to concomitant sea surface temperature rise and ocean acidification); and Sub-Saharan Africa (where global warming at the high end of the range projected for this century, i.e., more than 4°C above preindustrial levels, would be especially disruptive, resulting in high risk of reduced extent of croplands, reduced length of the growing season, increased hunger, and increased malaria transmission). [19.3.2]

[INSERT FIGURE TS.15 HERE
Figure TS.15: Some salient examples of multi-impacts hotspots identified in this assessment. [Figure 19-2]]

Emergent risks also arise from indirect, trans-boundary, and long-distance impacts of climate change, sometimes mediated by the adaptive responses of human populations (*high confidence*). Responses to climate change can result from localized impacts that generate distant harm via responses transmitted through human or ecological systems. [19.4] Several such emergent risks are identified with *high confidence*, for example:

- Increasing prices of food commodities on the global market due to local climate impacts, sometimes in conjunction with demand for biofuels, decrease food security and exacerbate malnutrition at distant locations. [19.4.1]
- Climate change will bear significant consequences for migration flows at particular times and places, creating risks as well as benefits for migrants and for sending and receiving regions and states. [19.4.2]
- The possibility that climate change will alter patterns of violence is a risk emerging in the literature. The effect of climate change on conflict and insecurity has the potential to become a key risk because the reported magnitude of the influence of the climate's variability on security is large. [19.4.2]
- Shifting species ranges in response to climate change adversely affect ecosystem function and services while presenting new challenges to conservation efforts. Where range shifts cannot track climatic changes, species are at risk of eventual extinction. [19.4.2]

Additional risks have emerged recently in the literature related to particular biophysical impacts of climate change (*high confidence*). These include decreasing viability of marine calcifying organisms due to ocean acidification; increasing production and allergenicity of pollen and allergenic compounds as well as decreasing nutritional quality of key food crops due to high ambient concentrations of CO_2; and adverse regional impacts arising from Solar Radiation Management implemented for the purposes of limiting global warming. [19.5, 19.5.2, 19.5.3, 19.5.4]

The risk of crossing tipping points in socio-ecological systems may be reduced by preserving ecosystem services (*medium confidence*). Tipping points are thresholds beyond which adverse impacts increase non-linearly. Some tipping points may be avoided by limiting the level of climate change and/or removing concomitant stresses such as overgrazing, overfishing, and pollution, but there is *low confidence* in location of such tipping points and measures to avoid them. [19.7.4]

Impacts of climate change avoided under a range of scenarios for mitigation of greenhouse gas emissions are potentially large and increasing over the 21st century (*high confidence*). Advances in the assessment and implementation of mitigation measures and adaptation strategies include for the first time evaluation of avoided damages from a range of strategies. Among the impacts assessed, benefits from mitigation are most immediate for ocean acidification and least immediate for impacts related to sea level rise. Since mitigation reduces the rate as well as the magnitude of warming, it also delays the need to adapt to a particular level of climate change impacts, potentially by several decades. [19.7.1]

Under any plausible scenario for mitigation and adaptation, some degree of risk from residual damages is unavoidable (*very high confidence*). For example, no model-based scenarios in the literature demonstrate the feasibility of limiting warming to a maximum of 1.5°C with at least 50% likelihood, and recent findings suggest that comprehensive adaptation to current climate risk is prohibitively expensive, indicating that adaptions to future changes are similarly constrained. Assessments of stringent mitigation scenarios suggest that they can potentially avoid one half of the aggregate economic impacts that would otherwise accrue by 2100, and between 20-60% of the physical impacts, depending on sector and region. [19.7.1, 19.7.2]

The design of risk-management strategies could be informed by observation and projection systems that provide an actionable early warning signal of an approaching threshold response. However, there is *low confidence* in the feasibility and requirements for such systems, since studies to date are highly simplified and limited in number. [19.7.3]

Table TS.8 presents specific examples of the hazards/stressors, key vulnerabilities, key risks, and emergent risks identified in the report. Box TS.7 integrates expert judgments about risks under the reasons for concern framework. Box TS.8 summarizes understanding of adaptation costs.

[INSERT TABLE TS.8 HERE
Table TS.8: A selection of the hazards/stressors, key vulnerabilities, key risks, and emergent risks identified in the report. The examples underscore the complexity of risks determined by various climatic hazards, non-climatic stressors, and multifaceted vulnerabilities. The examples show that underlying phenomena, such as poverty or insecure land-tenure arrangements, demographic changes, or tolerance limits of species and ecosystems that often provide important services to vulnerable communities, generate the context in which climate-change-related harm and loss can occur. The examples illustrate that current global megatrends (e.g., climate change, urbanization, demographic changes), in combination and in specific development contexts (e.g., in low-lying coastal zones), can generate new systemic risks that go far beyond existing adaptation and risk management capacities, particularly in highly vulnerable regions. [Table 19-3]]

Many impacts on small islands are generated from processes well beyond the borders of an individual nation or island, and generally they have negative effects (*high confidence*). Trans-boundary impacts on small islands may originate in distant regions including continental countries and high latitudes. Examples of the former include airborne dust from the Sahara and Asia reaching small islands far down-drift from the desert source; examples of the latter include large ocean swells generated by extra tropical cyclones and high latitude low pressure systems. [29.5.1, 29.5.2] Other trans-boundary impacts result from invasive plant and animal species that reach the warmth of tropical small islands and the spread of aquatic pathogens that may have implications for human health. For island communities the trans-boundary implications of existing and future “invasions” and human health challenges are projected to increase in a changing climate. [29.3.3.2, 29.5.3, 29.5.5]

_____ START BOX TS.6 HERE _____

Box TS.6. Consequences of Large Temperature Increase (e.g., >4°C)

Projections of climate change impacts at 4°C global mean temperature increase above preindustrial indicate large impacts for physical, biological, and human systems and, in turn, large aggregate impacts for society and the global economy (*high confidence*). Global-mean surface temperatures for 2081–2100 (relative to early industrial, 1886–1905) for RCP 6.0 and 8.5 will *likely* be in the 5–95% range of the CMIP5 climate models, i.e., 2.0°C–3.9°C (RCP6.0), 3.3°C–5.5°C (RCP8.5).

For 4°C global mean temperature increase above preindustrial, the effects of climate change on water resources and ecosystems are projected to become dominant over other drivers such as population increases and land use change (*medium confidence*). Widespread coral reef mortality is projected (*high confidence*). Agricultural production is expected to decline in mid-high latitudes once local temperature rise exceeds 3°C (and for lower temperature rise in the tropics), corresponding to a global temperature rise below 4°C (*medium confidence*). Beyond 4°C there is high risk of marked yield loss even at high latitudes (*medium confidence*). Extreme heat waves such as that experienced in Russia in 2010 can become typical of a normal summer for a 4°C increase (*high confidence*). Sea level rise in a 4°C world could result in the inundation of many small island states (*high confidence*). Emerging risks include exceedance of human physiological limits in some areas for a global temperature rise of 7°C (*medium confidence*).

Sub-Saharan Africa is identified as a multi-impacts hotspot in a 4°C world, with risks of increases in hunger and disease, and of loss of ecosystem function (*high confidence*). A 4°C increase would be expected to result in non-linear earth system responses: Amazon dieback (*medium confidence*); eventual, irreversible loss of the Greenland Ice Sheet (*high confidence*); and terrestrial carbon loss due to climate-carbon cycle feedback releasing CO_2 or CH_4 (*very likely*), which would accelerate climate change further. There would also be an increased chance of triggering the collapse of the West Antarctic Ice Sheet.

[12.4, 12.5, 19.4.3, 19.5.1, 19.6.3, 19.7.5, 23.4.1, WGI AR5 SPM, 2.4.3, 8.5.3, 12.4.1, Chapter 6, Table 13.5]

_____ END BOX TS.6 HERE _____

_____ START BOX TS.7 HERE _____

Box TS.7. Anthropogenic Interference with the Climate System

Anthropogenic interference with the climate system is occurring. [WGI AR5 SPM, 10.3-10.6] The impacts of climate change[1] are already widespread and consequential. [18.3-18.6] Determining whether anthropogenic interference is dangerous involves judgments about risks.

Science can quantify risks in a technical sense, based on the probability, magnitude, and scope of potential consequences of climate change. Interpreting risks and their potential danger, however, also requires value judgments, made across scales by people with differing goals and worldviews and without full certainty of what the future will hold. Judgments about the risks of climate change depend on the relative importance ascribed to economic vs. ecosystem assets, to the present vs. the future, and to the distribution vs. aggregation of impacts. From some perspectives, isolated or infrequent damages from climate change may not rise to the level of dangerous anthropogenic interference, but accumulation of the same kinds of damages could, as they become more widespread, more frequent, or more severe. The rate of climate change can also influence risks of damages, as reflected in Article 2.

The IPCC assesses scientific and technical understanding of risks and the range of possible outcomes. It also assesses understanding of how risks are perceived, as well as methods for incorporating different value systems in decisionmaking. The IPCC cannot, however, make a determination of the level of anthropogenic interference that is dangerous.

[INSERT FOOTNOTE 1: See Box TS.2 for description of differing usage of the term “climate change” in the IPCC and UNFCCC.]

Assessment of existing frameworks pertinent to Article 2 of the UNFCCC has led to evaluations of risk being updated in light of the advances since AR4, including SREX and the current report’s discussions of vulnerability, human security, and adaptation. The management of key and emergent risks of climate change and reasons for concern includes (i) mitigation that reduces the likelihood of physical impacts and (ii) adaptation that reduces the vulnerability and exposure of societies and ecosystems to those impacts. Many of the key vulnerabilities, key risks, and emergent risks identified in this report reflect differential vulnerability between groups due to, for example, age, wealth, or income status, and deficiencies in governance, which are particularly important in assessing risk from extreme events and risk associated with the distribution of impacts. [19.6.1, 19.6.3, 19.7]

Impacts of climate change have now been documented globally, covering all continents and the ocean (*high confidence*; Table TS.1). Detection and attribution of observed impacts of climate change supports assessments of current conditions with respect to the reasons for concern. The degree to which projected damages are now manifest, or the detection of stronger early warning signals for expected impacts, can contribute to a more comprehensive risk assessment for dangerous anthropogenic interference with the climate system. [18.6.2]

Updating of the reasons for concern (Box TS.7 Figure 1) leads to the following assessment:

- Unique human and natural systems tend to have very limited adaptive capacity, and hence we have *high confidence* that climate change impacts would outpace adaptation for many species and systems if a global temperature rise of 2°C over preindustrial levels were exceeded. In addition, there is new and stronger evidence to support the previous judgment of *high confidence* that a warming of up to 2°C above 1990-2000 levels would result in significant impacts on many unique and vulnerable systems, and would likely increase the endangered status of many threatened species, with increasing adverse impacts and increasing risk of extinctions (and increasing confidence in this conclusion) at higher temperatures. There is higher confidence in observed impacts on Arctic marine and terrestrial ecosystems and indigenous livelihoods (*medium to high confidence*), tropical coral reefs (*high confidence*) and glaciers in most mountain regions (*high confidence*). [18.6.2, 19.6.3]
- The overall risk from extreme events due to climate change has not changed significantly since AR4, but there is higher confidence in the attribution of some types of extreme events to human activity and in the assessment of the risk from extreme events in the coming decades. In addition, there is a new appreciation for the importance of exposure and vulnerability, in both developed and developing countries, in assessing risk associated with extreme events. [19.6.1, 19.6.3]
- Risk associated with the distribution of impacts is generally greatest in low-latitude, less developed areas, but because vulnerability is unevenly distributed within countries, some populations in developed countries are highly vulnerable to warming of less than 2°C, as noted in AR4 (*high confidence*). [19.6.3]
- Globally aggregated risk is underestimated because it does not include many non-monetized impacts, such as biodiversity loss, and because it omits many known impacts that have only recently been quantified, such as reduced labor productivity (*high confidence*). In addition, aggregated estimates of costs mask significant differences in impacts across sectors, regions, countries, and populations (*very high confidence*). The overall assessment of aggregate risk and confidence in that assessment has not changed since AR4. [19.6.3]
- The risk associated with large-scale singular events such as the at least partial deglaciation of the Greenland ice sheet remains comparable to that assessed in AR4. [19.6.3]

[INSERT BOX TS.7 FIGURE 1 HERE
Box TS.7 Figure 1: The dependence of risk associated with reasons for concern (RFCs) on the level of climate change, updated based on expert judgment in this assessment. The color scheme indicates the additional risk due to climate change (with white to purple indicating the lowest to highest level of risk, respectively). Purple color, introduced here for the first time, reflects the assessment that unique human and natural systems tend to have very limited adaptive capacity. [Figure 19-5]]

The determination of key risks as reflected, for example, in the reasons for concern in the Third and Fourth Assessment Reports did not distinguish between alternative development pathways. The development of risk profiles from Shared Socioeconomic Pathways and Representative Concentration Pathways is an important area of research that can lead to improvement in the framework developed in this report. [19.6.3]

_____ END BOX TS.7 HERE _____

_____ START BOX TS.8 HERE _____

Box TS.8. Adaptation Costs

Estimates of the global costs of adaptation continue to improve, but remain inconsistent in methods, sectoral coverage, purposes, and time frames. The most recent estimates suggest a range from 75 to 100 US$ billion per year globally by 2050 (*low confidence*), but important omissions from these estimates suggest the high end of this range could be much higher, and important shortcomings in the data and methods available for costing adaptation suggest the low end of this range could be substantially lower.

- Defining the benefits and cost of adaptation is difficult, is limited by data, and depends on value judgments. Estimating adaptation costs poses methodological, practical, and moral difficulties, with consequences for how adaptation can be funded. [17.3.6, 17.3.10, 17.3.11, 17.6]
- The existing estimates of global adaptation costs could be higher if sectors such as ecosystems and tourism and socially contingent effects are included, and if the adaptation deficits of developing countries are more fully taken into account. The global figures are based on only a few lines of evidence and cover a selected number of sectors. [17.6]
- Some evidence suggests that incremental adaptation costs increase over time as climate change unfolds (*low confidence*), but consideration of current adaptation deficits suggests that costs could be high in the short-term as well, and inconsistencies in the effect of economic development on adaptation capacity also confound the reliability of estimates of the trend over time. [17.6.3]

Adaptation costing studies suffer from the absence of a robust community of practice, with great inconsistencies in the purposes, methods, data quality, and sectoral coverage of these analyses, limiting attempts to aggregate the finer-scale study results across regions and time. Among these regional and local-scale analyses desirable characteristics include: a broad representation of relevant climate stressors to ensure robust economic evaluation; consideration of multiple alternative and/or conditional groupings of adaptation options; rigorous economic analysis of costs and benefits across the broadest possible market and nonmarket scope; and a strong focus on support of practical decision-making that incorporates consideration of sources of uncertainty. Few current studies manage to achieve all of these objectives. [17.6.3]

_____ END BOX TS.8 HERE _____

_____ START BOX TS.9 HERE _____

Box TS.9. Ocean Acidification

Anthropogenic ocean acidification (Box TS.9 Figure 1A) and climate change share the same primary cause at the global level, the increase of atmospheric carbon dioxide. [WGI AR5 2.2.1] The fundamental chemistry is well understood: the uptake of CO_2 into mildly alkaline ocean results in an increase in dissolved CO_2 and reductions in pH, dissolved carbonate ion, and the capacity of seawater to buffer changes in its chemistry (*very high confidence*). The changing chemistry of surface seawater can be projected with high accuracy from projections of atmospheric CO_2 levels in the open ocean, but not in coastal waters where eutrophication and upwelling contribute to local ocean acidification. [5.3.3.6, 30.5.4]

Ocean acidification occurs on a backdrop of other environmental changes, both global (e.g. warming, decreasing oxygen levels) and local (e.g. pollution, eutrophication), yet their combined impacts remain poorly understood. A pattern of impacts—some positive, others negative—emerges for some processes and organisms (*high confidence*; Box TS.9 Figure 1B), but key uncertainties remain from organismal to ecosystem levels. A wide range of sensitivities exists within and across organisms, with higher sensitivity in early life stages. [6.2.4] Lower pH decreases the rate of calcification of most, but not all, sea-floor calcifiers, reducing their competitiveness with non-calcifiers (*high confidence*; Chapters 5, 6, and 30). Growth and primary production are stimulated in seagrasses and some phytoplankton (*high confidence*), and harmful algal blooms could become more frequent (*limited evidence, medium agreement*). Adult fish remain relatively undisturbed by elevated CO_2, although serious behavioral disturbances have been reported in larval and juvenile reef fishes. [6.2.4] Natural analogues at CO_2 vents indicate decreased species diversity, biomass, and trophic complexity of communities living on the sea floor. Shifts in organisms' performance and distribution will change both predator-prey and competitive interactions, which could impact food webs and higher trophic levels (*limited evidence*, *high agreement*). [6.3]

A few studies provide *limited evidence* for adaptation in phytoplankton and mollusks. However, mass extinctions during times in Earth history with much slower rates of ocean acidification suggest that evolutionary rates are too slow for sensitive species to adapt to the projected rates of change (*high confidence*). [6.1.2]

The biological, ecological, and biogeochemical changes driven by ocean acidification will affect key ecosystem services. The oceans will become less efficient at absorbing CO_2 and hence moderating climate (*very high confidence*). The impacts of ocean acidification on coral reefs, together with those of bleaching and sea level rise, will diminish their role in shoreline protection as well as their direct and indirect benefits on the tourism industry (*limited evidence, high agreement*). [Box CC-CR] The global cost of production loss of mollusks could be over 100 billion USD by 2100. The largest uncertainty is how the impacts on prey will propagate through marine food webs. Models suggest that ocean acidification will generally reduce fish biomass and catch (*limited evidence, high agreement*) and that complex additive, antagonistic, and/or synergistic interactions will occur with other environmental and human factors.

[INSERT BOX TS.9 FIGURE 1 HERE
Box TS.9 Figure 1: A) Overview of the chemical, biological, socio-economic impacts of ocean acidification and of policy options. B) Effect of near future acidification on major response variables estimated using weighted random effects meta-analyses, with the exception of survival, which is not weighted. The effect size indicates which process is most uniformly affected by ocean acidification but large variability exists between species. Significance is determined when the 95% bootstrapped confidence interval does not cross zero. The number of experiments used in the analyses is shown in parentheses. * denotes a significant effect. [Box CC-OA]]

_____ END BOX TS.9 HERE _____

D) BUILDING RESILIENCE THROUGH MITIGATION, ADAPTATION, AND SUSTAINABLE DEVELOPMENT

This section evaluates the ways that human and social-ecological systems can build resilience through mitigation, adaptation, and sustainable development. It assesses understanding of climate-resilient pathways and of incremental versus transformational changes, and it considers co-benefits, synergies, and tradeoffs among mitigation, adaptation, and development.

D.i. Climate-resilient Pathways and Transformation

Climate change calls for new approaches to sustainable development that take into account complex interactions between climate and social-ecological systems (see Figure TS.16). Climate-resilient pathways for development are rooted in iterative processes of identifying vulnerabilities to climate change impacts; taking appropriate steps to reduce vulnerabilities in the context of development needs and resources and to increase the options available for vulnerability reduction and coping with surprises; monitoring emerging climate parameters and their implications, along with monitoring the effectiveness of vulnerability reduction efforts; and revising risk reduction responses on the basis of continuing learning. This process may involve a combination of incremental changes and, as necessary, significant transformations. [20.2.3.1, 20.6.2]

[INSERT FIGURE TS.16 HERE
Figure TS.16: Conceptual framework for assessing interactions between biophysical and societal stressors that impact the resilience of natural and human systems today and in the future. Actions, including climate change adaptation and mitigation, taken in the opportunity space lead to a diverse range of pathways and outcomes—toward a future of high risk, high vulnerability, and low resilience space or toward a future of low risk, low vulnerability, and high resilience space. [Figure 1-7]]

Assessment findings integrate a variety of complex issues in assessing climate-resilient pathways in a variety of regions at a variety of scales: sustainable development as the ultimate aim, mitigation as the way to keep climate change impacts moderate rather than severe, adaptation as a response strategy to cope with impacts that cannot be (or are not) avoided, and elements of sustainable development pathways that contribute to climate-resilience. In most cases, vulnerability reduction and appropriate risk management approaches will differ from situation to situation, calling for a multi-scale perspective. But most situations share at least one fundamental characteristic: threats to sustainable development are greater if climate change is substantial than if it is moderate.

The findings are based on a high level of consensus in source materials and in the expert communities, although the amount of supporting evidence is usually limited by the fact that so many aspects of sustainable development and climate change mitigation and adaptation, considered together over periods many decades into the future, are surrounded by issues that are beyond past and current observation and experience. The task of this part of the assessment is to move out into uncharted territory.

Because climate change is a growing threat to development, it is a high priority to identify and pursue climate-resilient pathways for sustainable development (*high confidence* based on *high agreement, medium evidence*). Added to other stresses on sustainable development, effects of climate change will make sustainability more difficult to achieve for many locations, systems, and affected populations, related to such objectives as poverty reduction, health, and livelihood security; but climate-resilient pathways can improve prospects for sustainable development. [20.2]

Climate-resilient pathways include (a) actions to reduce climate change and its impacts and (b) actions to assure that effective risk management and adaptation can be implemented and sustained (*high confidence*, based on *high agreement, medium evidence*). Adaptation and mitigation have the potential to both contribute to and impede sustainable development, and sustainable development strategies and choices have the potential to both contribute to and impede climate change responses. Both kinds of responses are needed, working together to reduce risks of disruptions from climate change. [20.3, 20.4]

In some cases, each of the two categories of responses can benefit the other as well, offering potentials for co-benefits from integration (*medium* to *high confidence*, based on *medium* to *high agreement, medium evidence*). Development pathways that are resilient with respect to a wide range of challenges and threats are more likely to be climate-resilient, while climate change risk reduction can contribute to strengthening capacities for risk management in other regards as well. Strategies to achieve each goal have the potential to reinforce the other, but windows of opportunity may narrow with time. [20.2.1, 20.3.3]

Paying attention to dynamic livelihoods and multidimensional poverty and the multifaceted impacts of climate change and climate change responses is central to achieving climate-resilient development pathways (*high confidence*). Business-as-usual development and climate policies will bring the poor and the marginalized precariously close to the two most undesirable future scenarios as conceptualized in the shared socio-economic pathways (SSPs): social fragmentation (fragmented world) and inequality (unequal world). Global inequality has been increasing, with new poverty pockets emerging in middle- and high-income countries and shifts from transient to chronic poverty, while at the level of communities, elite capture and unsupportive policy structures often propel less affluent households into deeper poverty. [13.4]

Avoiding limits to adaptation is a complex management challenge necessitating new integrative forms of risk governance (*medium agreement, limited evidence*). Limits to adaptation are influenced by cultural, institutional, and socio-economic factors. Consequently, avoiding limits will necessitate policy responses and awareness that goes beyond greenhouse gas mitigation and adaptation responses alone. Driving forces such as inequality and the disproportionate vulnerability of marginalized actors to climate-related disasters and catastrophic losses will need to be addressed. Hence, a portfolio of local, national, and international strategies will be needed to facilitate sustainable development that expands the range of climate to which socio-ecological systems can adapt. [16.4, 16.6, 16.7]

Prospects for climate-resilient development pathways are related fundamentally to what the world accomplishes with climate change mitigation (*high confidence*, based on *high agreement, medium evidence*). As the magnitude of climate change grows, the challenges to climate resilience grow; and above some high level of climate change, the impacts on most systems would be great enough that climate-resilience is no longer possible for many systems and locations (see Box TS.10). [20.6.1]

Because climate change vulnerabilities are significant for many areas, systems, and populations, climate-resilient pathways will often require transformations in order to assure sustainable development (*high confidence,* based on *high agreement, medium evidence*). Significantly large and/or rapid increases in extreme weather and climate events are less amenable to incremental adaptations to climate change and will often require more transformational change if development is to be sustained without major disruptions (see Box TS.10). [20.5]

At a global scale, climate-resilient pathways will include both climate change adaptation and mitigation. At sub-global scales, climate-resilient pathways will involve a range of actions appropriate to potentials for vulnerability/risk reduction at those scales (*high confidence,* based on *high agreement, medium evidence*). Although at a global scale both mitigation and adaptation are essential, relatively local scales in many developing regions have limited capacities to include mitigation in their climate-resilience strategies because they contribute very little to the causes of climate change. At all scales, however, actions are important to assure that effective risk management can be implemented and sustained. [20.2.3, 20.6.1]

D.ii. Examples of Co-benefits, Synergies, and Tradeoffs

Responses to the risks of climate change can have implications beyond their primary objectives for the resilience of societies and systems.

Example interactions among impacts and adaptation responses

Adaptation designed for one sector may interfere with the functioning of another sector, creating new risks (*high confidence*). For example, increasing crop irrigation in response to a drying climate can exacerbate water stress in downstream wetlands, where the latter otherwise provide important water cleaning services (*high* *confidence*). Examples of potential trade-offs among adaptation objectives are provided in Table TS.9. [4.3.3, 4.3.4, 19.3.2]

[INSERT TABLE TS.9 HERE
Table TS.9: Examples of potential trade-offs among adaptation objectives. [Table 16-2]]

Example interactions among impacts and mitigation responses

Certain approaches to reduce greenhouse-gas emissions imply greater risks for freshwater systems than others (*high agreement, limited evidence*). Bioenergy crops can require larger amounts of water for irrigation than the amount of water for other mitigation measures. Hydropower has negative effects on freshwater ecosystems that can be reduced by appropriate management. Carbon capture and storage can decrease groundwater quality. In some regions, afforestation can reduce renewable water resources but also flood risk. [3.7.2]

Use of the terrestrial biosphere in climate mitigation actions, such as through introduction of fast-growing tree species for carbon sequestration or the conversion of forest to biofuel plantations, may lead to negative impacts on ecosystems and biodiversity (*very high confidence*). The land use scenario accompanying the mitigation scenario RCP2.6, intended to avoid 2°C global warming, features large expansion of biofuel production displacing natural forest cover. [4.2.4]

Achieving emission targets without putting a price on carbon emissions from land-use has the potential to lead to very large reductions in forested area, and much higher overall costs for mitigation, compared to meeting the same targets while putting a price on all carbon emissions. Similarly, substantial regional variation in the availability of technologies exists, but the differences in how these are represented regionally are largely unexplored. [21.5.3]

There are opportunities to both reduce emissions of climate altering pollutants and at the same time improve local health in the communities that take action, as well as protecting health for populations worldwide through climate change abatement. Among others, mitigation-related actions with health co-benefits include:

- Reducing local emissions of health-damaging and climate-altering air pollutants from energy production and use in households and communities, through better combustion, energy efficiency, and a shift to cleaner renewable energy sources (*very high confidence*). [11.9]
- Providing access to reproductive health services and thus improving child and maternal health through increased birth spacing, while reducing population growth and consequent climate altering pollutant emissions over time (*high confidence*). [11.9]

Example interactions among mitigation, adaptation, and development

Climate policies, such as encouraging cultivation of biofuels and payments under REDD, will result in mixed and potentially detrimental impacts on land-use and on the livelihoods of poor and marginalized people (*medium confidence*). Mitigation efforts such as CDM and REDD+, as well as land acquisition for food and biofuel production, show preliminary negative impacts on the poor, particularly indigenous people and (women) smallholders. In rural areas, secondary impacts and trade-offs between mitigation and adaptation have implications for governance. Insurance schemes, social protection programs, and disaster risk reduction may enhance long-term livelihood resilience among poor and marginalized people, if policies address multidimensional poverty. Climate-resilient development pathways will have only marginal effects on poverty reduction, unless structural inequalities are removed and needs for equity among the poor and non-poor met. [9.3.3, 13.3.1, 13.3.2, 13.4.1, 13.4.2]

In Europe, there are opportunities for policies that improve adaptive capacity and also help meet mitigation targets (*high confidence*). Some agricultural practices can potentially mitigate GHG emissions and at the same time adapt crops to increase resilience to temperature and rainfall variability. Climate policy in transport and energy sectors to reduce emissions can improve population health. However there is also potential for unintended consequences of mitigation policies in the built environment (especially housing) and energy sectors. [23.8]

In Asia, multiple stresses caused by rapid urbanization, industrialization, and economic development will be compounded by climate change (*high confidence*). Climate change is expected to adversely affect sustainable development capabilities of most Asian developing countries by aggravating pressures on natural resources and the environment. Development of sustainable cities in Asia with fewer fossil fuel driven vehicles and with more trees and greenery would have a number of co-benefits including for public health. [24.4, 24.5, 24.6, 24.7]

For Australasia, significant synergies and trade-offs exist between alternative adaptation responses, and between mitigation and adaptation responses; interactions occur both within Australasia and between Australasia and the rest of the world (*very high confidence*). Increasing efforts to mitigate and adapt to climate change imply an increasing complexity of interactions, particularly at the intersections among water, energy, and biodiversity, but tools to understand and manage these interactions remain limited. Flow-on effects from climate change impacts and responses outside Australasia have the potential to outweigh some of the direct impacts within the region, particularly economic impacts on trade-intensive sectors such as agriculture (*medium confidence*), but they remain amongst the least explored issues. [25.7.5, 25.9.1, 25.9.2, Box 25-10]

Throughout North America, adaptation actions at the local level have the potential to result in synergies, conflicts, or tradeoffs with mitigation and other development actions and goals (*high confidence*). For example, reductions in emissions of greenhouse gases will in many cases bring proximal benefits for human health by reducing health-damaging air pollution concentrations. Conversely, sea walls can protect coastal properties, yet may negatively affect the structure and function of coastal ecosystems. [26.8]

In Central and South America, long-term planning and the related human and financial resource needs may be seen as conflicting with present social deficit in the welfare of the population. Such conditions weaken the importance of adaptation planning to climate change on the political agenda. Various examples demonstrate possible synergies between development, adaptation, and mitigation planning, which can help local communities and governments to allocate efficiently available resources in the design of strategies to reduce vulnerability. [27.3.4, 27.4.1, 27.4.2, 27.4.3, 27.4.4, 27.5].

In Central and South America, renewable energy has a potential impact on land use change and deforestation, but at the same time will be an important means of adaptation, particularly in Southeastern South America. Hydropower is currently the main source of renewable energy in Central and South America, followed by biofuels, notably bioethanol from sugarcane and biodiesel from soy. Southeastern South America is one of the main sources of production of the feedstocks for biofuels' production. Sugarcane and soy are *likely* to respond to the elevation of CO_2 and temperature with an increase in growth, which might lead to an increase in productivity and production. However, the drought effects expected for some regions in Central and South America will be critical, and scientific knowledge has to advance in this area. Advances in second generation bioethanol from sugarcane and other feedstocks will be important as a measure of adaptation, as they have the potential to increase biofuels productivity in the region. In spite of the large amount of arable land available in the region, the expansion of sugarcane and soy, related to biofuels production, might have some indirect land use change effects, producing teleconnections that could lead to deforestation in the Amazon and loss of employment in some countries. This is especially derived from the expansion of soy, which is used for biodiesel production inclusively. [27.3.6]

For small islands, adaptation and mitigation are not trade-offs, but can be regarded as complementary components in the response to climate change (*medium confidence*). For most small islands climate change is just one of a series of multiple stresses that must be coped with, and often it is not the most important one. Three key areas for adaptation-mitigation inter-linkages in small islands are identified: energy supply and use, tourism infrastructure and activities, and coastal wetlands. The alignment of these sectors for potential emission reductions together with adaptation needs offers co-benefits and opportunities in small islands. Lessons learned from adaptation and mitigation experiences in one island may offer some guidance to other small island states, though we have *low confidence* in the wholesale transfer of adaptation and mitigation options when the lenses through which they are viewed differ from one island state to the next, based on cultural, socio-economic, ecological, and political values. [29.6.2.1, 29.7.2, 29.8, 29.3.3]

For small islands, assistance from the international community is vital for supporting adaptation and mitigation programs, though there is increasing concern that some types of interventions may be maladaptive (*high agreement, medium evidence*). Caution is needed to ensure that donors are not driving the climate change agenda in small islands, as there is a risk that donor-driven adaptation and mitigation aid may not address the critical challenges confronting island governments and communities, and may not be aligned with the sustainable development goals of small islands. This may lead to inadequate adaptation or a waste of scarce resources and may unintentionally cause enhanced vulnerability by supporting inappropriate adaptation strategies that are externally derived, rather than optimizing the benefits of local practices that have proven to be efficacious through time. [29.8, Box 29-1, 29.6.2.3, 29.6.3]

Table TS.10 provides further specific examples of interactions to complement the assessment findings above.

[INSERT TABLE TS.10 HERE
Table TS.10: Illustrative examples of intra-regional interactions among adaptation, mitigation, and sustainable development.]

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Box TS.10. Adaptation Limits and Transformation

Adaptation can expand the capacity of natural and human systems to cope with a changing climate. However, there are limits to adaptation that, when exceeded, prevent the achievement of management goals or the maintenance of societal values. Such limits are context-specific and subject to uncertainty. Therefore, they are best considered in a risk management context that focuses on the values and objectives of actors. This allows limits to be defined as the point at which an actor's objectives (or biophysical system needs) cannot be secured from intolerable risks through adaptive actions (see Box TS.10 Figure 1). [16.2, Box 16-2] The determination of what constitutes an intolerable risk is made by actors at different scales of governance through processes of deliberation and social learning. Beyond a limit, there must be a change in objectives or needs, else actors will experience an escalating risk of loss and damage. [16.2, 16.4.3, 20.5, 20.6.1]

Limits to adaptation can arise from a diverse array of factors. The rate and magnitude of climate and socioeconomic changes are key determinants of adaptation limits, as they influence the vulnerability of natural systems as well as their capacity to respond. [16.3.1] The Representative Concentration Pathways and Shared Socioeconomic Pathways, for example, represent a broad range of greenhouse gas emissions futures and socioeconomic development storylines. [Box 20-3] The greater the rate and magnitude of climate change, the more likely limits to adaptation will be exceeded. [16.4.2, 20.5.1] Limits also arise from the subjective values of societal actors, which influence both the demand for adaptation and the perceived appropriateness of specific policies and measures. [16.2, 16.3.1, 16.3.4, 16.4.1] While limits fundamentally imply that adaptation can no longer avoid intolerable impacts, they can be viewed as "soft" if there are opportunities for impacts to be reduced over time through, for example, changes in laws, institutions, or values or the emergence of new technologies. [16.4.1] In contrast, "hard" limits are those which cannot be reduced through human agency and tend to be associated with biophysical processes, such as climate thresholds in natural systems. [16.4.1]

The Earth System is committed to some climate change in the future, and some degree of loss and damage may be inevitable. [20.5.1] Considering that climate change can include large-scale discontinuities and irreversible adverse consequences, the existence of limits to adaptation suggests greater attention to deliberate transformational change is needed. Such transformations, defined as fundamental changes in the attributes of a system, can occur through social and technological innovations or changes in behavior or institutions, but often they involve changes in political, economic, social, cultural or legal systems, as well as changes in individual and collective beliefs, values, and worldviews. [20.5.2] As such, transformational change may trigger societal debate over the acceptability of risk, mitigation, and adaptation strategies in order to reconcile conflicting goals and visions of the future while placing new and increased demands on governance structures at multiple levels.

[INSERT BOX TS.10 FIGURE 1 HERE
Box TS.10 Figure 1: Conceptual model of the determinants of acceptable, tolerable, and intolerable risks and their implications for limits to adaptation. [16.2, Figure 16-1]]

_____ END BOX TS.10 HERE _____

WGII Frequently Asked Questions

Chapters of the report supporting each FAQ are provided in square brackets.

1. Are we seeing impacts of climate change?

Yes, many climate-change impacts are already apparent. Impacts of recent observed climate change on physical, biological, and human systems have been detected on all continents and in most oceans. We have *medium* to *very high confidence* that several regions have experienced warming trends and more frequent high-temperature extremes. We have *high* to *very high confidence* that, due to rising temperatures, hydrological cycles have been disrupted by decreased snowpack, degradation of permafrost regions, and diminishing glaciers. Moreover, many ecosystems are experiencing climate-induced shifts in the activity, range, or abundance of the species that inhabit them, leading to changes in ecosystem function. There is emerging evidence that oceans are also displaying changes in physical and chemical properties that, in turn, are affecting coastal and marine ecosystems such as coral reefs, and other oceanic organisms such as crustaceans and zooplankton. Crops and other managed ecosystems are seeing changes as well. While crop yields and fishery stocks are sensitive to changes in temperature; only *limited evidence* confirms a role of climate change in crop and fish production.

[Chapters 3, 4, 5, 6, 7, 18, 22, 24, 25, 27, and 30; SPM]

2. Has climate change already affected food production?

Changes in crop and aquaculture production are sensitive to both climatic drivers and non-climatic socioeconomic drivers, making it difficult to isolate the changes caused by climate change. However, there is emerging evidence that agricultural crop yields are changing in many regions in response to climate. For example, there is *medium confidence* that declines attributable to climate change have been observed in the yields of wheat crops of some European countries. Moreover, there is *high confidence* that extreme heat has a negative effect on food nutritional quality. There is emerging evidence that other parts of the Earth system altered by climate change, (e.g. atmospheric CO_2, tropospheric ozone, and water and nitrogen cycles) can alter food production in complex ways. Hence, climate change will continue to affect food systems, with impacts that are widespread, complex, and varying over space and time.

[Chapters 6, 7, 18, 19, 22, and 23]

3. Is climate change bad news for everyone or will there be winners and losers?

Of the many climate-change impacts assessed in this report, only a few are positive. They will not be felt equally around the world. There is *very high confidence* that climate changes interact with vulnerability and exposure to shape differential risks and impacts. Climate change can act as a threat multiplier for those at the social or economic margins or in unfavorable locations. Climate change will have different implications for people across the world, with impacts that vary over time and depend on the rate and magnitude of climate change. For example, there is *medium* to *high confidence* that some countries will have increased opportunities for economic development, reduced instances of some diseases, or expanded areas of productive land. Other countries will face increased challenges for economic development, increased risks of some diseases, or degraded ecosystems. There is *medium confidence* that crop yields will vary by latitude, with yield losses in the tropics. In temperate regions, climate change could stimulate yield increases over the next few decades but decrease them after that. There is *high confidence* that the potential global catch for fisheries will change, with both positive and negative consequences from climate-induced impacts on ocean mixing and shifts in species range.

[Chapters 4, 6, 7, 10, 11, 13, 22, 25, and 30]

4. What aspects of ecosystems will change due to climate change, and how will that affect communities?

There is *high confidence* that many ecosystems are sensitive to climate change, interacting with other human activities. Changes in ecosystems influence society through diverse effects on available natural resources and ecosystem services. For example, there is emerging evidence that reductions in fish stocks will affect the livelihoods of fishing communities, as well as food security for those that rely on fish. There is *medium* to *high confidence* that ecosystem impacts can include losses of carbon, increased likelihood of the establishment and spread of invasive alien species, and loss of valuable biodiversity, disrupting ecosystem services that contribute towards the quality of human life.

[Chapters 4, 19, and 30]

5. What are key vulnerabilities, and what kinds of factors contribute to them?

Key vulnerabilities are those that have the potential to combine with climate-change impacts to result in severe consequences for society or social-ecological systems. Seven factors contribute to a key vulnerability. These are:

- the exposure of societies, communities, or social-ecological systems to climatic stressors
- the probability that these would experience major harm, loss, and damages
- the importance of the vulnerable systems
- the limited ability of societies or communities to cope with the climate-related hazards within existing capacities
- the limited ability of societies or communities to build adaptive capacities to reduce or limit vulnerability as environmental and climatic conditions change
- the persistence of vulnerable conditions and degree of irreversibility of consequences
- the presence of conditions that make societies highly susceptible or sensitive to cumulative stressors in complex, interacting systems

[Chapter 19]

6. Does climate change cause violent conflicts?

There is *medium confidence* that some factors that increase the risk of violent conflicts and civil wars are sensitive to climate change. *Robust evidence* demonstrates that low per capita incomes, economic contraction, and inconsistent state institutions, all of which are sensitive to climate change, are associated with the incidence of civil wars. There is little agreement about whether these factors cause violent conflicts. Climate-change policies, particularly those associated with changing property rights, can increase the risk of violent conflict. Policies and institutions at multiple scales that encourage economic growth, high per capita incomes, strong democratic institutions, social protection during economic and climate shocks, and robust institutional structures that protect property rights and manage conflicts reduce the risk that climate variability and extremes will lead to violence.

[Chapter 19]

7. How is ocean acidification related to climate change and how does it affect marine and coastal areas?

Ocean acidification is a consequence of increased atmospheric CO_2. This leads to a net transfer of CO_2 from the atmosphere to the oceans, resulting in an increase in dissolved CO_2 and a reduction in pH. Seawater with higher dissolved CO_2 has lower concentrations of dissolved carbonate ion, the building block for shells and skeletons of many marine organisms. There is *high confidence* that seawater acidity (pH) has numerous implications for ocean and coastal processes and organisms, including rates of primary production, the deposition of calcium carbonate in shells and skeletons, and the degradation of limestone.

[Chapter 5; Cross-chapter Box, Ocean Acidification]

8. What communities are most vulnerable to impacts of climate change?

Every society is vulnerable to the threats from climate change, although the nature of that vulnerability varies across regions and communities, and over time. Poorer communities tend to be more vulnerable to loss of life, while wealthier communities have more economic assets at risk. There is *high confidence* that differences among communities in age, race and ethnicity, socio-economic status, and governance have had significant influence on the outcome of past weather and climate extremes. Regions affected by violence or governance failure are particularly vulnerable. Other development challenges, such as gender inequality and low levels of educational attainment, also make communities vulnerable to climate change.

[Chapters 9, 10, 19, 26, and 27]

9. How are adaptation, mitigation, and sustainable development connected?

Adaptation, mitigation, and sustainable development are intrinsically related to each other in the context of climate change. Mitigation reduces the likelihood of physical impacts. Adaptation reduces the vulnerability and exposure of societies and ecosystems to those impacts. Together, both responses help define climate-resilient pathways that contribute to long-term sustainable development. There is *very high confidence* that interactions between adaptation and mitigation responses have both potential synergies and tradeoffs that vary according to context. There are many examples of the potential for co-benefits, but there are also examples of competitive relationships between adaptation and development, which, when poorly implemented, can aggravate the condition of vulnerable communities. Integrating adaptation, mitigation, and sustainable development simultaneously in long-term planning has the potential to amplify the benefits of each.

[Chapters 9, 13, 17, 19, 20, 25, and 29]

10. Why is it difficult to attribute observed changes to climate change?

Attribution addresses the question of whether observed changes were caused by climate change. The main challenge in attribution is separating the role of climate change from the roles of other factors. For example, widespread flooding in Australia and other parts of the western Pacific during 2010 and 2011 was caused by unusually heavy rainfall. This was related to La Niña conditions. La Niña is part of the naturally occurring ENSO variation, making it impossible, based on the available evidence, to attribute the flooding to climate change. In human systems, attributing observed changes to climate change is complicated by interactions with the effects of economic and social factors. The emerging literature discussing the relationship between climate change and poverty, working conditions, violent conflict, migration, and economic growth has many examples, but unequivocal attribution remains a challenge.

[Chapter 18]

11. Are risks of climate change mostly due to changes in extremes, changes in average climate, or both?

People and ecosystems across the world experience climate in many different ways. Average climate conditions are important. They provide a starting point for understanding how far ecosystems extend north and south, and for informing decisions about tourist destinations, other business opportunities, and crops to plant. But weather and climate extremes strongly influence losses and dislocations. Crops can fail following flood or drought. Buildings constructed to stricter codes are more likely to weather the waves or winds of a storm. And forests burn when high winds combine with low humidity. In a changing climate, many impacts for people, ecosystems, activities, and infrastructure will occur due to changes in the intensity, frequency, or duration of weather and climate extremes.

[Chapters 2, 4, 7, 8, 9, 10, 12, 13, 20, and 25; TS]

12. How much do we know about the world in 2100?

People can often guess what tomorrow might bring. But anticipating the future 5, 10, or 50 years out is increasingly difficult. On the scale of decades, technological revolutions, political movements, or singular events can shape the course of history in unpredictable ways. To understand potential impacts of climate change for societies and ecosystems at the end of this century, scientists use a variety of approaches. One is recognizing consequences of some intrinsic limits. The total amount of land or the number of species of mammals will not increase, for example. Another opportunity builds on simple relationships that have been robust over long periods. Scenarios are internally consistent descriptions of possible futures, reflecting factors like possible population growth, investments in technology, and commitments to protecting the environment. Over timeframes of a few years to as much as a century, they provide powerful means of exploring the implications of decisions that affect people, ecosystems, and economies. Scenarios can also link patterns of greenhouse gas emissions to underlying societal and economic trends, bridging from decisions to their consequences for climate.

[Chapters 1, 2, 4, 6, 17, 20, and 21; TS]

13. Why is climate change a challenge of managing risks?

For individuals, enterprises, or nations, success can hinge on making good decisions under uncertainty. Effective decisionmaking under uncertainty considers outcomes that are highly likely, but it also considers less probable outcomes that would have big consequences. As the WGII AR5 demonstrates, we know a great deal about impacts of climate change that have already occurred, and we understand many aspects of impacts projected for the future. But impacts of climate change also involve uncertainties, including some that are persistent. Future emissions of greenhouse gases will depend on societal decisions not yet made. Modeling future climate change and impacts entails uncertainties due to variability in Earth's physical systems and ecosystems and due to limits of current scientific understanding. We also have limited ability to characterize fully the resilience of people and ecosystems experiencing impacts. Good decisions about avoiding or managing the consequences of climate change build on available information, recognizing the value of timely investments and actions, even with consequential uncertainty. Managing risks positions societies, economies, and ecosystems to capitalize on the upside outcomes of climate change, while preparing for the full range of possible downside outcomes.

[Chapters 1, 2, 17, 19, 20, 21, and 25; TS]

14. What are the timeframes for mitigation and adaptation benefits?

Adaptation can reduce the damage from impacts that cannot be avoided. Mitigation strategies can decrease the amount of climate change that occurs, as summarized in the WGIII AR5. But the consequences of investments in mitigation emerge incrementally, not immediately. Over the next few decades, the climate change we experience will be determined primarily by the combination of past actions and current trends in greenhouse gas emissions. The next few decades are, in essence, an era of climate responsibility, where short-term risk reduction comes from adapting to the changes already underway, while we also take responsibility for the leverage of mitigation on the potential for climate change in the latter decades of the century, the era of climate options.

[Chapters 1, 2, 16, 19, 20, and 21; TS]

15. Can science identify thresholds beyond which climate change is dangerous?

Anthropogenic interference with the climate system is occurring. The impacts of climate change are already widespread and consequential. Determining whether anthropogenic interference is dangerous involves judgments about risks. Science can quantify risks in a technical sense, based on the probability, magnitude, and scope of potential consequences of climate change. Interpreting risks and the scale at which they become dangerous, requires value judgments, made by people with differing goals and worldviews and without full certainty of what the future will hold. Judgments about the risks of climate change depend on the relative importance ascribed to the present vs. the future, to economic vs. cultural, natural, and aesthetic assets, and to global GDP versus the interests of the most vulnerable. Isolated or infrequent damages from climate change may not rise to the level of dangerous anthropogenic interference, but accumulation of the same kinds of damages could, as they become more widespread, more frequent, or more severe. The IPCC assesses scientific and technical understanding of risks and the range of possible outcomes. It also assesses understanding of how risks are perceived, as well as methods for incorporating different value systems in decisionmaking. The IPCC cannot, however, make a determination of the level of anthropogenic interference that is dangerous.

[Chapters 1, 2, 4, 5, 6, 17, 18, 19, and 25; TS]

WGII CROSS-CHAPTER BOXES

Box CC-EA. Ecosystem Based Approaches to Adaptation - Emerging Opportunities

[Rebecca Shaw (USA), Jonathan Overpeck (USA), Guy Midgley (South Africa)]

Ecosystem-based approaches to adaptation (also termed Ecosystem-based Adaptation, EBA) integrate the use of biodiversity and ecosystem services into climate change adaptation strategies (e.g., CBD, 2009; Munroe *et al.*, 2011; Munroe *et al.*, 2011). EBA is implemented through the sustainable management of natural resources, as well as conservation and restoration of ecosystems, to provide and sustain services that facilitate adaptation both to climate variability and change (Colls *et al.*, 2009). The CBD COP 10 Decision X/33 on Climate Change and Biodiversity states further that effective EBA also “takes into account the multiple social, economic and cultural co-benefits for local communities”.

The potential for EBA is increasingly being realized (e.g., Munroe *et al.*, 2011), offering opportunities that integrate with or even substitute for the use of engineered infrastructure or other technological approaches. Engineered defenses such as dams, sea walls and levees, may adversely affect biodiversity, resulting in maladaptation due to damage to ecosystem regulating services (Campbell *et al.*, 2009, Munroe *et al.*, 2011). There is some evidence that the restoration and use of ecosystem services may reduce or delay the need for these engineering solutions (CBD, 2009). Well-integrated EBA is also more cost effective and sustainable than non-integrated physical engineering approaches, and may contribute to achieving sustainable development goals (e.g., poverty reduction, sustainable environmental management, and even mitigation objectives), especially when they are integrated with sound ecosystem management approaches. EBA also offers lower risk of maladaptation than engineering solutions in that their application is more flexible and responsive to unanticipated environmental changes.

EBA provides opportunities particularly in developing countries where economies depend more directly on the provision of ecosystem services (Vignola *et al.*, 2009), to reduce risks to climate change impacts and ensure that development proceeds on a pathways that are resilient to climate change (Munang *et al.*,). In these settings, ecosystem-based adaptation projects may be readily developed by enhancing existing initiatives, such as community-based adaptation and natural resource management approaches (e.g., Khan *et al.*, 2012, Midgley *et al.*, 2012; Roberts *et al.*, 2012)

Examples of ecosystem based approaches to adaptation include:

- Sustainable water management, where river basins, aquifers, flood plains, and their associated vegetation are managed or restored to provide resilient water storage and enhanced baseflows, flood regulation services, reduction of erosion/siltation rates, and more ecosystem goods (e.g., Midgley *et al.*, 2012, Opperman *et al.*, 2009).
- Disaster risk reduction through the restoration of coastal habitats (e.g., mangroves, wetlands and deltas) to provide effective measure against storm-surges, saline intrusion and coastal erosion;
- Sustainable management of grasslands and rangelands to enhance pastoral livelihoods and increase resilience to drought and flooding;
- Establishment of diverse and resilient agricultural systems, and adapting crop and livestock variety mixes to secure food provision. Traditional knowledge may contribute in this area through, for example, identifying indigenous crop and livestock genetic diversity, and water conservation techniques;
- Management of fire-prone ecosystems to achieve safer fire regimes while ensuring the maintenance of natural processes.

It is important to assess the appropriate and effective application of EBA as a developing concept through learning from work underway, and to build understanding of the social and physical conditions that may limit its effectiveness. Application of EBA, like other approaches, is not without risk, and risk/benefit assessments will allow better assessment of opportunities offered by the approach.

[INSERT FIGURE EA-1 HERE
Figure EA-1: Adapted from Munang *et al.* (2013). Ecosystem based adaptation approaches to adaptation can utilize the capacity of nature to buffer human systems from the adverse impacts of climate change through sustainable delivery of ecosystems services. A) Business as Usual Scenario in which climate impacts degrade ecosystems,

ecosystem service delivery and human well-being B) Ecosystem-based Adaptation Scenario which utilizes natural capital and ecosystem services to reduce climate-related risks to human communities.]

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Box CC-CR. Coral Reefs

[Jean-Pierre Gattuso (France), Ove Hoegh-Guldberg (Australia), Hans-Otto Pörtner (Germany)]

Coral reefs are shallow-water structures made of calcium carbonate mostly secreted by reef-building (scleractinian) corals and encrusting macroalgae. They occupy less than 0.1% of the ocean floor yet play multiple important roles throughout the tropics. About 275 million people live within 30 km of a coral reef (Burke et al., 2011) and are likely to derive some benefits from the ecosystem services that coral reefs provide (Hoegh-Guldberg, 2011) including those from provisioning (food, construction material, medicine), regulating (shoreline protection, water quality), supporting services (oxygen supply) and cultural (religion, tourism). This is especially true in small islands (29.3.3.1).

Most human-induced disturbances to coral reefs were local (e.g., coastal development, pollution, nutrient enrichment and overfishing) until the early 1980s when global and climate-related disturbances (ocean warming and acidification) began to occur. Temperature and seawater acidity are two of the most important environmental variables determining the distribution of coral reefs (Kleypas et al., 2001). As corals are centrally important as ecosystem engineers (Wild et al., 2011), the impacts on corals have led to widespread degradation of coral reefs.

A wide range of climatic and non-climatic stressors affect corals and coral reefs and negative impacts are already observed (5.4.2.4, 30.5.3, 30.5.6). Bleaching involves the breakdown and loss of endosymbiotic algae (genus *Symbiodinium*), which live in the coral tissues and play a key role in supplying the coral host with energy and nutrients (Baker et al., 2008) (see 6.2.5 for physiological details and 30.5 for a regional analysis). Mass coral bleaching and mortality, triggered by positive temperature anomalies, is the most widespread and conspicuous impact (Fig. 5X; see Sections, 5.4.2.4, 6.2.5, 25.6.2, 30.5 and 30.8.2). For example, the level of thermal stress at most of the 47 reef sites where bleaching occurred during 1997-98 was unmatched in the period 1903 to 1999 (Lough, 2000). Elevated temperature along with ocean acidification reduces the calcification rate of corals (*high confidence*; 5.4.2.4), and may tip the calcium carbonate balance of reef frameworks towards dissolution (*medium evidence and agreement*; 5.4.2.4). These changes will erode fish habitats with cascading effects reaching fish community structure and associated fisheries (*robust evidence, high agreement*, 30.5).

Around 50% of all coral reefs have experienced medium-high to very high impact of human activities (30-50% to 50-70% degraded; Halpern et al., 2008), which has been a significant stressor for over 50 years in many cases. As a result, the abundance of reef building corals is in rapid decline (1 to 2% per year, 1997-2003) in many Pacific and SE Asian regions (Bruno and Selig, 2007). Similarly, the abundance of reef-building corals has decreased by over 80% on many Caribbean reefs (1977 to 2001; Gardner et al., 2003), with a dramatic phase shift from corals to seaweeds occurring on Jamaican reefs (Hughes, 1994). Tropical cyclones, coral predators and coral bleaching have led to a decline in coral cover on the Great Barrier Reef (about 51% between 1985 and 2012; De'ath et al., 2012).

One third of all coral species exhibit a high risk of extinction, based on recent patterns of decline and other factors such as reproductive strategy (Carpenter et al., 2008). Although less well documented, non-coral benthic invertebrates are also at risk (Przeslawski et al., 2008). Fish biodiversity is threatened by the permanent degradation coral reefs, including in a marine reserve (Jones et al., 2004). While many factors, such as overfishing and local pollution, are involved in the decline of coral reefs, climate change through its pervasive influence on sea temperature, ocean acidity, and storm strength plays a very significant role.

There is *robust evidence* and *high agreement* that coral reefs are one of the most vulnerable marine ecosystems (Chapters 5, 6, 25, and 30). Globally, more than half of the world's reefs are under medium or high risk of degradation (Burke et al., 2011) even in the absence of climatic factors. Future impacts of climate stressors (ocean warming, acidification and sea level rise) will exacerbate the impacts of non-climatic stressors (*high agreement, robust evidence*). Even under optimistic assumptions regarding corals being able to rapidly adapt to thermal stress, one-third (9–60%, 68% uncertainty range) of the world's coral reefs are projected to be subject to long-term degradation under the RCP3-PD scenario (Frieler et al., 2013). Under the RCP4.5 scenario, this fraction increases to two-thirds (30–88%, 68% uncertainty range). If present day corals have residual capacity to acclimatize and/or adapt, half of the coral reefs may avoid high frequency bleaching through 2100 (*limited evidence, limited* *agreement*; Logan et al., sbm). Evidence of corals adapting rapidly, however, to climate change is missing or equivocal (Hoegh-Guldberg, 2012).

Damage to coral reefs has implications for several key regional services:

- *Resources*: Coral reefs produce 10-12% of the fish caught in tropical countries, and 20-25% of the fish caught by developing nations (Garcia & Moreno, 2003). Over half (55%) of the 49 island countries considered by Newton et al. (2012) are already exploiting their coral reef fisheries in an unsustainable way (13.X.X).
- *Tourism*: More than 100 countries benefit from the recreational value provided by their coral reefs (Burke et al., 2011). For example, the Great Barrier Reef Marine Park attracts about 1.9 million visits each year and generates A$ 5.4 billion to the Australian economy and 54,000 jobs (90% in the tourism sector; Biggs, 2011).
- *Coastal* protection: Coral reefs contribute to protecting the shoreline from the destructive action of storm surges and cyclones (Sheppard et al., 2005), sheltering the only habitable land for several island nations, habitats suitable for the establishment and maintenance of mangroves and wetlands, as well as areas for recreational activities. This role is threatened by future sea level rise, the decrease in coral cover, reduced rates of calcification and higher rates of dissolution and bioerosion due to ocean warming and acidification (5.4.2.4, 6.4, 30.5).

Coral reefs make a modest contribution to the global domestic product but their economic importance can be high at the country and regional scales (Pratchett et al., 2008). For example, tourism and fisheries represent on average 5% of the GDP of South Pacific islands (Laurans et al., 2013). At the local scale, these two services provide at least 25% of the annual income of villages in Vanuatu and Fiji (Pascal, 2011; Laurans et al., 2013).

Marine protected areas (MPAs) and fisheries management have the potential to increase ecosystem resilience and increase the recovery of coral reefs after climate change impacts such as mass coral bleaching (McLeod et al., 2009). Although they are key conservation and management tools, they are less effective in reducing coral loss from thermal stress (Selig et al., 2012) suggesting that they need to be complemented with additional and alternative strategies (Rau et al., 2012). Controlling the input of nutrients and sediment from land is an important complementary management strategy because nutrient enrichment can increase the susceptibility of corals to bleaching (Wiedenmann et al., 2012). There is also high confidence that, in the long term, limiting the amount of warming and acidity is central to ensuring the viability of coral reef systems and dependent communities (5.X.X and 30.5).

[INSERT FIGURE CR-1 HERE
Figure CR-1: A and B: the same coral community before and after a bleaching event in February 2002 at 5 m depth, Halfway Island, Great Barrier Reef. Coral cover at the time of bleaching was 95% bleached almost all of it severely bleached, resulting in mortality of 20.9% (Elvidge et al., 2004). Mortality was comparatively low due in part because these communities were able shuffle symbiont types to more thermo-tolerant types (Berkelmans and van Oppen, 2006; Jones et al., 2008). C and D: three CO2 seeps in Milne Bay Province, Papua New Guinea show that prolonged exposure to high CO2 is related to fundamental changes in coral reef structures (Fabricius et al., 2011). Coral communities at three high CO2 (Fig. XB; median pHT 7.7, 7.7 and 8.0), compared with three control sites (Fig. XA; median pHT 8.02), are characterized by significantly reduced coral diversity (-39%), severely reduced structural complexity (-67%), low densities of young corals (-66%) and few crustose coralline algae (-85%). Reef development ceases at pHT values below 7.7. Photo credit: R. Berkelmans (A and B) and K. Fabricius (C and D).]

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Box CC-RF. Impact of Climate-Change on Freshwater Ecosystems due to Altered River Flow Regimes
[Petra Döll (Germany), Stuart E. Bunn (Australia)]

It is widely acknowledged that the flow regime is a primary determinant of the structure and function of rivers and their associated floodplain wetlands, and flow alteration is considered to be a serious and continuing threat to freshwater ecosystems (Bunn and Arthington, 2002; Poff and Zimmerman, 2010; Poff *et al.*, 2010). Most species distribution models do not consider the effect of changing flow regimes (i.e. changes to the frequency, magnitude, duration and/or timing of key flow parameters) or they use precipitation as proxy for river flow (Heino *et al.*, 2009).

There is growing evidence that climate change will significantly alter ecologically important attributes of hydrologic regimes in rivers and wetlands, and exacerbate impacts from human water use in developed river basins (Aldous *et al.*, 2011; Xenopoulos *et al.*, 2005). By the 2050s, climate change is projected to impact river flow characteristics like long-term average discharge, seasonality and statistical high flows (but not statistical low flows) more strongly than dam construction and water withdrawals have done up to the year 2000 (Figure RF-1; Döll and Zhang, 2010). For one climate scenario, 15% of the global land area may suffer, by the 2050s, from a decrease of fish species in the upstream basin of more than 10%, as compared to only 10% of the land area that has already suffered from such decreases due to water withdrawals and dams (Döll and Zhang, 2010). Climate change may exacerbate the negative impacts of dams for freshwater ecosystems but may also provide opportunities for operating dams and power stations to the benefit of riverine ecosystems. This is the case if total runoff increases and, like in Sweden, the annual hydrograph becomes more similar to variation in electricity demand, i.e. with a lower spring flood and increased run-off during winter months (Renofalt *et al.*, 2010).

[INSERT FIGURE RF-1 HERE
Figure RF-1: Impact of climate change on the ecologically relevant river flow characteristics mean annual river flow and monthly low flow Q_{90} as compared to the impact of water withdrawals and dams on natural flows, as computed by a global water model (Döll and Zhang, 2010). Impact of climate change is the percent change of flow between 1961-1990 and 2041-2070 according to the emissions scenario A2 as implemented by the global climate model HadCM3. Impact of water withdrawals and reservoirs is computed by running the model with and without water withdrawals and dams that existed in 2002.]

Because biota are often adapted to a certain level of river flow variability, the larger variability of river flows that is due to increased climate variability is *likely* to select for generalist or invasive species (Ficke *et al.*, 2007). The relatively stable habitats of groundwater-fed streams in snow-dominated or glacierized basins may be altered by reduced recharge by meltwater and as a result experience more variable (possibly intermittent) flows (Hannah *et al.*, 2007). A high-impact change of flow variability is a flow regime shift from intermittent to perennial or vice versa. It is projected that until the 2050s, river flow regime shifts may occur on 5-7% of the global land area, mainly in semi-arid areas (Döll and Müller Schmied, 2012; see Chapter 3, Table 3-2).

In Africa, one third of fish species and one fifth of the endemic fish species occur in eco-regions that may experience a change in discharge or runoff of more than 40% by the 2050s (Thieme *et al.*, 2010). Eco-regions containing over 80% of Africa's freshwater fish species and several outstanding ecological and evolutionary phenomena are *likely* to experience hydrologic conditions substantially different from the present, with alterations in long-term average annual river discharge or runoff of more than 10% due to climate change and water use (Thieme *et al.*, 2010).

Due to increased winter temperatures, freshwater ecosystems in basins with significant snow storage are affected by higher river flows in winter, earlier spring peak flows and possibly reduced summer low flows (chapter 3.2.3). Strongly increased winter peak flows may lead to a decline in salmonid populations in the Pacific Northwest of the USA of 20-40% by the 2050s (depending on the climate model) due to scouring of the streambed during egg incubation, the relatively pristine high-elevation areas being affected most (Battin *et al.*, 2007). Reductions in summer low flows will increase the competition for water between ecosystems and irrigation water users (Stewart *et al.*, 2005). Ensuring environmental flows through purchasing or leasing water rights and altering reservoir release patterns will be an important adaptation strategy (Palmer *et al.*, 2009).

Observations and models suggest that global warming impacts on glacier and snow-fed streams and rivers will pass through two contrasting phases (Burkett *et al.*, 2005; Vuille *et al.*, 2008; Jacobsen *et al.*, 2012). In the first phase, when river discharge is increased due to intensified melting, the overall diversity and abundance of species may increase. However, changes in water temperature and stream-flow may have negative impacts on narrow range endemics (Jacobsen *et al.*, 2012). In the second phase, when snowfields melt early and glaciers have shrunken to the point that late-summer stream flow is reduced, broad negative impacts are foreseen, with species diversity rapidly declining once a critical threshold of roughly 50% glacial cover is crossed (Figure RF-2).

[INSERT FIGURE RF-2 HERE
Figure RF-2: Accumulated loss of regional species richness (gamma diversity) as a function of glacial cover GCC. Obligate glacial river macroinvertebrates begin to disappear from assemblages when glacial cover in the catchment drops below approximately 50%. Each data point represents a river site and lines are Lowess fits. Adapted by permission from Macmillan Publishers Ltd: *Nature Climate Change*, Jacobsen *et al.*, 2012, © 2012.]

River discharge also influences the response of river temperatures to increases of air temperature. Globally averaged, air temperature increases of 2°C, 4°C and 6°C are estimated to lead to increases of annual mean river temperatures of 1.3°C, 2.6°C and 3.8°, respectively (van Vliet *et al.*, 2011). Discharge decreases of 20% and 40% are computed to result in additional increases of river water temperature of 0.3° C and 0.8°C on average (van Vliet *et al.*, 2011). Therefore, where rivers will experience drought more frequently in the future, freshwater-dependent biota will suffer not only directly by changed flow conditions but also by drought-induced river temperature increases, as well as by related decreased oxygen and increased pollutant concentrations.

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Box CC-OA. Ocean Acidification

[Jean-Pierre Gattuso (France), Peter Brewer (USA), Ove Hoegh-Guldberg (Australia), Joan A. Kleypas (USA), Hans-Otto Pörtner (Germany), Daniela Schmidt (UK)]

Introduction

Anthropogenic ocean acidification and climate change share the same primary cause at the global level, the increase of atmospheric carbon dioxide (WGI, 2.2.1). Eutrophication and upwelling contribute to local ocean acidification (5.3.3.6, 30.5.4). Past and futures changes in chemistry are well known in the surface open ocean (WGI, 3.8.2 and 6.4.4) but are more difficult to project in the more complex coastal systems (5.3.3.6 and 30.5.2).

Chemistry and Projections

The fundamental chemistry of ocean acidification has long been understood: the uptake of CO_2 into mildly alkaline ocean results in an increase in dissolved CO_2 and reductions in pH, dissolved carbonate ion, and the capacity of seawater to buffer changes in its chemistry (*very high confidence*). The changing chemistry of surface seawater can be projected at the global scale with high accuracy from projections of atmospheric CO_2 levels. Time series observations of changing upper ocean CO_2 chemistry support this linkage (WGI Table 3.2 and Figure 3.17; WGII Figure 30.5). Projections of regional changes, especially in coastal waters (5.3.3.6), and at depth are more difficult; observations and models show with high certainty that fossil fuel CO_2 has penetrated at depths of 1 km and more. Importantly, the natural buffering of increased CO_2 is less in deep than in surface water and thus a greater chemical impact is projected. Additional significant CO_2 increases and pH decreases at mid-depths are expected to result from increases in microbial respiration induced by warming. Projected changes in open ocean, surface water chemistry for year 2100 based on representative concentration pathways (WGII, Figure 6.28) compared to preindustrial values range from a pH change of -0.14 unit with RCP 2.6 (421 ppm CO_2, +1 ºC, 22% reduction of carbonate ion concentration) to a pH change of -0.43 unit with RCP 8.5 (936 ppm CO_2, +3.7 ºC, 56% reduction of carbonate ion concentration).

Biological, Ecological, and Biogeochemical Impacts

The effects of ocean acidification on marine organisms and ecosystems have only recently been investigated. A wide range of sensitivities to projected rates of ocean acidification exists within and across organism groups and phyla with a trend for higher sensitivity in early life stages (*high confidence*; Kroeker et al., in press; 6.2.3-5, 6.3.4). A pattern of impacts, some positive, others negative, emerges for some processes and organisms (*high confidence*; Fig. X.C) but key uncertainties remain from organismal to ecosystem levels (Chap. 5, 6, 30). Responses to ocean acidification are exacerbated at high temperature extremes (*medium confidence*) and can be influenced by other drivers, such as oxygen concentration, nutrients, and light availability (*medium confidence*).

Experimental evidence shows that lower pH decreases the rate of calcification of most, but not all, sea-floor calcifiers such as reef-building corals (Box CC-CR, coralline algae (Raven, in press), bivalves and snails (Gazeau et al., in press) reducing their competitiveness compared to, e.g. seaweeds (Chap. 5, 6, 30). A reduced performance of these ecosystem builders would affect the other components of the ecosystem dependent on the habitats they create.

Growth and primary production are stimulated in seagrass and some phytoplankton (*high confidence*) and harmful algal blooms could become more frequent (*limited evidence*, *medium agreement*). Ocean acidification may significantly stimulate nitrogen fixation in the oceans (*limited evidence*, *low agreement*; 6.2.3, 6.3.4). There are few known direct effects on early stages of fish and adult fish remain relatively undisturbed by elevated CO_2. Serious behavioral disturbances were reported, mostly on larval and juvenile coral reef fishes (6.2.4).

Projections of ocean acidification effects at the ecosystem level are limited by the diversity of species-level responses. Natural analogues at CO_2 vents indicate decreased species diversity, biomass and trophic complexity of communities living on the sea-floor. Shifts in community structure have been documented in rocky shore environments (e.g., Wootton et al., 2008), in relation with rapidly declining pH (Wootton and Pfister, 2012). Differential sensitivities and associated shifts in performance and distribution will change predator-prey relationships and competitive interactions (6.2-3), which could impact food webs and higher trophic levels (*limited evidence, high agreement*).

There is *limited evidence* and *medium agreement* that some phytoplankton and mollusks can adapt to ocean acidification, indicating that the long-term responses of these organisms to ocean acidification could be less than responses obtained in short-term experiments. However, mass extinctions during much slower rates of ocean acidification in Earth history (6.1.2) suggest that evolutionary rates are not fast enough for sensitive animals and plants to adapt to the projected rate of change (*high confidence*).

The effect of ocean acidification on global biogeochemical cycles is difficult to predict due to the species-specific responses to ocean acidification, lack of understanding of the effects on trophic interactions, and largely unexplored combined responses to ocean acidification and other climatic and non-climatic drivers, such as temperature, concentrations of oxygen and nutrients, and light availability.

Risks

Climate risk is defined as the probability that climate change will cause specific physical hazards and that those hazards will cause impacts (19.5.2). The risks of ocean acidification to marine organisms, ecosystems, and ultimately to human societies, includes both the probability that ocean acidification will affect key processes, and the magnitude of the resulting impacts. The changes in key processes mentioned above present significant ramifications on ecosystems and ecosystem services (Fig. 19.3). For example, ocean acidification will cause a decrease of calcification of corals, which will cause not only a reduction in the coral's ability to grow its skeleton, but also in its contribution to reef building (*high confidence*; 5.4.2.4). These changes will have consequences for the entire coral reef community and on the ecosystem services that coral reefs provide such as fisheries habitat (*medium confidence*; 19.5.2) and coastal protection (*medium confidence*; Box CC-CR). Ocean acidification poses many other potential risks, but these cannot yet be quantitatively assessed due to the small number of studies available, particularly on the magnitude of the ecological and socioeconomic impacts (19.5.2).

Socioeconomic Impacts and Costs

The biological, ecological and biogeochemical changes driven by ocean acidification will affect several key ecosystem services. The oceans will become less efficient at absorbing CO_2, hence less efficient at moderating climate change, as their CO_2 content will increase (*very high confidence*). The impacts of ocean acidification on coral reefs, together with those of bleaching and sea level rise, will in turn diminish their role of shoreline protection in atolls and small island nations as well as their direct and indirect benefits on the tourism industry (*limited evidence*, *high agreement*; Box CC-CR).

There is no global estimate of the observed or projected economic costs of ocean acidification. The production of commercially-exploited shelled mollusks may decrease (Barton et al., 2012) resulting in an up to 13% reduction of US production (limited evidence, low agreement; Cooley and Doney, 2009). The global cost of production loss of mollusks could be over 100 billion USD by 2100 (Narita et al., 2012). The largest uncertainty is how the impacts on prey will propagate through the marine food webs and to top predators. Models suggest that ocean acidification will generally reduce fish biomass and catch (*limited evidence, high agreement*) and that complex additive, antagonistic and/or synergistic interactions will occur with other environmental (warming) and human (fisheries management) factors (Branch et al., 2012; Griffith et al., 2012). The annual economic damage of ocean-acidification-induced coral reef loss by 2100 has been estimated, in 2009, to be 870 and 500 billion USD, respectively for A1 and B2 SRES emission scenarios (Brander et al. 2012). Although this number is small compared to global GDP, it represents a large proportion of the GDP of some regions or small island states which rely economically on coral reefs.

Adaptation and Mitigation

The management of ocean acidification comes down to mitigation of the source of the problem and adaptation to the consequences (Rau et al., 2012; Billé et al., sbm). Mitigation of ocean acidification through reduction of atmospheric CO_2 is the most effective and the least risky method to limit ocean acidification and its impacts. Climate geoengineering techniques based on solar radiation management would have no direct effect on ocean acidification because atmospheric CO_2 would continue to rise (6.4.2). Techniques based on carbon dioxide removal could directly address the problem but their effectiveness at the scale required to ameliorate ocean acidification has yet to be demonstrated. Additionally, some ocean-based approaches, such as iron fertilization, would only re-locate ocean acidification from the upper ocean to the ocean interior, with potential ramifications on deep water oxygen levels (Williamson and Turley, 2012; 6.4.2; 30.3.2.3 and 30.5.7). Mitigation of ocean acidification at the local level could involve the reduction of anthropogenic inputs of nutrients and organic matter in the coastal ocean (5.3.4.2). Specific activities, such as aquaculture, could adapt to ocean acidification within limits, for example by altering the production process, selecting less sensitive species or strains, or relocating elsewhere. A low-regret approach is to limit the number and the magnitude of drivers other than CO_2. There is evidence, for example, that reducing a locally determined driver (i.e. nutrient pollution) may substantially reduce its synergistic effects with a globally determined driver such as ocean acidification (Falkenberg et al., 2013).

[INSERT FIGURE OA-1 HERE
Figure OA-1: A: Overview of the chemical, biological, socio-economic impacts of ocean acidification and of policy options (adapted from Turley & Gattuso, 2012). B: Multi-model simulated time series of global mean ocean surface pH (on the total scale) from CMIP5 climate model simulations from 1850 to 2100. Projections are shown for emission scenarios RCP2.6 (blue) and RCP8.5 (red) for the multi-model mean (solid lines) and range across the distribution of individual model simulations (shading). Black (grey shading) is the modelled historical evolution using historical reconstructed forcings. The models that are included are those from CMIP5 that simulate the global carbon cycle while being driven by prescribed atmospheric CO_2 concentrations. The number of CMIP5 models to calculate the multi-model mean is indicated for each time period/scenario (IPCC AR5 WG1 report, Figure 6.28). C: Effect of near future acidification on major response variables estimated using weighted random effects meta-analyses, with the exception of survival which is not weighted (Kroeker et al., in press). The effect size indicates which process is most uniformly affected by ocean acidification but large variability exists between species. Significance is determined when the 95% bootstrapped confidence interval does not cross zero. The number of experiments used in the analyses is shown in parentheses. * denotes a significant effect.]

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Box CC-RC. Regional Climate Summary Figures

[Noah S. Diffenbaugh (USA), Daithi Stone (Canada), Filippo Giorgi (Italy), Bruce Hewitson (South Africa), Richard Jones (UK), Geert Jan van Oldenborg (Netherlands)]

The WGII regional climate summary figures draw on climate model simulations archived in Phase 5 of the Coupled Model Intercomparison Project (CMIP5) (Taylor et al. 2012). The CMIP5 simulations are also the basis for the figures presented in Annex I of the WGI contribution (*Atlas of Global and Regional Climate Projections*). The CMIP5 archive includes output from approximately three dozen climate models, including atmosphere-ocean general circulation models (AOGCMs), AOGCMs with coupled vegetation and/or carbon cycle components, and AOGCMs with coupled atmospheric chemistry components. The number of models from which output is available, and the number of realizations of each model, varies between the different CMIP5 experiments.

In contrast to CMIP3 (which used the IPCC SRES scenarios), CMIP5 uses the Representative Concentration Pathways (RCPs) (van Vuuren et al. 2011) to simulate the climate response to possible changes in forcing over the 21st century. The WGI Atlas focuses on RCP4.5, with supplemental analysis of RCP2.6, RCP6.0, and RCP8.5. The WGII regional climate figures compare RCP4.5 and RCP8.5, using the same baseline, mid-21st-century, and late-21st-century time periods as the WGI Atlas (1986-2005, 2046-2065, 2081-2100). The RCPs exhibit overlapping likelihood of global warming in the mid-21st-century period (including median warming of 1.4˚C and 2.1˚C above the late-20th-century baseline in RCP4.5 and RCP8.5, respectively) (Rogelj et al. 2012), but divergent likelihood of global warming in the late-21st-century period (including median warming of 1.8˚C and 3.8˚C above the late-20st-century baseline in RCP4.5 and RCP8.5, respectively) (Rogelj et al. 2012). Given that real emissions have tracked on or above RCP8.5 in recent years (Peters et al. 2013), the regional climate figures are focused on the middle (RCP4.5) and upper end (RCP8.5) of the range of RCPs available in CMIP5.

The regional climate figures show the mean annual temperature and precipitation, categorizing differences in the CMIP5 simulation of the baseline and future periods into four classes. The classes are constructed based on the IPCC uncertainty guidance, which provides a quantitative basis for assigning likelihood statements (Mastrandrea et al. 2011). The classifications in the figures are constructed to parallel the 66-100% ("likely") and 90-100% ("very likely") probability ranges identified in the IPCC uncertainty guidance.

However, there are a number of plausible assignments of likelihood in a multi-model ensemble (e.g., (Knutti et al. 2010)). The classifications in the regional climate figures are based on two interpretations of likelihood reflected in the literature. The first interpretation is the likelihood that the climate in the future period is different than the climate in the baseline period (e.g., (Tebaldi et al. 2011). The regional climate figures use the percentage of models for which the simulated change exceeds two standard deviations of the simulated baseline variability as the measure of probability that the simulated future climate is statistically different than the simulated baseline climate. The second interpretation is the likelihood of the sign of change (e.g., (Christensen et al. 2007; Field et al. 2012). The regional climate figures use the percentage of models that exhibit the same sign of change as the measure of probability of increase or decrease in a given quantity.

The four classifications depicted in the regional climate figures are:

1) White indicates areas where less than 66% of the models exhibit difference between the future and baseline periods that exceeds twice the baseline variability.
2) Gray indicates areas where greater than 66% of the models exhibit difference between the future and baseline periods that exceeds twice the baseline variability, and less than 66% of the models agree on the sign of difference.
3) Colors with circles indicate areas where greater than 66% of the models exhibit difference between the future and baseline periods that exceeds twice the baseline variability, and greater than 66% of the models agree on the sign of the difference. The color contour shows the magnitude of the multi-model mean difference between the future and baseline periods.
4) Colors without circles indicate areas where greater than 90% of the models exhibit difference between the future and baseline periods that exceeds twice the baseline variability, and greater than 90% of the models agree on the sign of the difference. The color contour shows the magnitude of the multi-model mean difference between the future and baseline periods.

Only those models that have archived output from the historical, RCP4.5 and RCP8.5 experiments are included. For each of the included models, all realizations are used. For a given model, the mean and variability of each realization is first calculated for each period. The mean of the individual-realization mean and variability values are then calculated across the realizations of that model in each period, yielding model-mean mean and variability values derived from the timeseries of each realization (rather than from the mean of the timeseries). The difference between the model-mean in the future and baseline periods is then calculated for each model, and compared with each model's model-mean baseline variability. (Prior to analysis, each realization of each model is first interpolated to a common 1˚ geographical grid using linear interpolation.)

Because the regional climate figures quantify differences between 20-year periods, the measure of baseline variability is chosen to reflect the variability between 20-year periods in the baseline climate forcing. Given that the baseline period is selected as 1986-2005, the baseline variability is calculated as the standard deviation between the 20 20-year periods ending in the years 1986 through 2005 (1967-1986, 1968-1987, … , 1986-2005). Although the 20 20-year periods are not independent, they reflect the population of 20-year periods within the recent climate forcing regime, and a 20-year period that is more than two standard deviations removed is considered to be reflective of a different climate.

In addition to maps of the CMIP5 simulations, the regional climate figures also include maps of observed temperature and precipitation differences between the baseline period (1986-2005) and the early 20th century (1906-1925). The observational analyses use the CRU TS3.10.01 gridded station-based temperature and precipitation data (CRU 2012). On the observational panel, white indicates areas where the difference between the baseline and early-20th-century periods does not exceed two standard deviations of the early-20th-century variability. Colors indicate areas where the difference between the baseline and early-20th-century periods exceeds two standard deviations of the early-20th-century variability, with the color contours showing the magnitude of the difference. For the observational analyses, the early-20th-century variability is calculated as the standard deviation between the 20 20-year periods beginning in the years 1906 through 1925 (1906-1925, 1907-1926, … , 1925-1944).

[INSERT FIGURE RC-1 HERE
Figure RC-1: Change in annual temperature. For the CRU observations, differences are shown between the 1986-2005 and 1906-1925 periods, with white indicating areas where the difference between the 1986-2005 and 1906-1925 periods is less than twice the standard deviation of the 20 20-year periods beginning in the years 1906 through 1925. For CMIP5, white indicates areas where <66% of models exhibit a change greater than twice the baseline standard deviation of the respective model's 20 20-year periods ending in years 1986 through 2005. Gray indicates areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation, but <66% of models agree on the sign of change. Colors with circles indicate the ensemble-mean change in areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation and >66% of models agree on the sign of change. Colors without circles indicate areas where >90% of models exhibit a change greater than twice the respective model baseline standard deviation and >90% of models agree on the sign of change. The realizations from each model are first averaged to create baseline-period and future-period mean and standard deviation for each model, from which the multi-model mean and the individual model signal-to-noise ratios are calculated. The baseline period is 1986-2005. The late-21st century period is 2081-2100. The mid-21st century period is 2046-2065.]

[INSERT FIGURE RC-2 HERE
Figure RC-2: Change in annual precipitation. For the CRU observations, differences are shown between the 1986-2005 and 1906-1925 periods, with white indicating areas where the difference between the 1986-2005 and 1906-1925 periods is less than twice the standard deviation of the 20 20-year periods beginning in the years 1906 through 1925. For CMIP5, white indicates areas where <66% of models exhibit a change greater than twice the baseline standard deviation of the respective model's 20 20-year periods ending in years 1986 through 2005. Gray indicates areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation, but <66% of models agree on the sign of change. Colors with circles indicate the ensemble-mean change in areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation and >66% of models agree on the sign of change. Colors without circles indicate areas where >90% of models exhibit a

change greater than twice the respective model baseline standard deviation and >90% of models agree on the sign of change. The realizations from each model are first averaged to create baseline-period and future-period mean and standard deviation for each model, from which the multi-model mean and the individual model signal-to-noise ratios are calculated. The baseline period is 1986-2005. The late-21st century period is 2081-2100. The mid-21st century period is 2046-2065.]

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Box CC-TC. Case Study Building Long Term Resilience from Tropical Cyclone Disasters
[Yoshiki Saito (Japan), Kathleen McInnes (Australia)]

Tropical cyclones (also referred to as hurricanes and typhoons in some regions) cause powerful winds, torrential rains, high waves and storm surge, all of which can have major impacts on society and ecosystems. For example, Bangladesh and India account for 86% of mortality from tropical cyclones (Murray *et al.*, 2012), which is mainly due to the rarest and most severe storm categories (i.e. Categories 3, 4, and 5).

About 90 tropical cyclones occur globally each year (Seneviratne et al, 2012) although interannual variability is large. Changes in observing techniques particularly after the introduction of satellites in the late 1970s, confounds the assessment of trends in tropical cyclone frequencies and intensities. Therefore, SREX concluded that there is *low confidence* that any observed long-term (i.e. 40 years or more) increases in tropical cyclone activity are robust, after accounting for past changes in observing capability (Seneviratne, *et al.*, 2012; Chapter 2). There is also *low confidence* in the detection and attribution of century scale trends in tropical cyclones. Future changes to tropical cyclones arising from climate change are *likely* to vary by region. This is because there is *medium confidence* that for certain regions, shorter-term forcing by natural and anthropogenic aerosols has had a measurable effect on tropical cyclones. Tropical cyclone frequency is *likely* to decrease or remain unchanged over the 21st century, while intensity (i.e. maximum wind speed and rainfall rates) is *likely* to increase. Regionally specific projections have *lower confidencelower confidence* (see WG1 Box 14.2).

Longer term impacts from tropical cyclones includes salinisation of coastal soils and water supplies and subsequent food and water security issues from the associated storm surge and waves (Terry and Chui, 2012). However, preparation for extreme tropical cyclone events through improved governance and development to reduce their impacts provides an avenue for building resilience to longer term changes associated with climate change.

Densely populated Asian deltas are particularly vulnerable to tropical cyclones due to their large population density in expanding urban areas (Nicholls *et al.*, 2007). Extreme cyclones in Asia since 1970 caused over 0.5 million fatalities (Murray *et al.*, 2012) e.g., cyclones Bhola in 1970, Gorky in 1991, Thelma in 1998, Gujarat in 1998, Orissa in 1999, Sidr in 2007, and Nargis in 2008. Tropical cyclone Nargis hit Myanmar on 2 May 2008 and caused over 138,000 fatalities. Several-meter high storm surges widely flooded densely populated coastal areas of the Irrawaddy Delta and surrounding areas (Revenga *et al.*, 2003; Brakenridge *et al.*, 2012). The flooded areas were captured by a NASA MODIS image on 5 May 2008 (Figure TC-1).

[INSERT FIGURE TC-1 HERE
Figure TC-1: The intersection of inland and storm surge flooding. Red shows May 5, 2008 MODIS mapping of the tropical cyclone Nargis storm surge along the Irrawaddy Delta and to the east, Myanmar. The blue areas to the north were flooded by the river in prior years. (From Brakenridge *et al.*, 2012).]

Murray *et al.* (2012) compared the response to cyclone Sidr in Bangladesh in 2007 and Nargs in Myanmar in 2008 and demonstrated how disaster risk reduction methods could be successfully applied to climate change adaptation (Murray et al, 2012). Sidr, despite being of similar strength to Nargis, caused far fewer fatalities (3,400 compared to over 138000) and this was attributed to advancement in preparedness and response in Bangladesh through experience in previous cyclones such as Bhola and Gorky. The responses included the construction of multi-storied cyclone shelters, improvement of forecasting and warning capacity, establishing a coastal volunteer network, and coastal reforestation of mangroves. Birkmann and Teichman, (2010) caution that while the combination of risk reduction and climate change adaptation strategies may be desirable, different spatial and temporal scales, norm systems, and knowledge types and sources between the two goals can confound their effective combination.

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Box CC-WE. The Water-Energy-Food Nexus as Linked to Climate Change

[Douglas J. Arent (USA), Petra Döll (Germany), Ken Strzepek (UNU/USA), FerencToth (IAEA/Hungary), Blanca Elena Jimenez Cisneros (Mexico), Taikan Oki (Japan)]

Water, energy, and food are linked through numerous interactive pathways and subject to a changing climate, as depicted in Figure CC-WE-1. The depth and intensity of those linkages vary enormously between regions and production systems. Some energy technologies (biofuels, hydropower, thermal power plants), transportation fuels and modes and food products (from irrigated crops, in particular animal protein produced by feeding irrigated crops) require more water than others (Chapter 3.7.2, 7.3.2, 10.2,10.3.4, McMahon and Price, 2011, Macknick et al, 2012a, Cary and Weber 2008). In irrigated agriculture, climate, crop choice and yields determine water requirements per unit of produced crop, and in areas where water must be pumped or treated, energy must be provided (Kahn and Hajra 2009, Gertenet al. 2011). While food production and transport require large amounts of energy (Pelletier et al 2011), a major link between food and energy as related to climate change is the competition of bioenergy and food production for land and water (7.3.2, Diffenbaugh et al 2012, Skaggs et al, 2012).

[INSERT FIGURE WE-1 HERE
Figure WE-1: The water-energy-food nexus as related to climate change.]

Most energy production methods require significant amounts of water, either directly (e.g. crop-based energy sources and hydropower) or indirectly (e.g., cooling for thermal energy sources or other operations) (Chapter 10.2.2 and 10.3.4, and Davies et al 2013, van Vliet et al 2012). Water is also required for mining, processing, and residue disposal of fossil fuels. Water for biofuels, for example, has been reported by Gerbens-Leenes et al. 2012 who computed a scenario of water use for biofuels for transport in 2030 based on the Alternative Policy Scenario of the IEA. Under this scenario, global consumptive irrigation water use for biofuel production is projected to increase from 0.5% of global renewable water resources in 2005 to 5.5% in 2030, resulting in increased pressure on freshwater resources, with potential negative impacts on freshwater ecosystems. Water for energy currently ranges from a few percent to more than 50% of freshwater withdrawals, depending on the region and future water requirements will depend on electric demand growth, the portfolio of generation technologies and water management options employed (WEC 2010, Sattler et al., 2012). Future water availability for energy production will change due to climate change (Chapter 3.5.2.2).

Water may require significant amounts of energy for lifting, transport and distribution, treatment or desalination. Non-conventional water sources (wastewater or seawater) are often highly energy intensive. Energy intensities per m^3 of water vary by about a factor of 10 between different sources, e.g. locally produced or reclaimed wastewater vs. desalinated seawater (Plappally and Lienhard 2012, Macknick et al, 2012b). Groundwater (35% of total global water withdrawals, with irrigated food production being the largest user, Döll et al. 2012) is generally more energy intensive than surface water – in some countries, 40% of total energy use is for pumping groundwater. Pumping from greater depth (following falling groundwater tables) increases energy demand significantly– electricity use ($kWhr/m^3$) increases by a factor of 3 when going from 35 to 120 m depth (Plappally and Lienhard 2012). A lack of water security can lead to increasing energy demand and vice versa, e.g. over-irrigation in response to electricity or water supply gaps.

Other linkages through land use and management, e.g. afforestation, can affect water as well as other ecosystem services, climate and water cycles (4.4.4, Box 25-10). Land degradation often reduces efficiency of water and energy use (e.g. resulting in higher fertilizer demand and surface runoff), and many of these interactions can compromise food security (3.7.2, 4.4.4). Only a few reports have begun to evaluate the multiple interactions among energy, food, land, and water (McCornick *et al.*, 2008, Bazilian *et al.*, 2011, Bierbaum and Matson, 2013), addressing the issues from a security standpoint and describing early integrated modeling approaches. The interaction among each of these factors is influenced by the changing climate, which in turn impacts energy demand, bioproductivity and other factors (see Figure WE-1 and Wise et al, 2009), and has implications for security of supplies of energy, food and water, adaptation and mitigation pathways, air pollution reduction as well as the implications for health and economic impacts as described throughout this Assessment Report.

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Box CC-VW. Active Role of Vegetation in Altering Water Flows Under Climate Change

[Richard Betts (UK), Dieter Gerten (Germany), Petra Döll (Germany)]

Terrestrial vegetation dynamics, carbon and water cycles are closely coupled, for example by the simultaneous transpiration and CO_2 uptake through plant stomata in the process of photosynthesis, and by feedbacks of land cover and land use change on water cycling.Numerous experimental studies have demonstrated that elevated atmospheric CO_2 concentration leads to reduced opening of stomatal apertures, associated with a decrease in leaf-level transpiration (de Boer *et al.*, 2011; Reddy *et al.*, 2011). This physiological effect of CO_2 is associated with an increased intrinsic water use efficiency (iWUE) of plants, as less water is transpired per unit of carbon assimilated. Records of stable carbon isotopes in woody plants (Peñuelas *et al.*, 2011) corroborate this finding, suggesting an increase in iWUE of mature trees by 20.5% between the 1970s and 2000s. Increases since pre-industrial times have also been found for several forest sites (Andreu-Hayles *et al.*, 2011; Gagen *et al.*, 2011; Loader *et al.*, 2011; Nock *et al.*, 2011) and in a temperate semi-natural grassland (Koehler *et al.*, 2010), although in one boreal tree species iWUE ceased to increase after 1970 (Gagen *et al.*, 2011). However, the physiological CO_2 effect is accompanied by structural changes to C3 plants (including all tree species), i.e. increased biomass production, spatial encroachment and, thus, higher transpiration, as confirmed by Free Air CO_2 Enrichment (FACE) techniques (Leakey *et al.*, 2009).

There are conflicting views on whether the direct CO_2 effects on plants already have a significant influence on evapotranspiration and runoff at global scale. AR4 reported work by Gedney *et al.*, (2006) which suggested that physiological CO_2effects (lower transpiration) contributed to a supposed global increase in runoff seen in reconstructions by (Labat *et al.*, 2004). However, a more recent dataset (Dai *et al.*, 2009) showed different runoff trends in some areas. Detection of ecosystem influences on terrestrial water flows, hence, critically depends on the availability and quality of hydrometeorological observations (Haddeland *et al.*, 2011; Lorenz and Kunstmann, 2012).

A key influence on the significance of increased iWUE for large-scale transpiration is whether overall leaf area of primary vegetation has remained approximately constant (Gedney *et al.*, 2006) or has increased in some regions due to structural CO_2effects (as assumed in models by Piao *et al.*, 2007; Gerten *et al.*, 2008). While field-based results vary considerably between sites, tree ring studies suggest that tree growth did not increase globally since the 1970s in response to climate and CO_2change (Peñuelas *et al.*, 2011; Andreu-Hayles *et al.*, 2011). However, basal area measurements at over 200 plots across the tropics suggest that biomass and growth rates in intact tropical forests have increased in recent decades (Lewis *et al.*, 2009), which is also confirmed for 55 temperate forest plots, with a suspected contribution of CO_2 rise (McMahon *et al.*, 2010). The net impact of CO_2 on global-scale transpiration and runoff therefore remains poorly constrained.

Moreover, model results differ in terms of the importance of CO_2 effects for historical runoff relative to other drivers such as climate, land use change and irrigation water withdrawal. Other than Gedney *et al.*, (2006), Piao *et al.*, (2007) and Gerten *et al.*, (2008) found that CO_2 effects on global runoff were small relative to effects of precipitation, and that land use change (which often acts to decrease evapotranspiration and to increase runoff) was of second-most importance, as also supported by Sterling *et al.*, (2012) data and model analysis. By contrast, using a shorter time period and a smaller selection of river basins, Alkama *et al.*, 2011(2011) suggested that global effects of land use change on runoff have been negligible. Oliveira *et al.*, 2011(2011) furthermore point to the importance of changes in incident solar radiation and the mediating role of vegetation; their global simulations demonstrate, for example, that a higher diffuse radiation fraction during 1960–1990 increased evapotranspiration in the tropics by 3% due to increased photosynthesis from shaded leaves. Since the anthropogenic component of the precipitation and temperature contributions(i.e. of the radiative CO_2 effect) to runoff trends is not yet established, a full attribution of anthropogenic emissions of CO_2 (and other greenhouse gases)is still missing.

Analogously, there is uncertainty about how vegetation responses to future increases in CO_2 will modulate effects of climate change on the terrestrial water balance.21st-century continental- and basin-scale runoff is projected by some models to either increase more or decrease less when CO_2-induced increases in iWUE are included in addition to climate change (Betts *et al.*, 2007; Murray *et al.*, 2012), potentially reducing an increase in water stress due to rising population or climate change (Wiltshire *et al.*, submitted) – although other models project a smaller response (Cao *et al.*, 2009). Direct effects of CO_2 on plants have been modelled to increase future global runoff by 4–5% (Gerten *et al.*, 2008) up to 13% (Nugent and Matthews, 2012), depending on the assumed CO_2 trajectory and whether feedbacks of changes in vegetation structure and distribution to the climate are accounted for. The model analysis by

Alkama *et al.*, (2010) suggests that although the physiological CO_2 effect will be the second-most important factor for 21[st]-centuryglobal runoff and although both physiological and structural effects will amplify compared to historic conditions, runoff changes will still primarily follow the projected climatic changes. Using a large ensemble of climate change projections, Konzmann *et al.*, (2013) put hydrological changes into an agricultural perspective and suggest that direct CO_2 effects on crops reduce their irrigation requirements (Fig. CC-VW-1). Thus, adverse climate change impacts on crop yields might be partly buffered as iWUE improves (Fader *et al.*, 2010), but only if proper management abates limitation of plant growth by nutrient availability or other factors. Lower transpiration under rising CO_2 may also affect future regional climate change itself (Boucher *et al.*, 2009) and may enhance the contrast between land and ocean surface warming (Joshi *et al.*, 2008).

Application of a soil-vegetation-atmosphere-transfer model indicates complex responses of groundwater recharge to changes in different climatic variables mediated by vegetation,with computed groundwater recharge being always larger than would be expected from just accounting for changes in rainfall (McCallum *et al.*, 2010). In a warmer climate with increased atmospheric CO_2 concentration, iWUE of plants increases and leaf area may either increase or decrease, and even though precipitation may slightly decrease, groundwater recharge may increase as a net effect of these interactions (Crosbie *et al.*, 2010). Depending on the type of grass in Australia, the same change in climate is suggested to lead to either increasing or decreasing groundwater recharge in this location (Green *et al.*, 2007). For a location in the Netherlands, a biomass decrease was computed for each of eight climate scenarios indicating drier summers and wetter winters (A2 emissions scenario), using a fully coupled vegetation and variably saturated hydrological model. The resulting increase in groundwater recharge up-slope was simulated to lead to higher water tables and an extended habitat for down-slope moisture-adapted vegetation (Brolsma *et al.*, 2010).

Future anthropogenic and climate-driven land cover and land use changes will also affect regional evapotranspiration, surface and subsurface water flows, with the direction and magnitude of these changes depending on the direction and intensity of the changes in vegetation coverage,as shown e.g. for a river basin in Iowa (Schilling *et al.*, 2008) or for the Elbe river basin (Conradt *et al.*, 2012).Removal of vegetation acting as source of atmospheric moisture can change regional water cycling and decrease potential crop yields by up to 17%in regions otherwise receiving this moisture in the form of precipitation (Bagley *et al.*, 2012).Changes in vegetation coverage and structure due to long-term climate change or shorter-term extreme events such as droughts (Anderegg *et al.*, 2013) also affect the partitioning of precipitation into evapotranspiration and runoff, sometimes involving complex feedbacks with the climate system such as in the Amazon region (Port *et al.*, 2012; Saatchi *et al.*, 2013). As water, carbon and vegetation dynamics evolve synchronously and interactively under climate change (Heyder *et al.*, 2011) in that e.g. vegetation structure and composition can dynamically adapt to changing climatic and hydrologic conditions (Gerten *et al.*, 2007), it remains a challenge to disentangle the effects of future land cover changes on the water cycle.

[INSERT FIGURE VW-1 HERE
Figure VW-1: Percentage change (ensemble median across 19 GCMs used to force a vegetation and hydrology model) in net irrigation requirements of 12 major crops by the 2080s, assuming current extent of irrigation areas and current management practices. Top: impacts of climate change only; bottom: additionally considering physiological and structural crop responses to increased atmospheric CO_2 concentration. Taken from Konzmann *et al.* (2013).]

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Table TS.1: Observed impacts attributed to climate change with *medium* (*) or *high* (**) confidence. Impacts for physical, biological, and human systems are characterized across eight major world regions. For each observed impact, confidence in detection is equal to or greater than confidence in attribution. [Table 18-6, 18-7, 18-8, and 18-9]

REGION	Freshwater Resources & Systems	Terrestrial Ecosystems, Drought, & Wildfire	Coastal & Marine Systems	Human Systems
Africa	Retreat of tropical highland glaciers in East Africa* Lake surface warming & water column stratification increases in the Great Lakes & Lake Kariba** [13.2.1, 22.3.2, 22.5.1]	Tree density decreases in Sahel & semi-arid Morocco* Climate-driven range shifts of several southern plants & animals* Increased drought in the Sahel since 1970, partially wetter conditions since 1990* [22.2.2, 22.3.2]		Decline in fruit-bearing trees in Sahel*
Europe	Retreating glaciers in the Alps** Increase in rock slope failures in Western Alps** [18.3.1]	Earlier greening, earlier leaf emergence, & fruiting in temperate & boreal trees** Increased colonization of alien plant species in Europe* Earlier arrival of migratory birds in Europe since 1970* Increasing burnt forest areas during recent decades** [4.2.4, 4.4.1]	Poleward shifts in the distributions of zooplankton, fishes, seabirds, & benthic invertebrates, & conversion of polar into more temperate & temperate into more subtropical system characteristics in Northeast Atlantic** Phenology changes & retreat of colder water plankton to north in the Northeast Atlantic, with mean poleward movement of plankton reaching up to 200–250 km per decade from 1958–2005* Atlantic cod distribution shift due to warming, interacting with regime shift & regional changes in plankton phenology in North Sea.* Decreasing abundance of eelpout in Wadden Sea** [6.3.2, Table 6-8, Figure 6-16, 18.3.3, 30.5.1]	Stagnation of wheat yields in some countries in recent decades, due to warming and/or drought*
Asia	Permafrost degradation in Siberia, Central Asia, & Tibetan Plateau** Shrinking mountain glaciers across Asia.* Increased runoff in many rivers due to shrinking glaciers in the Himalayas & Central Asia** Surface water degradation in parts of Asia partially related to climate change* Earlier timing of maximum spring flood in Russian rivers** [Box 3-1, Box 3-2, 24.4.1, 28.2.1, WGI AR5 Chapter 4.3.2-4.3.3, 10.5.3]	Changes in plant phenology & growth in many parts of Asia, particularly in the north & east* Distribution shifts of many plant & animal species, particularly in the north of Asia, generally upwards in elevation or polewards* Advance of shrubs into the Siberian tundra* [4.2.1, Box 4-1, 24.4.2, 28.2.3]	Decline in coral reefs & large seaweeds in tropical Asian & Japanese waters** Shift from sardines to anchovies in Japanese Sea* [6.3.2, Figure 16-6, 24.4.3]	
Australasia	Significant decline in late-season snow depth at four alpine sites in Australia (1957-2002)*	Climate-related changes in genetics, growth distribution, & phenology of many species (e.g., earlier emergence of butterflies, change in plant flowering dates & bird breeding times, decline in body size of passerine birds)* [Table 25-3]	Mass bleaching of corals in the Great Barrier Reef, changes in coral calcification rates, & changes in coral disease dynamics** Multiple impacts of climate change on marine ecosystems from warming oceans, although other environmental changes may play a role. Examples are growth rate increases in fishes, intertidal-invertebrate range shifts, range shifts in near-shore fishes related to kelp decline, increasing abundance of northern marine species in Tasmania, recruitment declines of rock lobster & abalone, declines in growth rate & biomass of phytoplankton, southward expansion of some tropical seabirds in Australia** [6.3.2, Box 18-3, 25.6.2, Table 25-3]	Wine-grape maturation has advanced in recent decades, partly due to warming*

REGION	Freshwater Resources & Systems	Terrestrial Ecosystems, Drought, & Wildfire	Coastal & Marine Systems	Human Systems
North America	Primarily decreasing trends in amount of water stored in spring snowpack from 1960-2002** Observed shift to earlier peak flow in snow dominated rivers in Western North America** Runoff increases in the Midwestern & Northwestern US, decreases in Southern states* [26.2.2, WGI AR5 Chapter 2.6.2]	Species distribution shifts upward in elevation & northward in latitude across multiple taxa* Phenology changes* Increases in wildfire activity, including fire frequency & duration, length of fire season, & area burned* [26.4.1, 26.4.2, Box 26-2]	Northward range shifts of Northwest Atlantic fishes in response to warming since the 1960s, with some of the shifts being correlated with the Atlantic Multidecadal Oscillation* Earlier onset of Pink Salmon migration (Alaska), collapse of Sockeye Salmon spawning migration (Fraser River, BC), due to warming** Loss of biomass of midwater fishes off California Coast** [6.3.3, 6.6.3, Table 6-8, Figure 6-16]	Direct & indirect economic impacts of climate extremes on industry through reduced supply of raw material, the production process, the transportation of goods, & the demand for certain products* [26.8]
Central & South America	Retreat of tropical Andean glaciers in Venezuela, Colombia, Ecuador, Peru, & Bolivia (1950-2000) & glaciers & ice-fields in the extra tropical Andes** Changes in extreme flows in Amazon River* Changed discharge patterns in rivers in the Western Andes due to retreating glaciers & reduced snowpack; for major river basins in Colombia, decreased discharge during the last 30-40 years** Increased stream flow in sub-basins of the La Plata River, attributed to increasing precipitation, but also to trends in land-use changes that have reduced evapotranspiration** [27.2.1, 27.3.1]		Bleaching of coral reefs in the western Caribbean near the coast of Central America** [27.3.3]	Increase in frequency & extension of malaria* Increase in agricultural yields in Southeastern South America* [27.3.4, 27.3.7]
Polar Regions	Decreasing Arctic sea ice cover in summer & reduction in glacier ice volume, due to warming* Decreasing snow cover duration across the entire Arctic* Widespread permafrost degradation, especially in the southern Arctic** Rising winter minimum flows in most sectors of the Arctic due to enhanced groundwater input due to permafrost thawing* Disappearance of thermokarst lakes due to permafrost degradation in the low Arctic. New lakes being created in areas of formerly frozen peat** [28.2.1, 28.2.3, WGI AR5 Chapter 10.5.1]	Increase in shrub cover in tundra in North America & Eurasia.** Significant advance of Arctic tree-line in latitude & altitude, due to warming, although lower pace than expected due to insect outbreaks & land-use history. Changes in breeding area & population size of subarctic birds, due to warming & shrub encroachment in the tundra* Retreating snow-bed ecosystems & tussock tundra, due to prolonged thawing season & less precipitation in the form of snow.** Increasing occurrence of ice layers in the annual snow pack due to rain-on-snow events, affecting animal populations in the tundra* Increasing plant species in the West Antarctic Peninsula & nearby islands over the past 50 years** Increasing drought in high Arctic polar deserts** Increased frequency of wildfires in conifer forest at Arctic southern fringe, due to increasing summer temperature. Tundra wildfires are increasing in frequency in the Low Arctic, due to increasing summer air temperature & subsequent surface drought* [28.2.1, 28.2.3]	Sea ice loss negatively affecting many arctic & subarctic marine non-migratory mammals (walrus, seals, whales)** Reduced growth rate & body mass, lower survival & reproductive capacity of polar bears, linked to reduced off-shore range & sea-ice loss due to warming** Reduced reproductive success of Arctic seabirds, due to earlier sea-ice break-up* Reduced thickness of foraminifera shells due to acidification of Southern Ocean waters * Declines in Antarctic krill density in the Scotia Sea by ~30% since the 1980s, due to reduced winter sea ice extent & duration* Many Southern Ocean species of seals & seabirds, e.g., penguins & albatross, negatively responding to warmer conditions* Increased coastal erosion in Arctic, due to prolonged ice-free season at shore, increased exposure to wave activity, & degrading permafrost** [6.3.4, 28.2.2, 28.2.4, 28.2.5, 28.3.4]	Impact on livelihoods of Arctic indigenous peoples* [18.4.5, Box 18-5]
Small Islands		Tropical-bird population changes in Mauritius, due to changes in rainfall* [29.3.2]	Coral bleaching near many tropical small islands** [29.3.1]	

Table TS.2: Illustrative selection of some recent extreme impact events for which the role of climate has been assessed in the literature. The table shows confidence assessments as to whether the associated meteorological events made a substantial contribution to the impact event, as well as confidence assessments of a contribution of anthropogenic emissions to the meteorological event. The assessment of confidence in the findings is not necessarily a conclusion of the listed literature but rather results from assessment of the literature. Assessment of the role of anthropogenic emissions in the impact event requires a multi-step evaluation. [Table 18-4]

YEAR	REGION	EXTREME IMPACT EVENT		METEOROLOGICAL EVENT	
		Impact / damage	Confidence in contribution of extreme weather event to observed damage	Meteorological event	Confidence in contribution of anthropogenic emissions to extreme weather event
2003	Europe	excess death toll exceeding 70,000	*very high*	hottest summer in at least 500 years	*high*
2005	North Atlantic / USA	1,700 deaths and over 100 US$ Bn in damage	*very high*	record number of tropical storms, hurricanes, and category 5 hurricanes since 1970	*very low*
2006-2007	Europe	partial second flowering or extended flowering in 2006, early flowering in 2007	*high*	hottest record fall and winter in at least 500 years	*medium*
2010	Western Russia	burned area > 12,500km	*low*	hottest summer since 1500	*medium*
2011	Thailand	prolonged (up to 2 month) inundation of urban and industrialized areas, insured loss 8-11 US$ Bn, total loss ca. 45 US$ Bn	*very high*	wettest monsoon on record in middle and upper Chao Phraya Basin	*very low*
2010	Colombia	exceptionally heavy rainfall and floods, 4 M people affected, 7.8 US$ Bn total damage	*very high*	ENSO-related second and third highest SST in Caribbean on record in late 2010; second most active storm and hurricane season	*low*
2010	Pakistan	worst ever known floods in the region, 2000 people killed, 20 M affected, total loss 40 US$ Bn	*very high*	exceptionally high rainfall amounts over northern Pakistan with unusual atmospheric circulation patterns	*very low*
2011	Queensland, Australia	>200,000 people affected, >30,000 homes flooded, damages and cost to economy 2.5 – 10 US$ Bn	*very high*	2010 wettest year on record for Queensland, with extreme precipitation in January 2011 on saturated ground; record high Southern Oscillation Index in 2010	*low*

Table TS.3: Illustrative examples of adaptation experience, as well as approaches to reduce vulnerability and enhance resilience. Adaptation actions can be influenced by climate variability, extremes, and change, and by exposure and vulnerability at the scale of risk management. Many examples and case studies demonstrate complexity at the level of communities or specific regions within a country. It is at this spatial scale that complex interactions between vulnerabilities, inequalities, and climate change come to the fore. At the same time, place-based examples illustrate how larger-level drivers and stressors shape differential risks and livelihood trajectories, often mediated by institutions.

Early warning systems for heat
EXPOSURE AND VULNERABILITY : Factors affecting exposure and vulnerability include age, pre-existing health status, level of outdoor activity, socio-economic factors including poverty and social isolation, access to and use of cooling, physiological and behavioral adaptation of the population, urban heat island effects, and urban infrastructure. [11.7,SREX Table SPM.1]
CLIMATE INFORMATION AT THE GLOBAL SCALE: Observed: *Very likely* decrease in the overall number of cold days and nights and increase in the overall number of warm days and nights, on the global scale between 1951 and 2010. *Medium confidence* that the length of warm spells, including heat waves, has increased globally since 1950. Projected: *Virtually certain* that, in most places, there will be more hot and fewer cold temperature extremes as global temperature increases, for events defined as extremes on both daily and seasonal timescales. [WGI AR5 2.6.1, 12.4.3]
CLIMATE INFORMATION AT THE REGIONAL SCALE: Observed: *Medium confidence* in an increase in heat waves or warm spells over North America and Central America, Europe and the Mediterranean region, parts of Asia and Australia/New Zealand, and Southern Africa. Insufficient evidence for assessment or spatially varying trends in heat waves or warm spells for South America and most of Africa. Warming since 1901 generally greater in mid-to-high latitude regions. Projected: *Likely* that, under RCP8.5 in most regions, a 20-year maximum temperature event will at least double its frequency and in many regions occur every two years or annually, while 20-year minimum temperature events will become exceedingly rare by the end of the 21st century. *Likely* more frequent, longer, and/or more intense heat waves or warm spells in most regions of the world. [WGI AR5 2.4.3, 12.4.3; SREX Tables 3-2, 3-3]
DESCRIPTION: Heat-health early warning systems are instruments to prevent negative health impacts during heat waves. Weather forecasts are used to predict situations associated with increased mortality or morbidity. Essential and common components include identifying weather situations that adversely affect human health, monitoring weather forecasts, activating mechanisms for issuing warnings, targeting notifications of adaptation actions to the most vulnerable populations, and providing heat avoidance advice to the general population. Warning systems for heat waves have been used in Europe, the United States, Canada, and Australia. [11.7.3, 25.8.1, 26.9.1]
BROADER CONTEXT: •Heat warning systems appear effective in raising awareness of the risks associated with heat waves, although it is less certain whether this extends to behavioral changes. •Heat health warning systems can be combined with other elements of a health protection plan as has been done in France and Victoria, Australia, for example building capacity to support communities most at risk, supporting and funding health services, and distributing public health information. •In Africa, Asia, and elsewhere, early warning systems have been used to provide warning of and reduce a variety of risks, related to famine and food insecurity; cyclones, flooding, and other weather-related hazards; exposure to air pollution from fire; and vector-borne and food-borne disease outbreaks. [11.7.3, 25.8.1, 22.4.5, 11.7, , 15.3.2, box 21-3, 24.4.1, 24.4.6, Box 25-6]

Mangrove restoration to reduce flood risks and protect shorelines from storm surge
EXPOSURE AND VULNERABILITY : Loss of mangroves increases exposure of coastlines to storm surge, wave erosion, and tropical cyclones. Exposed infrastructure, livelihoods, and people are vulnerable to associated damage. Areas with development in the coastal zone, such as on small islands, are particularly vulnerable. [15.3.4, 29.7.2]
CLIMATE INFORMATION AT THE GLOBAL SCALE: Observed: *Likely* increase in extreme sea levels since 1970, mainly caused by rising mean sea level. *Low confidence* that any reported long-term changes in tropical cyclones are robust. Projected: By the end of the 21st century, *likely* that the global frequency of tropical cyclones will either decrease or remain essentially unchanged. *Likely* increase in both global mean tropical cyclone maximum wind speed and rainfall rates. *More likely than not* substantial increase in the frequency of the most intense tropical cyclones in some basins. [WGI AR5 2.6.3, 3.7.5, 11.3.2, Box 14.2]
CLIMATE INFORMATION AT THE REGIONAL SCALE: Observed: Regional rates of sea level change can vary significantly from the global mean. Mean significant wave height *likely* increased since the mid-1980s over much of the mid-latitude North Atlantic, the North Pacific, and the Southern Ocean. For tropical cyclones observed over the satellite era, increases in the intensity of the strongest storms in the Atlantic appear robust. Projected: For all ocean basins, tropical cyclone frequency is projected to decline or remain the same, the mean lifetime maximum intensity of tropical cyclones is

projected to increase or remain the same, and cyclone-associated rainfall rates are projected to increase. In the North Atlantic and the eastern part of the North Pacific, the frequency of category 4/5 tropical cyclones is projected to increase.
Very likely increase in the occurrence of future extreme sea level and related coastal flooding events with increasing global mean sea level, but *low confidence* in region-specific projections in storminess and storm surges.
[WGI AR5 2.6.3, 3.4, 3.7, 13.7.2; Figures 3.6-3.8, 13.19; Box 14.2]

DESCRIPTION:
Mangrove restoration and rehabilitation has occurred in a number of locations (Vietnam, Myanmar, Samoa, and Brazil, for example) to reduce coastal flooding risks and protect shorelines from storm surge. In Vietnam, restored mangroves have been shown to attenuate wave height and thus reduce wave damage and erosion. They protect aquaculture industry from storm damage and reduce saltwater intrusion.
[8.3.3.7, 2.3.4, 15.3.4, 27.3.3, 22.4.5]

BROADER CONTEXT:
•Considered a low-regrets option benefiting sustainable development, livelihood improvement, and human well-being through improvements for food security and reduced risks from flooding, wave damage, and erosion.
•Synergies with mitigation given that mangrove forests are sinks for carbon.
•Restoration and rehabilitation can help build local knowledge, capacity, and strategies to institutionalize climate change adaptation and resilience in local planning and development.
•Mangrove bioshields created from exotic species can detrimentally impact native ecosystems.
[8.4.2.4, Box 5.4, 29.7.2, 15.3.4]

Community-based adaptation and traditional practices in small island contexts

EXPOSURE AND VULNERABILITY:
With small land area, often low elevation coasts, and concentration of human communities and infrastructure in coastal zones with limited resettlement opportunities, small islands are particularly vulnerable to rising sea levels and impacts such as inundation, saltwater intrusion, and shoreline change. Island vulnerability to climate change may be related to the experience and perceptions of islanders to both climate and non-climate stressors.
[29.3.3, 29.6.1, 29.6.2]

CLIMATE INFORMATION AT THE GLOBAL SCALE:
Observed: *Likely* increase in extreme sea levels since 1970, mainly caused by rising mean sea level.
Low confidence that any reported long-term changes in tropical cyclones are robust.
Likely increase in the number of heavy precipitation events in more regions than the number has decreased since 1950.
Projected: *Very likely* that the rate of global mean sea level rise during the 21st century will exceed the rate observed during 1971-2010 for all RCP scenarios.
By the end of the 21st century, *likely* that the global frequency of tropical cyclones will either decrease or remain essentially unchanged.
Likely increase in both global mean tropical cyclone maximum wind speed and rainfall rates.
More likely than not substantial increase in the frequency of the most intense tropical cyclones in some basins.
For short-duration precipitation events, *likely* shift to more intense individual storms and fewer weak storms.
[WGI AR5 2.6.2, 2.6.3, 3.7.5, 11.3.2, Box 14.2, 13.5.1, table 13.5, 12.4.5]

CLIMATE INFORMATION AT THE REGIONAL SCALE:
Observed: Regional rates of sea level change can vary significantly from the global mean.
Mean significant wave height *likely* increased since the mid-1980s over much of the mid-latitude North Atlantic, the North Pacific, and the Southern Ocean.
For tropical cyclones observed over the satellite era, increases in the intensity of the strongest storms in the Atlantic appear robust.
Projected: For all ocean basins, tropical cyclone frequency is projected to decline or remain the same, the mean lifetime maximum intensity of tropical cyclones is projected to increase or remain the same, and cyclone-associated rainfall rates are projected to increase. In the North Atlantic and the eastern part of the North Pacific, the frequency of category 4/5 tropical cyclones is projected to increase.
Very likely increase in the occurrence of future extreme sea level and related coastal flooding events with increasing global mean sea level, but *low confidence* in region-specific projections in storminess and storm surges.
[WGI AR5 2.6.3, 3.4, 3.7, 13.7.2; Figures 3.6-3.8, 13.19; Box 14.2]

DESCRIPTION:
There is growing awareness of the role of traditional technologies and skills in adapting to climate change in small island contexts. In the Solomon Islands, relevant traditional practices include elevating concrete floors to keep them dry during heavy precipitation events and building low aerodynamic houses with palm leaves as roofing to avoid hazards from flying debris during cyclones, supported by perceptions that traditional construction methods are more resilient to extreme weather. In Fiji after cyclone Ami, mutual support and risk sharing formed a central pillar for community-based adaptation, with unaffected households fishing to support those with damaged homes. Intensive participatory consultations across stakeholders and sectors within communities and capacity building taking into account traditional practices have been shown to be vital to the success of adaptation initiatives in island communities, such as in Fiji or Samoa.
[29.6.2]

BROADER CONTEXT:
• Perceptions of self-efficacy in addressing climate stress can be an important pre-condition for anticipatory adaptation in islands. For example, individuals' belief in their own ability to cope with water scarcity based on past experience is a key driver of attitudes to and choice of adaptation strategy in Kiribati.
•The relevance of community-based adaptation principles to island communities, as a facilitating factor in adaptation planning and implementation, has been highlighted, for example with empowerment that helps people help themselves while addressing local priorities and building on local knowledge and capacity.
[29.6.2]

Farming practices in Africa, such as zai and integration of trees into annual cropping systems
EXPOSURE AND VULNERABILITY: Land degradation and soil infertility have negatively impacted yields in parts of Africa, such as in Zambia, Malawi, the highlands of Ethiopia, Burkina Faso, and the drylands of the Sahel. Soil erosion, soil compaction due to livestock trampling, and low soil water holding capacity reduce plant growth. [7.5.2, Table 9-6, Box 22-4]
CLIMATE INFORMATION AT THE GLOBAL SCALE: Observed: Increase in globally averaged near surface temperatures since 1900, with warming particularly marked since the 1970s. *Very likely* decrease in the overall number of cold days and nights and increase in the overall number of warm days and nights, on the global scale between 1951 and 2010. *Medium confidence* that the length of warm spells, including heat waves, has increased globally since 1950. *Medium confidence* in global precipitation change over land since 1950. *Likely* increase in the number of heavy precipitation events in more regions than the number has decreased since 1950. *Low confidence* in any observed large-scale trends in drought. Projected: For RCP 4.5, 6.0, and 8.5, global mean surface air temperatures are projected to at least *likely* exceed 2° C with respect to preindustrial by 2100. *Virtually certain* that, in most places, there will be more hot and fewer cold temperature extremes as global temperature increases, for events defined as extremes on both daily and seasonal timescales. *Virtually certain* increase in global precipitation as global mean surface temperature increases. Regional to global-scale projections of soil moisture and drought remain relatively uncertain. For short-duration precipitation events, *likely* shift to more intense individual storms and fewer weak storms. [WGI AR5 2.4, 2.5.1, 2.6.1, 2.6.2, 12.3.1, 12.4.1, 12.4.3, 12.4.5; Figures 2.28, 12.2, 12.5]
CLIMATE INFORMATION AT THE REGIONAL SCALE: Observed: Increase in frequency of warm days and nights in northern and southern part of continent and decrease in frequency of cold days and nights in southern part of continent. Overall increase in dryness and modest increases in rainfall over most of equatorial Africa and the Red Sea coast (*medium confidence*). Projected: *Likely* increase in warm days and decrease in cold days in all regions of Africa (*high confidence*). Increase in warm days largest in summer and fall (*medium confidence*). *Likely* more frequent and/or longer heat waves and warm spells in Africa (*high confidence*). [22.2.2; SREX Tables 3-2, 3-3]
DESCRIPTION: Zai uses small pits dug manually during the dry season, combined with contour stone bunds to slow runoff. Animal manure or compost is placed in each pit. The pits facilitate water infiltration and concentrate runoff water, and the applied organic matter improves soil nutrient status and attracts termites, which positively affect soil structure. The practice can also improve tree growth amid crop rows, and trees, especially nitrogen-fixing varieties, can be integrated as an independent strategy. Trees reduce crop exposure to wind and heavy rainfall and improve moisture retention and rainwater capture. Factors that have enabled farmer-managed natural regeneration include in southern Niger devolving tree ownership from the state to the farmer, as well as community-based efforts involving partnerships of farmers and NGOs. [7.5.2, Table 9-6, Box 22-4, 15.3.4]
BROADER CONTEXT: •Both techniques can improve yields, water retention, food security, and income generation, also reversing land degradation. •Tree growth, through production of fruit, animal fodder, or fuelwood, can expand livelihood options and allow diversification, thereby enhancing resilience. •Zai is a very labor-intensive technique, which can be expedited through use of animal-drawn implements. • Farmer-managed natural regeneration has been paired with other low-cost behavioral actions, for example in Ethiopia, aiming to reverse ecosystem degradation and promote reforestation with benefits for carbon sequestration. [7.5.2, Table 9-6, Box 22-4, 15.3.4, 17.4.1]

Adaptive approaches to flood defense in Europe
EXPOSURE AND VULNERABILITY : In some countries, a high percentage of the population is exposed to flooding. Exposed assets and infrastructure represent a substantial fraction of national GDPs. [Box 5-3]
CLIMATE INFORMATION AT THE GLOBAL SCALE: Observed: *Likely* increase in extreme sea levels since 1970, mainly caused by rising mean sea level. *Likely* increase in the number of heavy precipitation events in more regions than the number has decreased since 1950. Projected: *Very likely* that the rate of global mean sea level rise during the 21st century will exceed the rate observed during 1971-2010 for all RCP scenarios. For short-duration precipitation events, *likely* shift to more intense individual storms and fewer weak storms. [WGI AR5 2.6.2, 3.7.5, 12.4.5, 13.5.1, Table 13.5]
CLIMATE INFORMATION AT THE REGIONAL SCALE: Observed: Increased heavy wintertime precipitation since the 1950s in some areas of Northern Europe (*medium confidence*). Increased heavy precipitation since the 1950s in some parts of west-central Europe and European Russia, especially in winter (*medium confidence*). Isostasy and decreasing sea level in Scandinavia. Projected: Overall precipitation increase in Northern Europe and decrease in Southern Europe (*medium confidence*). Increased extreme precipitation in Northern and Atlantic regions of Europe during all seasons, and in Central Europe except in summer (*high confidence*). Annual increases of intense precipitation days over the Mediterranean region. Storm activity over the North Atlantic *likely* to increase and extend farther downstream into Europe, and to decrease on both the north and south flanks, especially

over the Mediterranean (*medium confidence*).

Likely reduction in the occurrence of Northern Hemisphere extratropical storms, although the most intense storms reaching Europe *likely* to increase in strength. An increase in the North Atlantic Oscillation *likely* to increase the number of wintertime storms heading into Northern Europe and the average intensity of precipitation per storm.

[23.2.2; WGI AR5 Box 14.3; SREX Table 3-2]

DESCRIPTION:

Several governments have made ambitious efforts to address flood risk over the coming century. In the Netherlands, government recommendations include "soft" measures preserving land from development to accommodate increased river inundation; raising the level of lakes to ensure continuous freshwater supply; restoring natural estuary and tidal regimes; maintaining flood protection through beach nourishment; and ensuring necessary political-administrative, legal, and financial resources. The plan is estimated to cost €2.5 to 3.1 billion a year through 2050, 0.5% of the current Dutch annual GNP. The British government has also developed extensive adaptation plans to adjust and improve flood defenses for the protection of the Thames estuary and the city of London from future storm surges and river flooding. Pathways for different adaptation options and decisions depending on eventual sea level rise have been analyzed.

[Box 5-3, 23.7.1]

BROADER CONTEXT:

- The Dutch plan is considered a paradigm shift, addressing coastal protection by "working with nature" and providing "room for river." The concept of creating space for water and integrating water management approaches with goals of environmental protection is an essential component of integrated water management.
- The British plan incorporates iterative, adaptive decisions depending on the eventual sea level rise.
- The large infrastructure project of the Thames flood defense barrier involved public-private partnerships.
- In cities in Europe and elsewhere, the importance of having strong political leadership or government champions to drive the initial development of climate adaptation plans has been noted.

[Box 5.3, 23.7.1, 17.5.3, 8.5.3, 23.7.4, 23.7.2]

Index-based insurance for agriculture in Africa

EXPOSURE AND VULNERABILITY:

Susceptibility to food insecurity and depletion of farmers' productive assets following crop failure. Low prevalence of insurance due to absent or poorly developed insurance markets or to amount and timing of premium payments. The most marginalized and resource-poor especially may have limited ability to afford insurance premiums.

[Box 22-3, 13.3.2, 10.7.6]

CLIMATE INFORMATION AT THE GLOBAL SCALE:

Observed: *Very likely* decrease in the overall number of cold days and nights and increase in the overall number of warm days and nights, on the global scale between 1951 and 2010.

Medium confidence that the length of warm spells, including heat waves, has increased globally since 1950.

Likely increase in the number of heavy precipitation events in more regions than the number has decreased since 1950.

Low confidence in any observed large-scale trends in drought.

Projected: *Virtually certain* that, in most places, there will be more hot and fewer cold temperature extremes as global temperature increases, for events defined as extremes on both daily and seasonal timescales.

Regional to global-scale projections of soil moisture and drought remain relatively uncertain.

For short-duration precipitation events, *likely* shift to more intense individual storms and fewer weak storms.

[WGI AR5 2.6.1, 2.6.2, 12.4.3, 12.4.5]

CLIMATE INFORMATION AT THE REGIONAL SCALE:

Observed: Increase in frequency of warm days and nights in northern and southern part of continent and decrease in frequency of cold days and nights in southern part of continent.

Overall increase in dryness and modest increases in rainfall over most of equatorial Africa and the Red Sea coast (*medium confidence*).

Projected: *Likely* increase in warm days and decrease in cold days in all regions of Africa (*high confidence*). Increase in warm days largest in summer and fall (*medium confidence*).

Likely more frequent and/or longer heat waves and warm spells in Africa (*high confidence*).

[22.2.2; SREX Tables 3-2, 3-3]

DESCRIPTION:

A recently introduced mechanism that has been piloted in a number of rural locations, including in Malawi, Ghana, and Ethiopia. When conditions reach a particular predetermined threshold where significant losses are likely to occur--weather conditions such as excessively high or low cumulative rainfall or temperature peaks affecting average crop yields or revenues--the insurance pays out. Where understanding of insurance is low, participation rates can be improved by using simulation games, as piloted in Ethiopia and Malawi, or by more conventional training methods.

[9.4.2, 15.2.4, 13.3.2, Box 22-3]

BROADER CONTEXT:

- Can be considered a low-regrets climate change adaptation option.
- The mechanism allows risk to be shared across communities, with costs spread over time, while overcoming obstacles to traditional agricultural and disaster insurance markets. It can be integrated with other strategies such as micro-finance and social protection programs.
- Risk-based premiums foster risk awareness and risk reduction by providing financial incentives to policyholders to reduce their risk profile.
- Challenges can be associated with limited availability of accurate weather data, difficulties in establishing which weather conditions cause losses, and varying weather conditions between adjacent areas and meteorological stations. Basis risk (i.e., farmers suffer damage but no payout is triggered based on weather data) can promote distrust. There can also be difficulty in scaling up successful pilot schemes.
- Insurance for work programs can enable cash-poor farmers to work for insurance premiums by engaging in community-identified disaster risk reduction projects.

[15.2.4, 13.3.2, Box 22-3, 15.2.2, Box 25-7, 10.7.6, 10.7.5]

Relocation of agricultural industries in Australia

EXPOSURE AND VULNERABILITY :

Crops sensitive to changing patterns of rainfall, water availability, and temperature.
[7.5.2]

CLIMATE INFORMATION AT THE GLOBAL SCALE:

Observed: Increase in globally averaged near surface temperatures since 1900, with warming particularly marked since the 1970s.
Very likely decrease in the overall number of cold days and nights and increase in the overall number of warm days and nights, on the global scale between 1951 and 2010.
Medium confidence that the length of warm spells, including heat waves, has increased globally since 1950.
Medium confidence in global precipitation change over land since 1950.
Likely increase in the number of heavy precipitation events in more regions than the number has decreased since 1950.
Low confidence in any observed large-scale trends in drought.
Projected: For RCP 4.5, 6.0, and 8.5, global mean surface air temperatures are projected to at least *likely* exceed 2° C with respect to preindustrial by 2100.
Virtually certain that, in most places, there will be more hot and fewer cold temperature extremes as global temperature increases, for events defined as extremes on both daily and seasonal timescales.
Virtually certain increase in global precipitation as global mean surface temperature increases.
Regional to global-scale projections of soil moisture and drought remain relatively uncertain.
For short-duration precipitation events, *likely* shift to more intense individual storms and fewer weak storms.
[WGI AR5 2.4, 2.5.1, figure 2.28, 2.6.1, 2.6.2, 12.3.1, 12.4.1, figure 12.2, figure 12.5, 12.4.3, 12.4.5]

CLIMATE INFORMATION AT THE REGIONAL SCALE:

Observed: Mean temperature increase of 0.9°C per decade over Australia since 1911 (*very high confidence*).
Cool extremes rarer and hot extremes more frequent and intense over Australia and New Zealand (*high confidence*).
Late autumn/winter decreases in precipitation in Southwestern Australia since the 1970s and Southeastern Australia since the mid-1990s, and annual increases in precipitation in Northwestern Australia since the 1950s (*very high confidence*).
Significant increases in annual intensity of heavy precipitation in recent decades for sub-daily events in Australia (*high confidence*).
Projected: Further warming of Australasia this century *virtually certain*, greatest over inland areas and least in coastal areas.
Hot days and nights more frequent and cold days and nights less frequent during the 21st century in Australia and New Zealand (*high confidence*).
Annual decline in precipitation over southwestern Australia (*high confidence*) and in southern Australia (*medium confidence*). Reductions strongest in the winter half-year (*high confidence*).
Increase in intensity of rare daily rainfall extremes (*high confidence*) and of annual daily extremes (*medium confidence*) in Australia and New Zealand.
Drought occurrence to increase in Southern Australia (*high confidence*).
Snow depth and snow area to decline in Australia (*very high confidence*).
Freshwater resources projected to decline in the highly populated southeast and the far southwest of Australia.
[25.5.1, Table 25-1]

DESCRIPTION:

Industries and individual farmers are relocating parts of their operations, for example for rice, wine, or peanuts in Australia, or are changing land use in situ in response to recent climate change or perceptions of future change. There have been new investments in grapes in Tasmania and switching from grazing to cropping in South Australia. Adaptive movement of crops has also occurred elsewhere, such as in China.
[7.5.2, Table 9-6, 25.7.2, Box 25-5]

BROADER CONTEXT:

•Considered transformational adaptation in response to impacts of climate change.
•Positive or negative implications for communities in origin and destination regions, with substantial changes required in transport chains, inputs, management, or growing contracts.
•Some decisions run across scales and include many stakeholders, with comprehensive regional assessments across enterprises and economic and resource outcomes needed.
[7.5.2, 25.7.2, Box 25-5]

Table TS.4: Entry points, strategies, measures, and options for managing the risks of climate change. These approaches should be considered overlapping rather than discrete, and they are often pursued simultaneously. Examples given can be relevant to more than one category.

Entry Point	Category			Examples	Chapter Reference(s)
Vulnerability reduction through development and planning	Forms of sectoral integration	Human development	Specific measures	Low regrets options to reduce structural inequalities: improved access to education, nutrition, health facilities, energy, safe settlement structures, social support structures; reduced gender inequality and marginalization in other forms.	13.1.2, 13.3.1, 13.4.1, 13.4.2, 22.3.1
		Poverty alleviation		Insurance schemes, social protection programs, disaster risk reduction. Improved access to and control of local resources, land tenure, and storage facilities. Low regrets options to reduce structural inequalities.	13.1.2, 13.3.1, 13.3.2, 13.4.1
		Livelihood security		Income and asset diversification. Improved infrastructure. Access to technology and decision-making fora, enhanced agency.	13.1.1, 13.3.1, 13.4.1
		Disaster risk reduction and management		Early warning systems.	11.7.3, 22.4.5, 26.9.1
		Ecosystem management		Maintaining wetlands and urban green spaces, coastal afforestation.	8.3.3, Box 8.1, 15.3.1, Box CC-EA
		Spatial or land-use planning		Provisioning of adequate housing, infrastructure, and services. Managing development in flood prone and other high risk areas.	8.1.4, 8.4.3, 8.5.3
Adaptation	Structural/ concrete	Engineered	Specific options	Sea walls, water storage, improved drainage, beach nourishment, flood shelters. Improved infrastructure.	14.3.1, Table 14-2
		Technological		New crop and animal varieties, efficient irrigation and water use, hazard mapping and monitoring, early warning systems, home insulation.	14.3.1, Table 14-2
		Ecosystem-based		Wetland reestablishment, reestablishment of floodplains, bushfire fuel-reduction actions.	14.3.1, Table 14-2
		Services		Social safety nets, food banks, vaccination programs, municipal services.	14.3.1, Table 14-2
	Institutional	Economic	Specific options	Financial incentives, insurance and other risk spreading.	13.3.2, 14.3.2, Table 14-2
		Laws and regulations		Land zoning laws, building standards, easements.	14.3.2, Table 14-2
		Government policies and programs		National and local adaptation plans, urban upgrading programs, municipal water conservation programs, disaster planning and preparedness.	14.3.2, Table 14-2
	Social	Educational	Specific options	Awareness raising, extension services.	14.3.3, Table 14.2
		Informational		Hazard mapping and monitoring, early warning, community support groups.	14.3.3, Table 14-2
		Behavioral		Household preparation, evacuation planning, retreat and migration, water conservation, storm drain clearance.	14.3.3, Table 14-2
Transformation	Spheres of change	Practical	Specific strategies	Social and technical innovations, behavioral shifts, or institutional and managerial changes that produce measurable outcomes.	20.5.2
		Political		Changes in the political, social, cultural and ecological systems or structures that currently contribute to risk and vulnerability or impede practical transformations.	20.5.2
		Personal		Changes in individual and collective assumptions, beliefs, values, and worldviews that influence climate change responses.	20.5.2
Mitigation	See WGIII AR5.				

Table TS.5: Examples of risks that increase with increasing level of climate change. Examples of potential positive impacts are also given. Risks increasing moderately or severely from now until the 2040s, which can be considered an era of climate responsibility, are described, in addition to risks increasing from ~2050 through the end of the 21st century, which can be considered to represent an era of climate options. For risks increasing in both the era of climate responsibility and the era of climate options, the potential for proactive adaptation to reduce the risks is characterized as low or high, with detail provided on adaptation issues and prospects. Risks increasing in the era of climate options can generally be reduced through globally effective mitigation occurring during the era of climate responsibility and the era of climate options. Increasing risks in the era of climate responsibility are generally difficult to reduce substantially through mitigation, even with globally effective mitigation. They can be managed through vulnerability reduction, adaptation, and transformations that promote climate-resilient development pathways.

---------------- LEGEND ----------------

ERA & ADAPTATION POTENTIAL	Risk for current (C) and hypothetical fully adapted (A) state. Color scheme depicts the additional risk due to climate change. White to red indicates lower and higher levels of risk, respectively. The vertical axis of each bar represents the level of climate change (T). The horizontal blue line indicates the level of climate change at the end of the era of climate responsibility.		
T C A	A risk increasing moderately as early as the era of climate responsibility (now through the 2040s), which can be reduced substantially with proactive adaptation.	T C A	A risk increasing moderately as early as the era of climate responsibility (now through the 2040s), which will be difficult to reduce substantially even with proactive adaptation.
T C A	A risk increasing moderately or severely during the era of climate options (~2050 through the end of the 21st century), which can be reduced substantially with proactive adaptation. The risk can generally be reduced through globally effective mitigation occurring during the era of climate responsibility and the era of climate options.	T C A	A risk increasing moderately or severely during the era of climate options (~2050 through the end of the 21st century), which will be difficult to reduce substantially even with proactive adaptation. The risk can generally be reduced through globally effective mitigation occurring during the era of climate responsibility and the era of climate options.
T C	A risk increasing moderately as early as the era of climate responsibility (now through the 2040s), for which potential for risk reduction via proactive adaptation was not assessed.	T C	A risk increasing moderately or severely during the era of climate options (~2050 through the end of the 21st century), for which potential for risk reduction via proactive adaptation was not assessed.

CLIMATE DRIVERS	Where particular climate driver(s) are especially relevant for an assessed risk, they are indicated via the symbols below.						
	Average temperature		Extreme temperature		Precipitation		Extreme precipitation
CO_2	CO_2 concentration & ocean acidification		Damaging cyclone		Snow cover		Sea level

REGION	CROSS-SECTORAL RISKS Risk	Era & Adaptation Potential	Adaptation Issues/Prospects	Chap. Ref.
Global	Stringent mitigation scenarios can potentially avoid one half of the aggregate economic impacts that would otherwise accrue by 2100, and between 20-60% of the physical impacts, depending on sector and region.	C		19.7.1, 19.7.2
	Key risks associated with global temperature rise in excess of 4°C relative to preindustrial levels include exceedance of human physiological limits in some locations and nonlinear earth system responses (*high confidence*).	C A		19.5.1, 19.6.3, Box TS.6
	Warming of up to 2°C above 1990-2000 levels would result in significant impacts on many unique and vulnerable systems, and would likely increase the endangered status of many threatened species (*high confidence*), with increasing adverse impacts and increasing risk of extinctions (and increasing confidence in this conclusion) at higher temperatures.	C A C A	Unique human and natural systems tend to have very limited adaptive capacity. Climate change impacts would outpace adaptation for many species and systems if a global temperature rise of 2°C over preindustrial levels were exceeded (*high confidence*).	19.6.3

	Since AR4, the assessment of overall risk from extreme events due to climate change has not changed significantly, but there is higher confidence in the attribution of some types of extreme events to human activity and in the assessment of the risk from extreme events in the coming decades.			There is a new appreciation for the importance of exposure and vulnerability, in both developed and developing countries, in assessing risk associated with extreme events.	19.6.1, 19.6.3
REGION	**FRESHWATER RESOURCES AND SYSTEMS**				
	Risk	**Climate Driver(s)**	**Era & Adaptation Potential**	**Adaptation Issues/Prospects**	**Chap. Ref.**
Global	Hydrological impacts of climate change increase with increasing greenhouse-gas emissions (*high agreement, robust evidence*).			A low-emissions pathway reduces damage costs and costs of adaptation.	Table 3-2, 3.4, 3.5, 3.6.5
	Glaciers will continue to lose mass, with meltwater yields from stored glacier ice eventually diminishing as the glaciers shrink (*high agreement, robust evidence*).				3.4.4
Europe	Climate change is *likely* to further increase coastal and river flood risk and, if unabated, will substantially increase flood damages (monetary losses and people affected).			Adaptation can prevent most of the projected damages (*high confidence*).	23.3.1, 23.5.1, 23.7.1, 23.8.3
Asia	Shrinking of glaciers in Central Asia and the Himalayas is projected to affect water resources in downstream river catchments. Population growth and increasing demand arising from higher standards of living could worsen water security in many parts of Asia and affect many people in the future.			Water saving technologies and changing to drought tolerant crops have been found to be successful adaptation options in the region.	24.4.1, 24.9.3
Australasia	Systematic constraints on water resource use in southern Australia, driven by rising temperatures and reduced cool-season rainfall (*high confidence*).			Integrated responses encompassing management of supply, recycling, water conservation, and increased efficiency across all sectors are available but face implementation constraints.	25.2, 25.5.1, Box 25-2
	Increased frequency and intensity of flood damage to settlements and infrastructure in Australia and New Zealand, driven by increasing extreme rainfall although the amount of change remains uncertain (*high confidence*).			In many locations, continued reliance on increased protection alone would become progressively less feasible.	Table 25-1, 25.4.2, 25.10.3, Box 25-8
North America	Throughout North America, it is *very likely* that the 21[st] century will witness decreases in water quality, and increases in flooding and droughts under climate change, with these impacts exacerbated by other anthropogenic drivers. It will also witness decreases in water supplies for urban areas and irrigation in some areas of North America, with confounding effects of development.				26.3, 26.8
Central and South America	For regions already vulnerable in terms of water supply, such as the semi-arid zones in Chile-Argentina, North Eastern Brazil, and Central America and the tropical Andes, glacier retreat and a reduction in water availability due to expected precipitation reduction and increased evapotranspiration demands are expected, affecting water supply for large cities, small communities, hydropower generation, and the agriculture sector.			Current practices to reduce the mismatch between water supply and demand could be used to reduce future vulnerability.	27.3.1, 27.6.1
REGION	**TERRESTRIAL ECOSYSTEMS, DROUGHT, & WILDFIRE**				
	Risk	**Climate Driver(s)**	**Era & Adaptation Potential**	**Adaptation Issues/Prospects**	**Chap. Ref.**
Global	Drying of soils is projected in most dry regions (*medium confidence*).				3.4.9, 3.5, WGI AR5 12.4.5
	For freshwater ecosystems (*high confidence*) and terrestrial ecosystems (*medium confidence*), direct human impacts such as land-use change, pollution, and water resource development will continue to dominate threats to ecosystems, with climate change becoming an increasing additional stress through the century, especially for high-warming scenarios such as RCP 6.0 and 8.5.			Management actions can reduce, but not eliminate, exposure to climate-driven ecosystem impacts, and can increase ecosystem adaptability (*high confidence*).	Box CC-RF, 4.3.3, 4.4.1, 4.4.3

	For high altitude and latitude freshwater and terrestrial ecosystems, climate changes exceeding those projected under RCP 2.6 will lead to major changes in species distributions and ecosystem function.				4.3.2, 4.3.3, 4.4.1
	Even for mid-range rates of climate change (i.e., RCP 4.5 and 6.0), many species will be unable to move fast enough to track suitable climates (*medium confidence*). Era of relevance depends on species and habitat type.			Low migration capacity and large flat areas pose the most serious problems for tracking climate. Capacity for natural adaptation is substantial but, for many ecosystems and species, insufficient to cope with the rate and magnitude of climate change projected under RCP 6.0 or 8.5.	4.3.2, 4.3.3, 4.4.1, 4.4.3
	Large magnitudes of climate change will negatively impact species with populations primarily restricted to protected areas, mountaintops, or mountain streams, even those that potentially migrate fast enough to track suitable climates (*high confidence*).			Capacity for ecosystems to adapt to climate change can be increased by, for example, assisted translocation.	4.3.2, 4.3.4, 4.4.1, 4.4.3
	Increased extinction risk for a substantial fraction of species during and beyond the 21st century, especially as climate change interacts with other pressures, such as habitat modification, over-exploitation, and invasive species (*very high confidence*).			Capacity for ecosystems to adapt to climate change can be increased by reducing other stresses; reducing habitat fragmentation and increasing connectivity; maintaining a large pool of genetic diversity and functional evolutionary processes; and manipulation of disturbance regimes.	4.3.2, 4.4.1, 4.4.3
Africa	Many fragile terrestrial and aquatic ecosystems are implicitly or explicitly water dependent. Impacts of climate change will be superimposed onto already water-stressed catchments with complex land uses, engineered water systems, and a strong historical socio-political and economic footprint (*high confidence*).				22.3.2, 22.3.3
Europe	Changes in habitats and species will result in local extinction (*high confidence*) and continental scale shifts (*low/medium confidence*). Increasing local loss of native species and extinction of species across most sub-regions of Europe by 2050 (medium emissions) with economic development and land-use change. Introduction and expansion of invasive species, especially those with high migration rates, from outside Europe will increase with climate change (*medium confidence*).				23.4.4, 23.6.4, 23.6.5, 23.10, Table 23.2
	Climate change will increase damage to forests from pests and diseases in all sub-regions (*high confidence*), from wildfires in Southern Europe (*high confidence*), and from storms (*low confidence*).				23.4.4
Asia	Terrestrial systems are under increasing pressure from both climatic and non-climatic drivers. The projected changes in climate will impact vegetation and increase permafrost degradation during the 21st century (*high confidence*). The largest changes are expected in cold northern and high-altitude areas, where boreal and subalpine trees will *likely* invade treeless arctic and alpine vegetation, and evergreen conifers will *likely* invade deciduous larch forest.				24.2.2, 24.4.2, 24.4.3, 24.9.3
Australasia	Loss of montane ecosystems and some endemic species in Australia, driven by rising temperatures, increased fire risk and drying trends (*high confidence*).			Fragmentation of landscapes, limited dispersal and evolutionary capacity limit adaptation options.	25.6.1
	Projected changes in climate and increasing atmospheric CO_2 have the potential to benefit forest growth in cooler regions except where soil nutrients or rainfall are limiting (*high confidence*).	CO_2			25.7.1, 25.7.2
	Increased damages to ecosystems and settlements, economic losses, and risks to human life from wildfires in most of southern Australia and many parts of New Zealand, driven by drying trends and rising temperatures (*high confidence*).			Building codes, design standards, local planning mechanisms, and public education can assist with adaptation and are being implemented in regions that have experienced major events.	25.2, Table 25-1, 25.6.1, 25.7.1, Box 25-6
North America	A global increase of 2°C would have widespread adverse impacts on many ecosystems, *likely* reducing biodiversity and ecosystem services (*high confidence*).				26.4

Central and South America	Continued climate change together with land use change and fire activity could cause much of the Amazon forest to transform abruptly to more open, dry-adapted ecosystems, and in doing so, put a large stock of biodiversity at elevated risk and create a large new net greenhouse gas source to the atmosphere (*low confidence*). The combination of climate change and land-use change in the Amazon will cause accelerated drying and drought frequency in the region (*medium confidence*), and there is *low confidence* that these Amazon changes will affect rainfall in agricultural regions elsewhere on the planet.			Rigorously applied adaptation measures could lower the risk of abrupt change in the Amazon, as well as the impacts of that change (*medium confidence*).	4.2.2, 4.2.4, 4.3.3, Box 4-3, Box 4-4, Figure 4-10
Polar Regions	Continued climate change could push the boreal-arctic system across a tipping point in this century and cause an abrupt transformation of the ecology and albedo of this region, as well as the release of greenhouse gases from thawing permafrost and burning forests (*low confidence*).			Adaption measures will be unable to prevent substantial change in the boreal-arctic system (*high confidence*).	4.2.2, 4.2.4, 4.3.3, Box 4-3, Box 4-4, Figure 4-10

COASTAL & MARINE SYSTEMS

REGION	Risk	Climate Driver(s)	Era & Adaptation Potential	Adaptation Issues/Prospects	Chap. Ref.
Global	Under medium socio-economic development assumptions, the expected direct global annual cost of coastal flooding (adaptation and residual damage costs) may reach 300 US$ billion per year in 2100 without adaptation and 90 US$ billion per year with adaptation under a 1.26 m sea-level rise scenario.				5.4.3, 5.5.3
	While developed countries are expected to be able to adapt to even high levels of sea-level rise, small island states and some low-lying developing countries are expected to face very high impacts and associated annual damage and adaptation costs of several percentage points of GDP (*high agreement*). Developing countries and small island states within the tropics relying on coastal tourism are impacted not only directly by future sea-level rise and associated extremes but also by the impacts of coral bleaching and ocean acidification and reductions in tourist flows from other regions (*very high confidence*).	CO_2			5.4.3, 5.5.3
	Physical effects of climate change on marine ecosystems may act, under some circumstances, as an additional pressure that cannot be ameliorated by local conservation measures or a reduction in human activities like fishing (*high confidence*).	CO_2			6.4
	Some warm water corals and their reefs will continue to respond to warming with species replacement, bleaching, and decreased coral cover. The projected degradation of some marine ecosystems such as coral reefs and Mediterranean intertidal communities is *very likely* to pose substantial challenges for coastal societies where livelihoods and food security may depend on ecosystem health.			Genetic adaptation may occur; the capacity to compensate for or keep up with the rate of ongoing thermal change is limited (*low confidence*).	6.2, 6.3, 6.5.2, 30.4, 30.5.3, 30.5.6, Box CC-CR
	Through species gains and losses correlated with warming, the diversity of animals and plants will increase at mid and high latitudes (*high confidence*) and fall at tropical latitudes (*low confidence*), leading to a large-scale redistribution of global catch potential for fishes and invertebrates (*medium confidence*). Animal displacements are projected to lead to a 30–70% increase in the fisheries yield of high-latitude regions but a drop of 40–60% in the tropics by 2055 relative to 2005 under the SRES A1B scenario (*medium confidence* for the general trend of shifting fisheries yields, *low confidence* for the magnitude of change).				6.2.5, 6.3.2, 6.4, 6.5, 6.5.2
	Changes in ocean mixing, nutrient levels, and primary productivity are *very likely* to have positive consequences for some fisheries and negative ones for others through the de-oxygenation of deep water environments and associated spread of hypoxic zones (*medium agreement, medium evidence*).				30.5, 6.2, 6.3, 6.5
	Changes to surface winds, sea level, wave height, and storm intensity will increase the risks associated with coastal and ocean based industries such as shipping, oil, gas, and mineral extraction (*medium agreement, medium evidence*).				30.6, 6.5
Africa	Impacts of climate change, mainly through sea level rise, combined with other extreme events (such as high tide levels and high storm swells) have the potential to threaten coastal zones, particularly coastal towns (*high confidence*).				22.3.2, 22.3.4, 22.3.7
Europe	Costs of adapting dwellings or upgrading coast defence will increase under all scenarios (*high confidence*).				23.3.2, 23.6.5, 23.7.3

Region	Risk	Climate Driver(s)	Era & Adaptation Potential	Adaptation Issues/Prospects	Chap. Ref.
	Climate change will not decrease net fisheries economic turnover in some parts of Europe (e.g., Bay of Biscay) (*low confidence*) due to introduction of new (high temperature tolerant) species. Climate change will not entail relocation of fishing fleets (*high confidence*).				23.4.6
Asia	In the Asian Arctic, rising sea levels will interact with projected changes in permafrost and the length of the ice-free season to cause increased rates of coastal erosion (*high agreement, medium evidence*).				24.4.3
Australasia	Significant change in community structure of coral reef systems in Australia, driven by increasing sea-surface temperatures and ocean acidification (*high confidence*).	CO_2		The natural ability of reefs to adapt to projected changes is limited.	Box CC-CR, 25.6.2, 30.5
	Widespread damages to coastal infrastructure and low-lying ecosystems in Australia and New Zealand if sea level rise exceeds 1m (*high confidence*). Risks from sea level rise *very likely* continue to increase beyond 2100 even if temperatures are stabilized.			Managed retreat is a long-term adaptation strategy for human systems but options for some natural ecosystems are limited due to the rapidity of change and lack of suitable space for inland migration.	WGI AR5 13.ES; Box 25-1, Table 25-1, 25.4.2, 25.6.1-2
Polar Regions	Shifts in the timing of seasonal biomass production could disrupt matched phenologies in food webs, leading to decreased abundance of high latitude marine organisms (*medium confidence*).				28.2.2, 28.3.2
REGION	**HUMAN SYSTEMS**				
	Risk	**Climate Driver(s)**	**Era & Adaptation Potential**	**Adaptation Issues/Prospects**	**Chap. Ref.**
Global	Global arable area is *likely* to increase from 2007 to 2050 (*high agreement, medium evidence*), with projected increases over this period of between 9% and 25% (*medium agreement, medium evidence*). From the mid-21st century onwards, the human food system at scales from the local to global and particularly in low-latitude lands will be seriously and negatively affected by projected climate change (*high agreement, robust evidence*). For 4-6 °C global mean temperature above pre-industrial levels, global risks to food production and security may become very severe (*high agreement, medium evidence*).			Adaptation possibilities for food systems vary widely in effectiveness. Adaptation will increase in effectiveness up to ca. 3°C local mean warming above pre-industrial, after which the net benefits no longer increase (*medium confidence*).	7.1, 7.2, 7.3, 7.4, 7.5, 7.6, Figures 7-5, 7-9
	Without adaptation, moderate warming of up to 2°C local temperatures is expected to reduce yields on average for the major cereals (wheat, rice, and maize) in temperate regions, although many individual locations may benefit (*medium confidence*). There is confirmation that even modest warming up to 2°C will decrease yields in low-latitude tropical regions (*medium agreement, robust evidence*).			Benefits of adaptation are greater for wheat, rice, and maize in temperate rather than tropical regions.	7.1, 7.3.2, 7.4-6, Figs 7-5, 7-6, 7-7, 7-9
	Yield reductions of more than 5% are *more likely than not* beyond 2050 and *likely* by the end of the century. From the 2070s, all positive yield changes are in temperate regions, suggesting yield reductions in the tropics are *very likely* by this time and substantial, particularly for wheat (*high agreement, robust evidence*).				7.4, Figures 7-5, 7-6, and 7-7
	Climate change will lead to higher prices and increased volatility in agricultural markets, which might undermine global food supply security while affecting rural households depending on whether they are net buyers or net sellers of food (*medium* to *high confidence*).			Deepening agricultural markets through reforming trade and institutional efforts to improve the predictability and reliability of the world trading system, as well as investing in supply capacity of small-scale farms in developing countries, could help reduce market volatility and manage food supply shortages (*medium agreement*).	9.3.3
	In the next few decades, climate change will increase incidence of injury, disease, and death due to more intense heat waves, storms, floods, and fires; increase risk of under-nutrition in some developing regions; reduce work capacity and labor productivity in vulnerable populations; increase risks of food- and water-borne diseases and vector-borne infections; and modestly improve health outcomes in some areas due to lower impacts of cold, shifts in food production, and reduction of disease-carrying vectors. Positive health effects will be out-weighed, world-wide, by the magnitude and severity of negative impacts.			Impacts on health will be reduced, but not eliminated, in populations that benefit from rapid social and economic development, particularly among the poorest and least healthy groups.	11.4, 11.5, 11.6, 11.7

	For RCP 8.5 by 2100, limits to adaptation for health impacts may be exceeded in many areas of the world (*high confidence*), related to sea level rise, storms, loss of agricultural productivity, and daily temperature/humidity conditions that exceed coping mechanisms.				11.8
	Climate change threatens human security, because it a) undermines livelihoods, b) compromises culture and identity, c) increases migration that people would rather have avoided, and d) undermines the ability of states to provide the conditions necessary for human security (*high agreement, robust evidence*). Increases in the rate and magnitude of climate change increase the risk to human security by exacerbating negative feedbacks between cultural processes, migration, and violent conflict.			Human security breakdowns almost never have single causes, but instead emerge from the interaction of multiple factors. For populations already socially marginalized and resource dependent with limited capital assets, human security will be progressively undermined as the climate changes.	12.1.2, 12.2, 12.7
Africa	Spatial convergence of impacts in different sectors creates impact "hotspots" involving new interactions, for example, in Sub-Saharan Africa where global warming at the high end of the range projected for this century, i.e., more than 4°C above preindustrial levels, would be especially disruptive, resulting in high risk of reduced extent of croplands, reduced length of the growing season, increased hunger, and increased malaria transmission.				19.3.2
	Temperature rise and a reduction in growing season length by mid-century are expected to significantly reduce crop productivity with strong adverse effects on food security. New challenges to food security are emerging as a result of strong urbanization trends on the continent and increasingly globalized food chains, which require better understanding of the multi-stressor context of food and livelihood security.				22.3.4
	Climate change is expected to increase the burden of a wider range of health outcomes (*medium confidence*).				22.3.5
Europe	Increasing heat wave mortality across most sub-regions of Europe by 2050 (medium emissions) with economic development and land-use change. Particularly in Southern Europe, increased frequency and intensity of heat waves (*high confidence*) will have adverse implications for health, agriculture, energy production, transport, tourism, labour productivity, and built environment (*medium confidence*).				23.2.2, 23.5.1, Tables 23-4, 23-5
	Climate warming will decrease space heating demand and increase cooling demand (*high confidence*), with income growth driving the largest part of this increase from 2000-2050 (especially in eastern regions) (*medium confidence*). Climate change will increase problems associated with overheating in domestic housing.			Energy efficient buildings and cooling systems as well as demand-side management will reduce future energy demands.	23.3.2, 23.3.4
	Climate change will increase yields in Northern Europe (*medium confidence*) but decrease cereal yields in Southern Europe (*high confidence*).				23.4.1, 23.4.2, 23.5.1
	Climate change will increase irrigation needs (*high confidence*), but future irrigation will be constrained by reduced runoff, demand from other sectors, and economic costs. By 2050s, irrigation will not be sufficient to prevent damage from heat waves to crops (*medium confidence*).				23.4.1, 23.4.3, 23.7.2
	Climate change will decrease hydropower production from reductions in rainfall in all sub-regions except Scandinavia (*high confidence*). Climate change will inhibit thermal power production during summer (*medium confidence*).			Plant modifications and operational changes can reduce adverse impacts.	23.3.4
	No significant impacts are projected before 2050 in winter or summer tourism except for ski tourism in low- and mid-altitude sites and under limited adaptation (*medium confidence*). After 2050, tourism activity will decrease in southern Europe (*low confidence*) and increase in northern/continental Europe (*medium confidence*).				23.3.6
	Increasing damage of cultural buildings and loss of cultural landscapes across most sub-regions by 2050 (medium emissions). Climate change and sea level rise will damage cultural heritage and iconic places such as Venice (*medium confidence*), and some cultural landscapes will be lost forever (*low/medium confidence*).				23.5.4, Table 23-5
Asia	The impacts of climate change on food production and food security will vary by region with many regions experiencing a decline in productivity (*medium confidence*). This is evident in the case of rice production, with lower yields as a result of shorter growing periods and heat-induced sterility. There are a number of regions that are already near the critical temperature threshold. In parts of Asia, increases in flood and drought will exacerbate rural poverty due to negative impacts on rice crops and increases in food prices and the cost of living (*high confidence*).			There are many potential adaptation strategies such as crop breeding, but research on their effectiveness is limited.	24.4.4, 24.4.6

	More frequent and intense heat-waves will increase mortality and morbidity in vulnerable groups. Increases in heavy rain and temperature will increase the risk of diarrheal diseases and malaria (*high confidence*).				24.4.6
Australasia	Increasing morbidity, mortality, and infrastructure damages during heat waves in Australia, resulting from increased frequency and magnitude of extreme temperatures (*high confidence*). Vulnerable populations include the elderly, children, and those with existing chronic diseases.			Aging trends and prevailing social dynamics constrain effectiveness of adaptation responses.	25.8.1
	Significant reduction in food production in the Murray-Darling Basin, far south-eastern Australia, and some eastern and northern areas of New Zealand if scenarios of severe drying are realized (*high confidence*).			More efficient water use, allocation, and trading would increase the resilience of systems in the near term but cannot prevent significant reductions in agricultural production and severe consequences for ecosystems and some rural communities at the dry end of the projected range.	25.2, 25.5.1, 25.7.2, Box 25-5
North America	Without adaptation, projected changes in temperature, precipitation, and extreme events would result in notable productivity declines in major crops by the end of the 21st century (*very high confidence*). Given that North America is a significant source of global food supplies, there will *likely* be a negative effect on global food security if projected productivity declines are not addressed with substantial investments in adaptation (*medium confidence*).			Adaptation may ameliorate many climate impacts to agriculture, but the institutional support mechanisms currently in place are insufficient to ensure effective, equitable, and sustainable adaptation strategies.	26.5
	Given current levels of adaptation, there are *likely* to be increased health impacts from heat extremes among vulnerable communities, populations, and individuals.			Health impacts from increasing heat extremes will depend on the pace of adaptation (*high confidence*).	26.6
Central and South America	Climate-change-related changes in agricultural productivity are expected to vary greatly spatially. In Southeastern South America, where projections indicate more rainfall, average productivity could be sustained or increased until the mid-century (SRES: A2, B2) (*medium confidence*). In Central America, northeast Brazil, and parts of the Andean region, increases in temperature and decreases in rainfall could decrease productivity in the short-term (before 2025), threatening food security of the poorest populations.				27.3.4
	It is *very likely* that climate variability and change may exacerbate current and future risks to health, given the region's vulnerabilities in existing health, water, sanitation and waste collection systems, nutrition, and pollution.				27.3.7
Polar Regions	Spatial convergence of impacts in different sectors creates impact "hotspots" involving new interactions, for example in the Arctic where sea ice loss and thawing disrupts transportation, buildings, other infrastructure, and potentially disrupts Inuit culture (*high confidence*).				19.3.2
	Significant impacts on the availability of key subsistence marine and terrestrial species are projected as climate continues to change with the ability to maintain economic livelihoods being affected (*high confidence*). Changing sea-ice conditions will result in more difficult access for hunting marine mammals.				28.2.6
	Increased economic opportunities and challenges for culture, security, and environment are expected with the increased navigability of Arctic marine waters and the expansion of land- and fresh water-based transportation networks (*high confidence*).				28.2.6, 28.4.2
Small Islands	Spatial convergence of impacts in different sectors creates impact "hotspots" involving new interactions, for example in the environs of Micronesia, Mariana Island, and Papua New Guinea where coral reefs are highly threatened due to exposure to concomitant sea surface temperature rise and ocean acidification (*high confidence*).	CO_2			19.3.2

Table TS.6: Assessment of climate change impacts by European sub-region and sector (by 2050, medium emissions) With economic development, with land use change. No further planned adaptation. [Table 23-4]

	Alpine	Southern	Northern	Continental	Atlantic	
Infrastructure						
Wind energy production	→ (black)	↗ (green) → (black) ↘ (green) [1]	→ (black)	→ (black)	↗ (green) → (black) ↘ (red)	23.3.4
Hydropower generation	↗ (green) ↘ (red) [2]	↘ (red)	↗ (green) → (black)	↘ (red)	↗ (green) ↘ (red)	23.3.4
Thermal power production	→ (black) ↘ (red)	→ (black) ↘ (red)	→ (black)	→ (black) ↘ (red)	→ (black) ↘ (red)	23.3.4, 8.2.3.2
Energy consumption (net annual change)	↘ (green)	↗ (red)	↘ (green)	↘ (green)	↘ (green)	23.3.4, 23.8.1
Road accidents [3]	→ (black) ↘ (green)	↘ (green)	→ (black) ↘ (green)	→ (black) ↘ (green)	→ (black) ↘ (green)	23.3.3
Rail delays (weather-related)	?	?	↗ (red)	?	↗ (red) ↘ (green) [4]	23.3.3, 8.3.3.6
Load factor of inland ships	?	?	?	↘ (red)	↘ (red)	23.3.3
River flood damages	?	?	?	↗ (red) ↘ (green)	↗ (red) ↘ (green)	23.3.1
Transport time and cost in ocean routes	?	?	↘ (green)	↘ (green)	?	23.3.3, 18.3.3.3.5
Length of ski season	→ (black) ↘ (red)	?	↘ (red)	↘ (red)	?	23.3.6, 3.5.7
Food and Fibre production						
Wine production	?	↘ (red)	?	↗ (green) ↘ (red)	↗ (green) ↘ (red)	23.3.5, 18.3.3.1, 23.4.1
Arable Production	↗ (green) ↘ (red)	↘ (red)	↗ (green) ↘ (red)	→ (black) ↘ (red)	↗ (green) ↘ (red)	23.4.1
Livestock production	↗ (green) ↘ (red)	↘ (red)	↗ (green)	→ (black) ↘ (red)	↗ (green) ↘ (red)	23.4.2
Water availability for agriculture	→ (black) ↘ (red)	↘ (red)	→ (black) ↘ (red)	↘ (red)	↘ (red)	23.4.3
Forest productivity	?	↘ (red)	↗ (green)	?	↗ (green)	23.4.4
Pest and plant diseases	↗ (red)	↗ (red) ↘ (green)	↗ (red)	↗ (red) ↘ (green)	↗ (red) ↘ (green)	23.4.1, 23.4.4
Bioenergy production	?	↘ (red)	↗ (green)	?	?	23.4.5
Health and Social Impacts						
Heat wave mortality	→ (black)	↗ (red)	↗ (red)	↗ (red)	↗ (red)	23.5.1
Damage on cultural buildings	↗ (red)	↗ (red) ↘ (green)	↗ (red)	↗ (red)	↗ (red)	23.5.4
Loss of cultural landscapes	↗ (red)	?	↗ (red)	↗ (red)	↗ (red)	23.5.4
Enviromental quality						

Air quality (ozone background levels)	?	?	?	?	?	23.6.1
Water quality	→	↘	→	→	↘	23.6.3
Local loss of native species and extinction of species	↗	↗	↗	↗ →	↗	23.6.4

Code. Green means a "beneficial change" and Red means a "harmful", ? No relevant literature found

- ↗ Increasing
- → No change in
- ↘ Decreasing
- ↗ → A range from no change to increasing
- → ↘ A range from no change to decreasing
- ↗ ↘ A range from increasing to decreasing

FOOTNOTES

[1] Simulations have been performed, but mostly for the period after 2070.

[2] The increasing trend is for Norway.

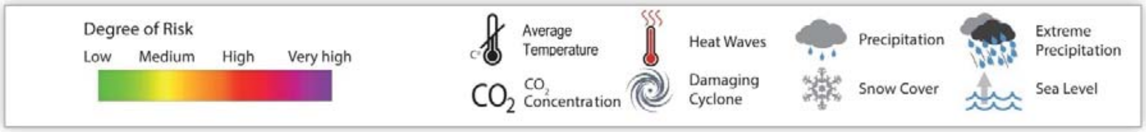
[3] The decreasing trend refers mainly to the number of severe accidents.

[4] Impacts have been studied and quantified for UK only. The increasing trend stands for summer delays and the decreasing trend for winter delays.

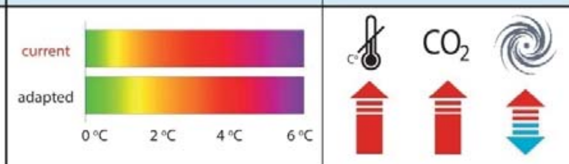
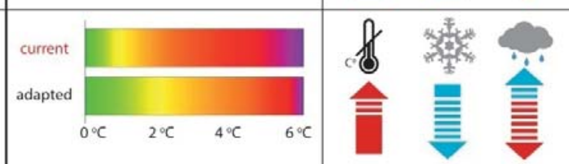
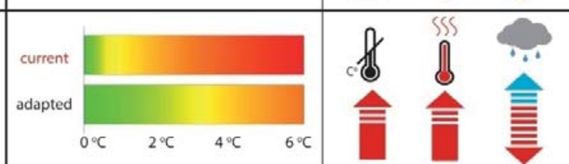
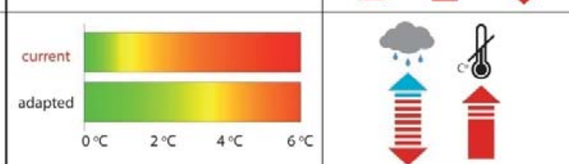
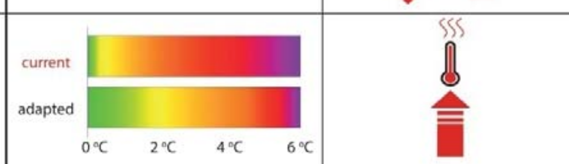
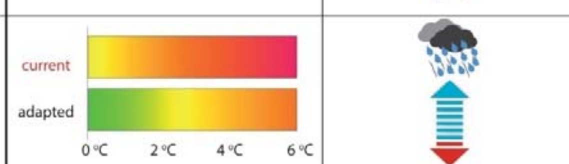
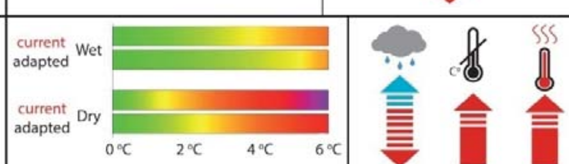
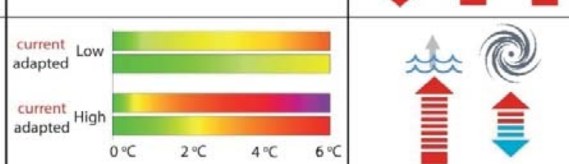
[5] In both seasons, no significant impacts are expected by 2020, while more substantial changes are expected by 2080. For 2050 impacts are assumed to vary linearly (although this may not be the case).

[6] The constant trend stands for the Mediterranean, where some studies estimate no changes due to climate change at least until 2030 or even 2060.

Table TS.7: Key regional risks during the 21st century from climate change for Australia and New Zealand. Color bars indicate risk as a function of global mean temperature relative to pre-industrial, based on the studies assessed and expert judgement, for the current (top bar) and a hypothetical fully adapted state (bottom bar). For each risk, relevant climate variables and trends are indicated by symbols, in approximate order of priority. Where relevant climate projections span a particularly wide range even for a given amount of global mean temperature change, risks are shown in two pairs for high and low end projections, each without and with effective adaptation*. [Table 25-8]



Arrows show projected future changes in key drivers under a range of climate and mitigation scenarios. Arrows pointing in both directions indicate that the direction of change (indicated by red and blue colours) is uncertain. Narrow horizontal bars indicate the range of potential changes, with more bars indicating greater uncertainty. Thick bars are used where the direction of change is highly certain and some amount of further change over the 21st century is virtually unavoidable even under mitigation scenarios.

Key Regional Risk		Risk for current and hypothetical fully adapted state	Key Climate Drivers and Trends	Key adaptation issues / prospects
Impacts that can be delayed but now appear very difficult to avoid entirely, even with globally effective mitigation and proactive adaptation	Significant change in community structure of coral reef systems in Australia [25.6.2, 30.5, Box CC-CR]			Limited evidence for autonomous genetic adaptation of corals; other adaptation options are limited to reducing other stresses, mainly enhancing water quality and limiting pressures from tourism and fishing
	Loss of montane eco-systems and some endemic species in Australia [25.6.1]			Direct adaptation options are limited, but reducing other stresses such as pests, diseases and predator control and enhancing connectivity of habitats provides immediate co-benefits; need to consider translocation and migration
Impacts that have the potential to be severe but can be moderated or delayed significantly by globally effective mitigation and a portfolio of available adaptation measures	Wild fire damages to ecosystems and settlements and risks to human life in southern Australia and many parts of New Zealand [Table 25-1, Box 25-6]			Part of integrated landscape management; trade-offs exist between different management objectives and settlement patterns and goals
	Systematic constraints on water resource use in southern Australia [25.5.1, Box 25-2, 25-9]			Water resources already struggling to meet unlimited demand in many locations and exacerbated by projected population growth; effective adaptation relies on combination of demand and supply mechanisms
	Increase in morbidity and mortality and infrastructure failure during heat waves in Australia [25.7.4, 25.8.1]			Linked to social dynamics and ageing population in cities; transport and power infrastructure already at coping limit in many regions, with significant financial costs from future upgrades
	Increased frequency and intensity of flood damage to infrastruc-ture and settlements in Australia and New Zealand [25.2, Table 25-1, Box 25-8, 25-9]			Significant adaptation deficit in some regions to current flood risk; effective adaptation includes land-use controls and relocation as well as protection and accommodation of increased risk to ensure flexibility
Impacts that have a low or currently unknown probability but cannot be ruled out even with globally effective mitigation, and would present major challenges if realized	Significant reduction in food production in the Murray-Darling Basin, far south-east Australia and eastern and northern parts of New Zealand [25.2, Table 25-1, 25.6.1, 25.7.2, Box 25-2, 25-5]			Immediate co-benefits from improved management of over-allocated water resources and balancing competing demands, but the extreme dry end would threaten agricultural production as well as ecosystems and some rural communities
	Widespread damages to coastal infrastructure and low-lying ecosys-tems in Australia and New Zealand [Table 25-1, 25.6.1, 25.6.2, Box 25-2, 25-9]			Adaptation deficit in some locations to current coastal erosion and flood risk; successive building and protection cycles constrain flexible responses; effective adaptation includes land-use controls and ultimately relocation as well as protection and accommodation

* For rainfall and its impact on food production, wet and dry scenarios represent approximately the 10 and 90 percentile range of current model projections and RCP emissions scenarios.
For sea level, the low scenario is a 0.39 m rise by 2100 (mid-range model projections, RCP 2.6); the high scenario is a 1.5 m rise by 2100 (semi-empirical models, RCP 8.5). See AR5 WGI Chap 13 for more details. Under either scenario, sea level would continue to rise beyond 2100, but the focus of the risk assessment here is for risks that could be realised during the 21st century.

Table TS.8: A selection of the hazards/stressors, key vulnerabilities, key risks, and emergent risks identified in the report. The examples underscore the complexity of risks determined by various climatic hazards, non-climatic stressors, and multifaceted vulnerabilities. The examples show that underlying phenomena, such as poverty or insecure land-tenure arrangements, demographic changes, or tolerance limits of species and ecosystems that often provide important services to vulnerable communities, generate the context in which climate-change-related harm and loss can occur. The examples illustrate that current global megatrends (e.g., climate change, urbanization, demographic changes), in combination and in specific development contexts (e.g., in low-lying coastal zones), can generate new systemic risks that go far beyond existing adaptation and risk management capacities, particularly in highly vulnerable regions. [Table 19-3]

Hazard/Stressor	Key vulnerabilities	Key risks	Emergent risks
Examples from terrestrial and inland water systems			
Rising air, soil, and water temperature.	Exceedence of eco-physiological climate tolerance limits of species, increased viability of alien organisms.	Loss of native biodiversity, increase in alien organism dominance.	Cascades of native species loss due to interdependencies.
	Epidemiological response to spread of temperature-sensitive vectors (insects).	Novel or much more severe pest and pathogen outbreaks.	Interactions between pest, drought, and fire interactions can lead to new risks and large negative impacts on ecosystems.
Examples from ocean systems			
Rising water temperature, increase of (thermal and haline) stratification, and marine acidification. [6.1.1] *(also Chapter 24)*	Tolerance limits of endemic species surpassed, increased abundance of invasive organisms, high vulnerability of warm water coral reefs and respective ecosystem services for coastal communities. [6.2.2, 6.2.5]	Loss of endemic species, mixing of ecosystem types, increased dominance of invasive organisms, loss of coral cover and associated ecosystems with reduction of biodiversity. [6.3.2]	Enhancement of risk due to interactions, e.g., acidification and warming for calcareous organisms. [6.3.5]
Examples from urban areas			
Inland flooding.	Urban areas with large numbers of poor, uninsured people exposed to flood events including low-income informal settlements. Environmental health consequences from overwhelmed, aging, poorly maintained, and inadequate urban drainage infrastructure combined with widespread impermeable surfaces. Inadequate local governance. Increased mosquito and water borne diseases.	Increasing urban flooding with increasing volume and velocity of flood waters on the one hand and increasing vulnerability on the other leads to key risks particularly in urban areas with large numbers of people who are poor and/or exposed to flooding.	Larger and more frequent flooding impacting a much larger population. Impacts reaching the limits of insurance; shift in the burden of risk management from the state to those at risk leading to greater inequality and property blight; abandonment of urban districts and the creation of high risk/high poverty spatial traps.
Changing hazard profile including novel hazards and new multi-hazard complexes.	Newly exposed populations and infrastructure, especially for those with limited capacity for multi-hazard risk forecasting and where risk reduction capacity is limited, e.g., where risk management planning is overly hazard specific including where physical infrastructure is predesigned in anticipation of other risks.	Risks from failures within coupled systems, e.g., reliance of drainage systems on electric pumps, reliance of emergency services on roads and telecommunications, psychological shock from unanticipated risks.	Loss of faith in risk management institutions. Potential for large events that are magnified by a lack of preparation and capacity to respond.
Examples from human health			
Increasing frequency and intensity of extreme heat. *(also chapter 19)*	Older people living in cities are most vulnerable to heat waves, and their population is projected to triple from 2010-2050.	Increased mortality and morbidity during heat waves, particularly in people with pre-existing conditions.	Overloading of health and emergency services. Mortality, morbidity, and productivity loss, particularly for manual workers in hot climates.
Increasing temperatures, increased variability in precipitation.	Food insecurity translates into malnutrition, which is among the largest disease burdens in poorer populations.	Progress in reducing mortality and morbidity from malnutrition may slow or reverse and constitutes a new key risk.	Combined impacts of climate impacts, population growth, plateauing productivity gains, land demand for livestock, biofuels, persistent inequity, and on-going food insecurity for the poor.
Examples from livelihoods and poverty			
Soaring demand (and prices) of biofuels due to climate change policies.	Unclear and/or insecure land tenure arrangements.	Risk of dispossession of land due to "land grabbing" in developing countries.	Creation of large groups of landless farmers unable to support themselves. Social unrest due to disparities between intensive energy production and neglected food production.
Increasing frequency of extreme events (droughts, floods). For example if 1:20 year drought/flood becomes 1:5 year flood/drought.	Livelihoods subject to damage to their productive assets (e.g. in case of droughts – herds of livestock; if floods – dikes, fences, terraces).	Risk of the loss of livelihoods and harm due to shorter time for recovery between extremes. Pastoralists restocking after a drought may take several years; in terraced agriculture, need to rebuild terraces after flood, which may take several years.	Collapse of coping strategies with risk of collapsing livelihoods. Adaptation mechanisms such as insurance fail due to increasing frequency of claims.

Hazard/Stressor	Key vulnerabilities	Key risks	Emergent risks
Examples from Chapter 19			
Warming and drying (degree of precipitation changes uncertain). [WGI AR5 SPM, TS.5.3, 11.3, 12.4]	Limits to coping capacity to deal with reduced water availability; increasing exposure and demand due to population increase; conflicting demands for alternative water uses; socio-cultural constraints on some adaptation options. [19.2.2, 19.3.2, 19.6.1, 19.7.5]	Risk of harm and loss due to livelihood degradation from systematic constraints on water resource use that lead to supply falling far below demand. In addition, limited coping and adaptation options increase the risk of harm and loss. [19.3.2]	Negative outcomes to sending and/or receiving regions from migration of populations due to limits on agricultural productivity and livelihoods. [19.3.2, 19.4.2]
Examples from Africa			
Increasing temperature.	Health of exposed and vulnerable groups (increased exposure to heat, change in the transmission dynamics of vector-borne diseases).	Increase in disease burden – changes in the patterns of infection. Decrease in outdoor worker productivity due to high temperature, increase in heat related morbidity and mortality.	Emerging and re-emerging disease epidemics.
	Vulnerability of aquatic systems and vulnerability of aquatic ecosystem services due to increased water temperatures.	Loss of aquatic ecosystems and risks for people who might depend on these resources.	
Examples from Europe			
Extreme weather events. *(also Chapter 19)*	Limited coping and adaptive capacity as well as high sensitivity of different sectors, e.g., transport, energy, and health.	Stress on multiple sectors can cause systemic risks due to interdependencies among sectors.	Disproportionate intensification of risk due to increasing interdependencies.
Examples from Asia			
Thawing of permafrost due to rising temperature in northern Asia.	Existence of structures and infrastructure on permafrost and high dependence of civil life on them.	Instability of or damage to structures and infrastructures.	Projected exacerbation of instability of residential buildings, pavements, pipelines used to transport petroleum and gas, pump stations, and extraction facilities.
Projected increase in frequency of various extreme events (heat waves, floods, and droughts) and sea level rise. *(also Chapter 19)*	Convergence of livelihoods and properties into coastal megacities, especially into areas not sufficiently protected against natural hazards.	Loss of human life and assets due to coastal floods accompanied by increasing vulnerabilities caused by occurrence of other extreme events like heat waves and droughts.	Projected increase in disruption of basic services such as water supply, sanitation, energy provision, and transportation systems, which themselves could increase vulnerabilities.
Examples from Australasia			
Warming and increased temperature high extremes in Australia. [25.2, Table 25-1, Figure 25-5]	Urbanization, aging of population and vital infrastructure. [25.3, Box 25-9, 25.10.2]	Increase in morbidity, mortality, and infrastructure failure during heat waves. [25.8.1, 25.10.2]	Increasing risk from compound extreme events across time, space and governance scales, and cumulative adaptation needs. [25.10.2, 25.10.3, Box 25-9]
Potential for sea level rise beyond 2100 exceeding 1m [25.2, WGI AR5 Chapter 13]	Long lifetime of coastal infrastructure, concentration and further expansion of coastal population and assets; conflicting priorities and time preferences constraining adaptation options; limited scope for managed retreat in highly developed areas.	Widespread damages to coastal infrastructure and low-lying ecosystems. [Box 25-1, 25.10.2]	
Examples from North America			
Increases in frequency and/or intensity of extreme events, such as hurricanes, river and coastal floods, heat waves, and droughts. [26.2] *(also Chapter 19)*	Declining state of physical infrastructure in urban areas as well as increases in income disparities. [26.7]	Risk of serious harm and losses in urban areas, particularly in coastal environments due to enhanced vulnerabilities of social groups and physical systems combined with increases of extreme weather events. [26.8]	Inability to reduce vulnerability in many areas results in increase in risk greater than change in physical hazard. [26.8]
Higher temperatures, decreases in runoff, and lower soil moisture. [26.2, 26.3]	Increasing vulnerability of small landholders in agriculture. [26.5]	Increased losses and decreases in agricultural production increase food and job insecurity for small landholders and social groups in that region. [26.5]	Increasing risks of social instability and local economic disruption due to internal migration. [26.2, 26.8]

Table TS.9: Examples of potential trade-offs among adaptation objectives. [Table 16-2]

Sector	Strategy	Adaptation Objective	Real or Perceived Externality
Agriculture	Biotechnology and genetically modified crops	Enhance drought and pest resistance; enhance yields	Perceived risk to public health and safety; ecological risks associated with introduction of new genetic variants to natural environments
	Subsidized drought assistance; crop insurance	Provide financial safety net for farmers to ensure continuation of farming enterprises	Creates moral hazard and inequality if not appropriately administered
	Increased use of chemical fertilizer and pesticides	Maintain or enhance crop yields; suppress opportunistic agricultural pests and invasive species	Increased discharge of nutrients and chemical pollution to the environment; increased emissions of greenhouse gases; increased human exposure to pollutants
Biodiversity	Migration corridors; expansion of conservation areas	Enable natural adaptation and migration to changing climatic conditions	Unknown efficacy; concerns over property rights regarding land acquisition; governance challenges
	Anticipatory endangerment listings	Enhance regulatory protections for species potentially at-risk due to climate change	Addresses secondary rather than primary pressures on species; concerns over property rights; regulatory barriers to economic development
	Assisted migration	Facilitate conservation of valued species	Potential for externalities for ecological and human systems due to species relocation
Coasts	Sea walls	Protect assets from inundation and/or erosion	High direct and opportunity costs; equity concerns; ecological impacts to coastal wetlands
	Managed retreat	Allow natural coastal and ecological processes; reduce long-term risk to property and assets	Undermines private property rights; significant governance challenges associated with implementation
	Migration out of low-lying areas	Preserve public health and safety; minimize property damage and risk of stranded assets	Loss of sense of place and cultural identify; erosion of kinship and familial ties; impacts to receiving communities
Water resources management	Desalination	Increase water resource reliability and drought resilience	Ecological risk of saline discharge; high energy demand and associated carbon emissions; creates disincentives for conservation
	Water trading	Maximize efficiency of water management and use; increases flexibility	Undermines public good/social aspects of water
	Water recycling/reuse	Enhance efficiency of available water resources	Perceived risk to public health and safety

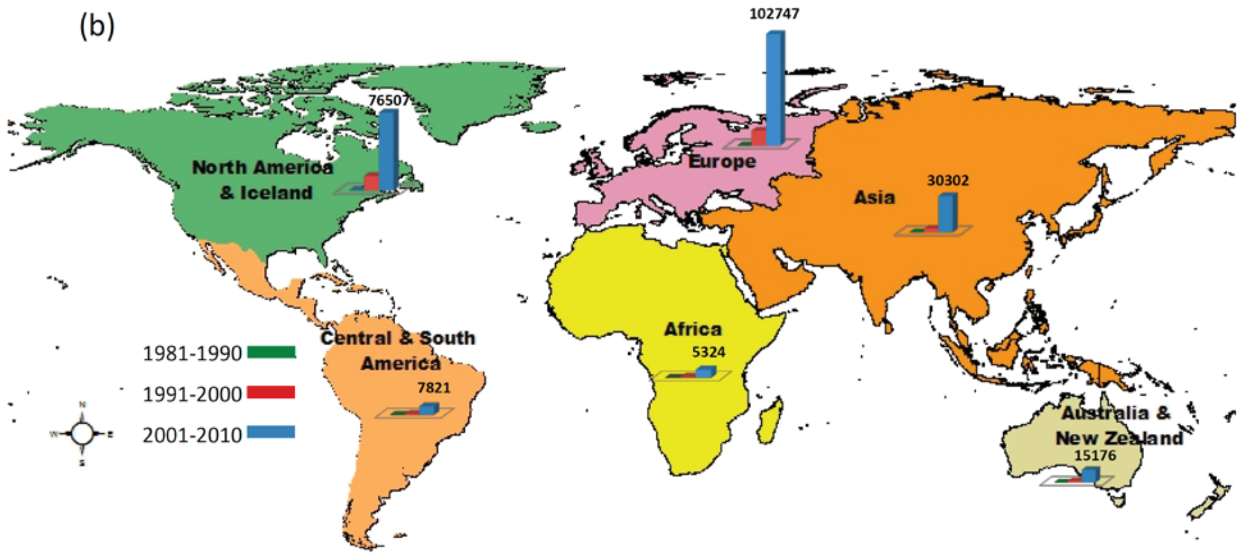
Table TS.10: Illustrative examples of intra-regional interactions among adaptation, mitigation, and sustainable development.

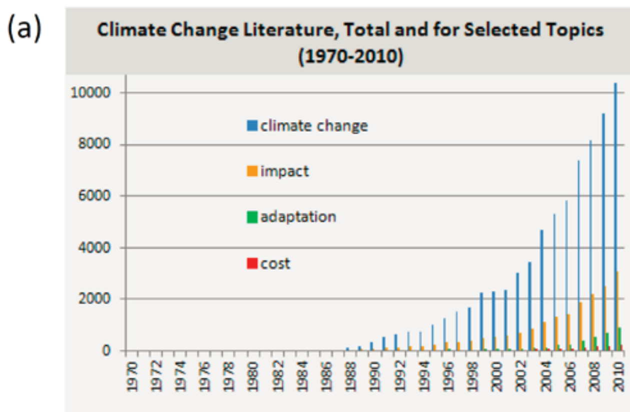
Green infrastructure and green roofs	
Objectives: *Storm water management, adaptation to increasing temperatures, reduced energy use, urban regeneration*	
Relevant Sectors: *Infrastructure, energy use, water management*	
Overview: Benefits of green infrastructure and roofs can include reduction of storm water runoff and the urban heat island effect, improved energy performance of buildings, reduced noise and air pollution, health improvements, better amenity value, increased property values, improved biodiversity or species migration, and inward investment. Trade-offs can result between higher urban density to improve energy efficiency and open space for green infrastructure. [8.3.3.7, 14.2.2.1, 17.4.1, 23.7.4, table 25-6]	
Location	**Example, with interactions**
London	The Green Grid for East London seeks to create interlinked and multi-purpose open spaces to support regeneration of the area. It aims to connect people and places, to absorb and store water, to cool the vicinity, and to provide a diverse mosaic of habitats for wildlife. [8.3.3]
New York	In preparation for more intense storms, New York is using green infrastructure to capture rainwater before it can flood the combined sewer system; implementing green roofs, blue roofs, and porous pavements for streets; and elevating boilers and other equipment above ground. [26.4.3]
Singapore	Singapore has used several anticipatory plans and projects to enhance green infrastructure including its Streetscape Greenery Master Plan, constructed wetlands or drains, and community gardens. Under its Skyrise Greenery project, Singapore has provided subsidies and handbooks for rooftop and wall greening initiatives. [8.3.3]
Durban	In Durban, ecosystem-based adaptation is part of its climate change adaptation strategy, seeking a more detailed understanding of the ecology of indigenous ecosystems and ways in which biodiversity and ecosystem services can reduce vulnerability of ecosystems and people. Examples include a pilot green roof project and its Community Reforestation Programme in which communities produce indigenous seedlings used in the planting and managing of restored forest areas. Needs for knowledge, new data collection, expertise, and resources, along with direct and immediate developmental co-benefits, have been identified in developing a network of bio-infrastructure. [8.3.3]

Water management	
Primary Objective: *Water resource management given multiple stressors in a changing climate*	
Relevant Sectors: *Water use, energy use, biodiversity*	
Location	**Example, with interactions**
New York	New York has a well-established program to protect and enhance its water supply through watershed protection. The Watershed Protection Program includes city ownership of land that remains undeveloped and coordination with landowners and communities to balance water-quality protection, local economic development, and improved wastewater treatment. The city government indicates it is the most cost-effective choice for New York given the costs and environmental impacts of a filtration plant. [8.3.3]
Africa	Water stress has encouraged dam construction to ensure water resource resiliency, but in some parts of Africa this has resulted in deleterious health impacts. Dam building can stimulate the reproduction of parasites in lakes nearby human settlements, amplifying the risk of schistosomiasis and leishmaniasis. [22.3.5]
Capital cities in Australia	Many Australian capital cities are reducing reliance on catchment runoff and groundwater—water resources most sensitive to climate change and drought—and are diversifying supplies through desalination plants, water reuse including sewage and storm water recycling, and integrated water cycle management that considers climate change impacts. Demand is being reduced through water conservation and water sensitive urban design and, during severe shortfalls, through implementation of restrictions. The water augmentation program in Melbourne includes a desalinization plant. Trade-offs beyond energy intensiveness have been noted, such as damage to sites significant to aboriginal communities and higher water costs that will disproportionately affect poorer households. [Box 25-2, 14.7.2]

Payment for environmental services and green fiscal policies	
Primary Objective: *Management incorporating the costs of environmental externalities and the benefits of ecosystem services*	
Relevant Sectors: *Biodiversity, ecosystem services*	
Location	**Example, with interactions**
Central and South America	A variety of payment for environmental services (PES) schemes have been implemented in Latin America. For example, national-level programs have operated in Costa Rica and Guatemala since 1997 and in Ecuador since 2008. Examples to date have shown that PES can finance conservation, ecosystem restoration and reforestation, and better land-use practices. Uniform payments for beneficiaries can be inefficient if, for example, recipients that promote greater environmental gains receive only the prevailing payment. [27.3.2, 27.6.2, table 27-8, 17.5.2, 17.5.4]
Brazil	Municipal funding in Brazil tied to ecosystem-management quality is a form of revenue transfer important to funding local adaptation actions. State governments collect a value-added tax redistributed among municipalities, and some states allocate revenues in part based on municipality area set aside for protection. This mechanism has helped improve environmental management and increased creation of protected areas. It benefits relations between protected areas and surrounding inhabitants, as the areas can be perceived as opportunities for revenue generation rather than as obstacles to development. The approach builds on existing institutions and administrative procedures and thus has low transaction costs. [8.4.3, Box 8-3]

Renewable energy	
Primary Objective: *Renewable energy production and reduction of emissions*	
Relevant Sectors: *Biodiversity, agriculture, food security*	
Location	**Example, with interactions**
Central and South America	Renewable resources, especially hydroelectric power and biofuels, account for substantial fractions of energy production in countries such as Brazil. Where bioenergy crops compete for land with food crops, substantial trade-offs can exist. Land-use change to produce bioenergy can affect food crops, biodiversity, and ecosystem services. Lignocellulosic feedstocks, such as sugarcane second-generation technologies, do not compete with food. [27.3.6, Table 27-6]
Australia and New Zealand	Mandatory renewable energy targets and incentives to increase carbon storage support both increased biofuel production and increased biological carbon sequestration, with impacts on biodiversity depending on implementation. Benefits can include reduced erosion, additional habitat, and enhanced connectivity, with risks or lost opportunities associated with large-scale monocultures especially if replacing more diverse systems. Large-scale land-cover changes can affect catchment yields and regional climate in complex ways. New crops such as oil mallees or other eucalypts may provide multiple benefits, especially in marginal areas, displacing fossil fuels or sequestering carbon, generating income for landholders (essential oils, charcoal, bio-char, biofuels), and providing ecosystem services. [Box 25-10, Table 25-6]



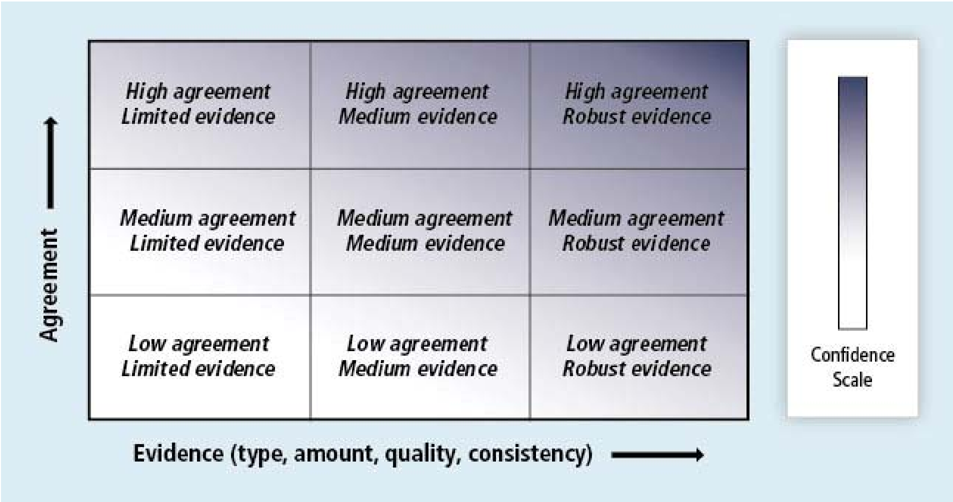


(c)

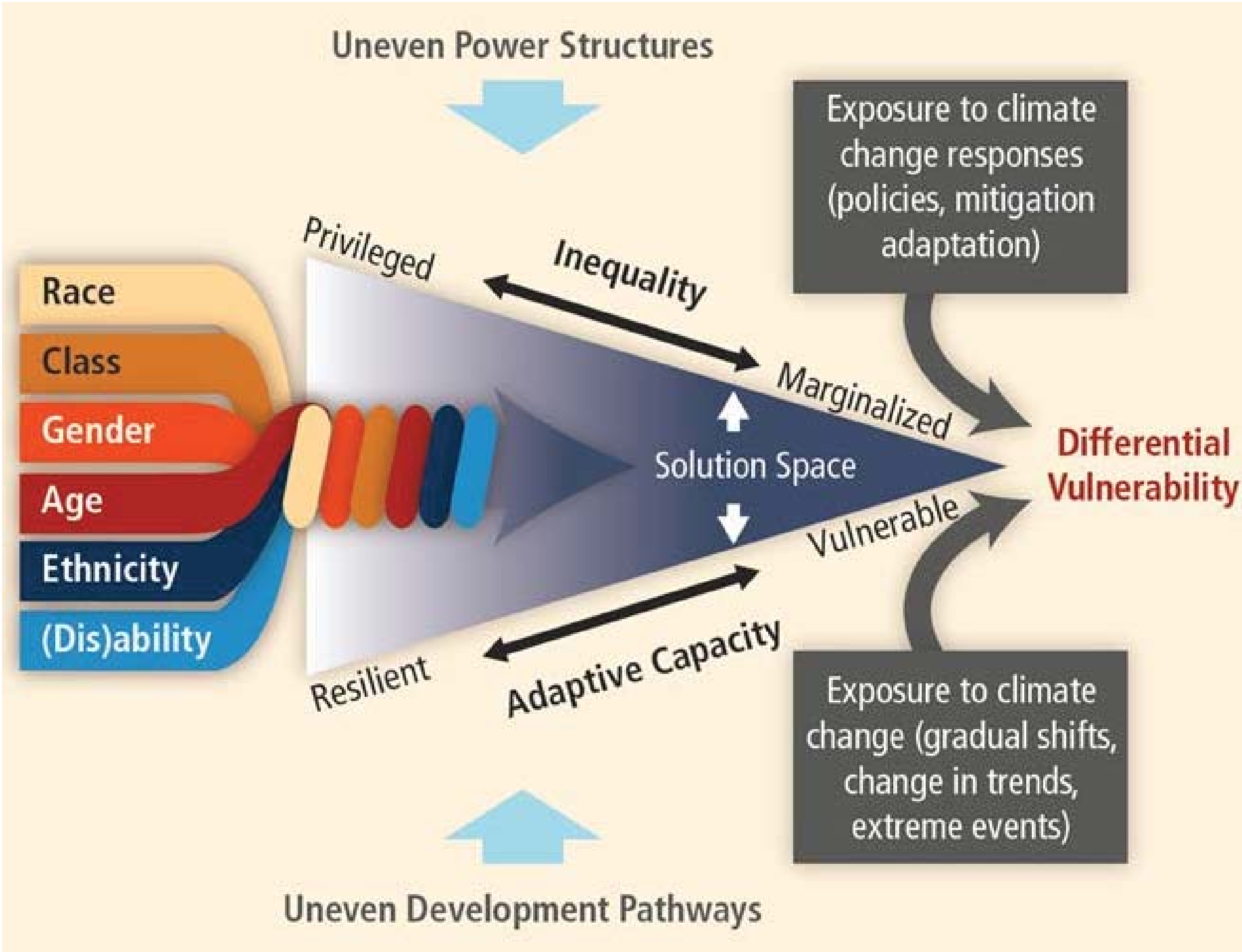
Climate Change Literature by Region (Title, Key Words, or Abstract)

	1981-1990	1991-2000	2001-2010
Africa	0	509	4815
Asia	9	2821	27472
Europe	71	12218	90458
North America	290	11926	64281
Central and South America	2	677	7142
Australia and New Zealand	7	1654	13515

Box TS.1 Figure 1: Results of English literature search using the Scopus bibliographic database from Reed Elsevier Publishers. (a) Annual global output of publications on climate change and related topics: impacts, adaptation, and costs (1970-2010). (b) Country affiliation of authors of climate change publications summed for IPCC regions for three time periods: 1981-1990, 1991-2000, and 2001-2010, with total number during the period 2001-2010. (c) Results of literature searches for climate change publications with individual countries mentioned in publication title, abstract, or key words, summed for all countries by geographic region. [Figure 1-1]



Box TS.3 Figure 1: Evidence and agreement statements and their relationship to confidence. The shading increasing towards the top right corner indicates increasing confidence. Generally, evidence is most robust when there are multiple, consistent independent lines of high-quality evidence. [Figure 1-4]



Box TS.4 Figure 1: Intersecting yet simultaneous and dynamic axes of privilege and marginalization, shaped by people's multiple identities and embedded in uneven power relations and development pathways. Together, they result in differential vulnerability to the same exposure to climate change and climate change responses. These intersecting dimensions ("intersectionality") illustrate systemic vulnerability and multidimensional deprivation that determine inequality and adaptive capacity while being transformed as a result of negative climate change impacts and risks as well as consequences of policy responses, often to the detriment of the poor and disadvantaged. [Figure 13-4]

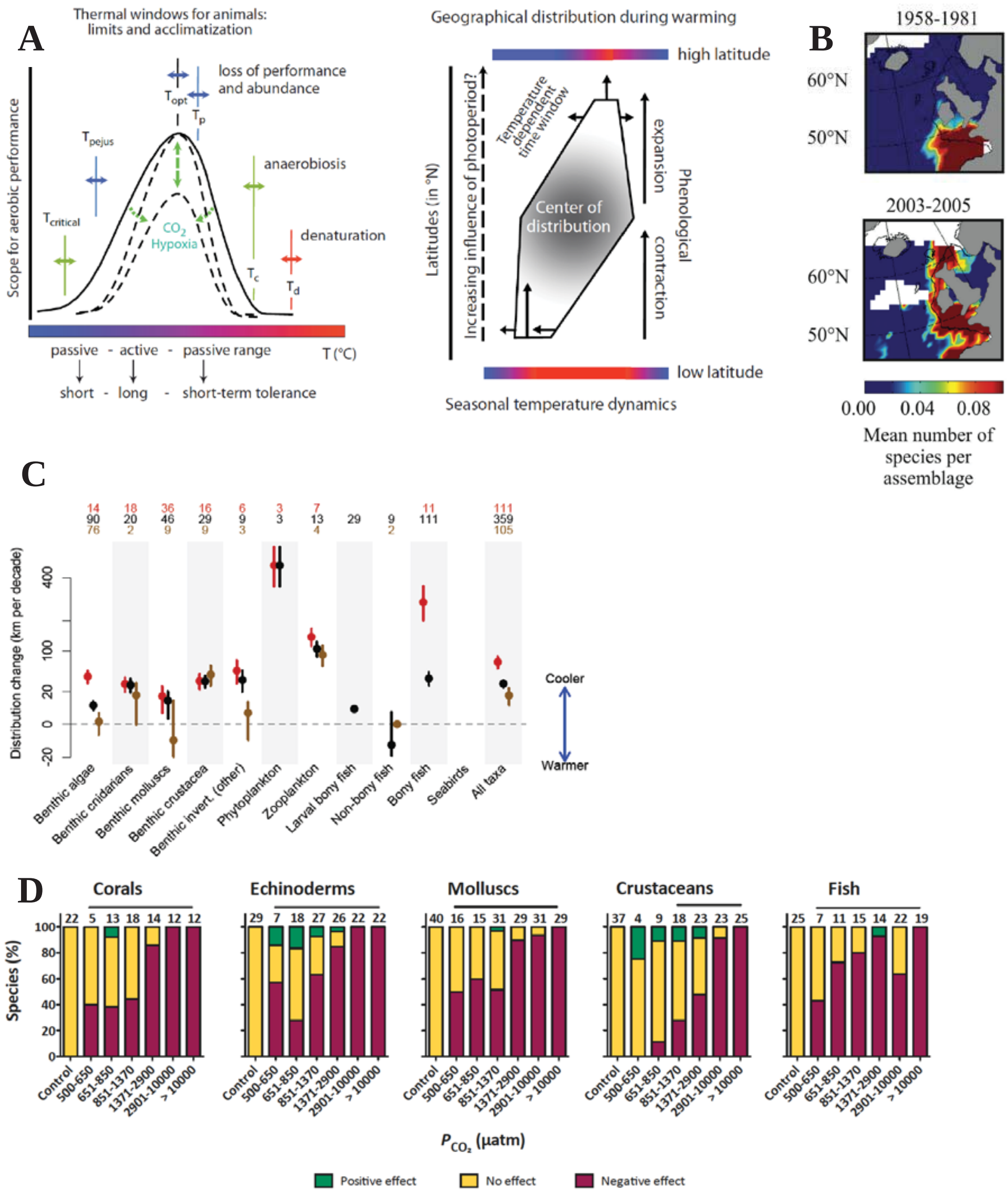


Figure TS.1: Thermal specialization of species, sensitive to ocean acidification and hypoxia (A, left) causes warming induced distribution shifts (A, right). An example (B) is the northward expansion of warm-temperate species in the Northeast Atlantic. Differential distribution change across functional groups (C) will be influenced by species-specific impacts of future ocean acidification across phyla (D). Detailed introduction of each panel follows: A) Mechanisms linking organism to ecosystem response explain the why, how, when, and where of climate sensitivity (blue to red color gradients illustrate transition from cold to warm temperatures). As all biota, animals specialize on limited temperature ranges, within which they grow, behave, reproduce, and defend themselves by immune responses (left). Optimum temperatures (T_{opt}) indicate performance maxima, pejus temperatures (T_p) the limits to long-term tolerance, critical temperatures (T_c) the transition to anaerobic metabolism, and denaturation temperatures (T_d) the onset of cell damage. These thresholds can shift by acclimatization (horizontal arrows). Under elevated CO_2 levels and in hypoxic waters performance levels can decrease and windows of performance be narrowed (dashed green arrows pointing to dashed black curves). Shifts in biogeography result during climate warming (right). The polygon delineates the range in space and time, the level of grey denotes abundance. Species display maximum productivity in southern spring, wide seasonal coverage in the center, and a later productivity maximum in the North. The impact of photoperiod increases with latitude (dashed arrow). During warming, the southern temperature and time window contracts while the northern one dilates (directions and shifts indicated by arrows). Control by water column characteristics or photoperiod may overrule temperature control in some organisms (e.g., diatoms), causing contraction of spatial distribution in the north. B) Long-term changes in the mean number of warm-temperate pseudo-oceanic species in the Northeast Atlantic from 1958 to 2005. C) Rates of change in distribution (km $decade^{-1}$) for marine taxonomic groups, measured at the leading edges (red), and trailing edges (brown). Average distribution shifts calculated using all data, regardless of range location, are in black. Distribution rates have been square-root transformed; standard errors may be asymmetric as a result. Positive distribution changes are consistent with warming (into previously cooler waters, generally poleward). Means ± standard error are shown, with number of observations and significance (*p<0.1, **p<0.05, ***p<0.01). D) % fraction of studied scleractinian coral, echinoderm, molluscan, crustacean, and fish species affected negatively, positively, or not at all by various levels of ambient CO_2. Effects considered include those on life stages and processes reflecting physiological performance (O_2 consumption, aerobic scope, behaviors, scope for behaviors, calcification, growth, immune response, acid-base balance, gene expression, fertilization, sperm motility, developmental time, production of viable offspring, morphology). Horizontal bars above columns represent frequency distributions significantly different from controls. [Figures 6-7, 6-10, 6-11, and 30-11]

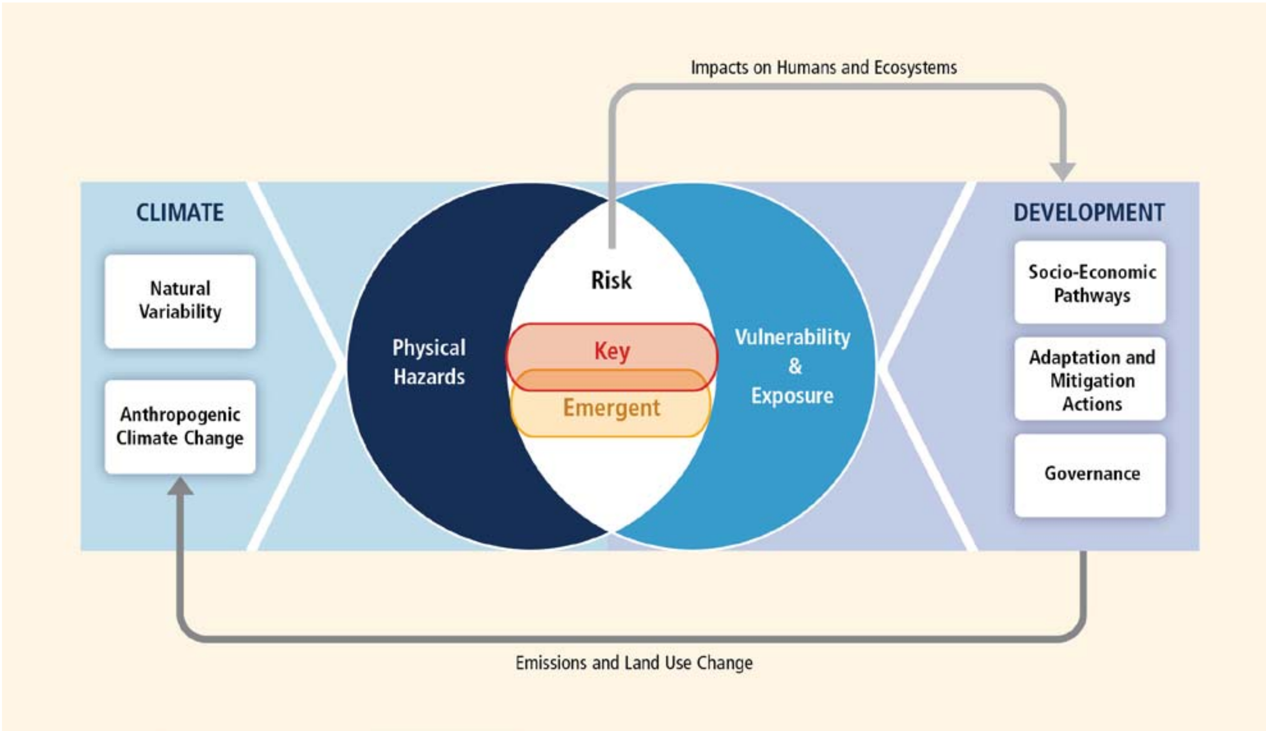


Figure TS.2: Schematic of the interaction among the physical climate system, exposure, and vulnerability producing risk. Risks are a product of a complex interaction between physical hazards associated with climate change and climate variability on the one hand, and the vulnerability of a society or a social-ecological system and its exposure to climate-related hazards on the other. The definition and use of "key" and "emergent" are indicated in Section C.ii. Vulnerability and exposure are, as the figure shows, largely the result of socio-economic development pathways and societal conditions. Changes in both the climate system (left side) and development processes (right side) are key drivers of the different core components (vulnerability, exposure, and physical hazards) that constitute risk. [19.1, Figure 19-1]

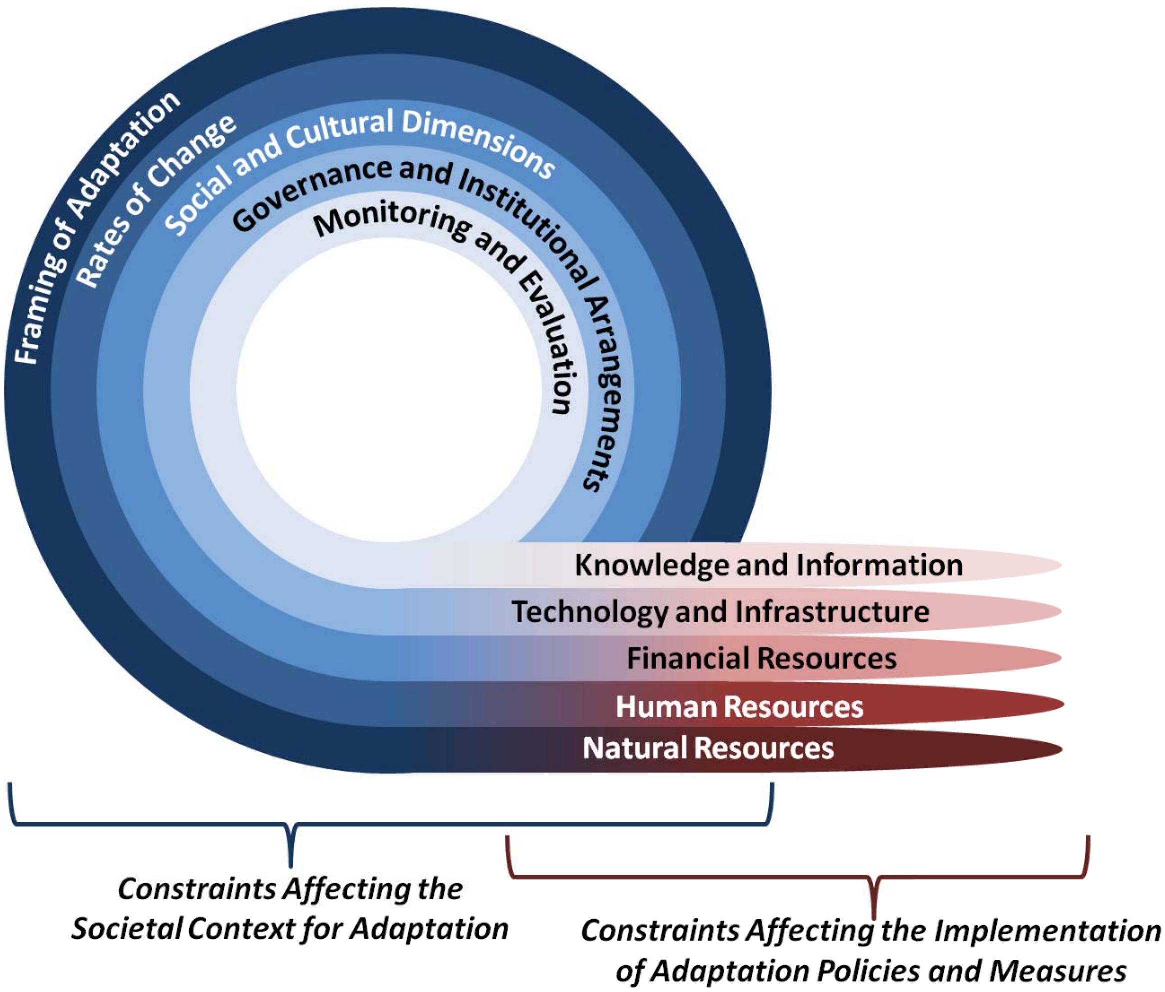


Figure TS.3: Key adaptation constraints assessed, categorized into two groups. One group reflects constantly evolving biophysical and socio-economic processes that influence the societal context for adaptation. These processes subsequently influence the second group of constraints affecting the implementation of specific adaptation policies and measures that could be deployed to achieve a particular objective. [Figure 16-2]

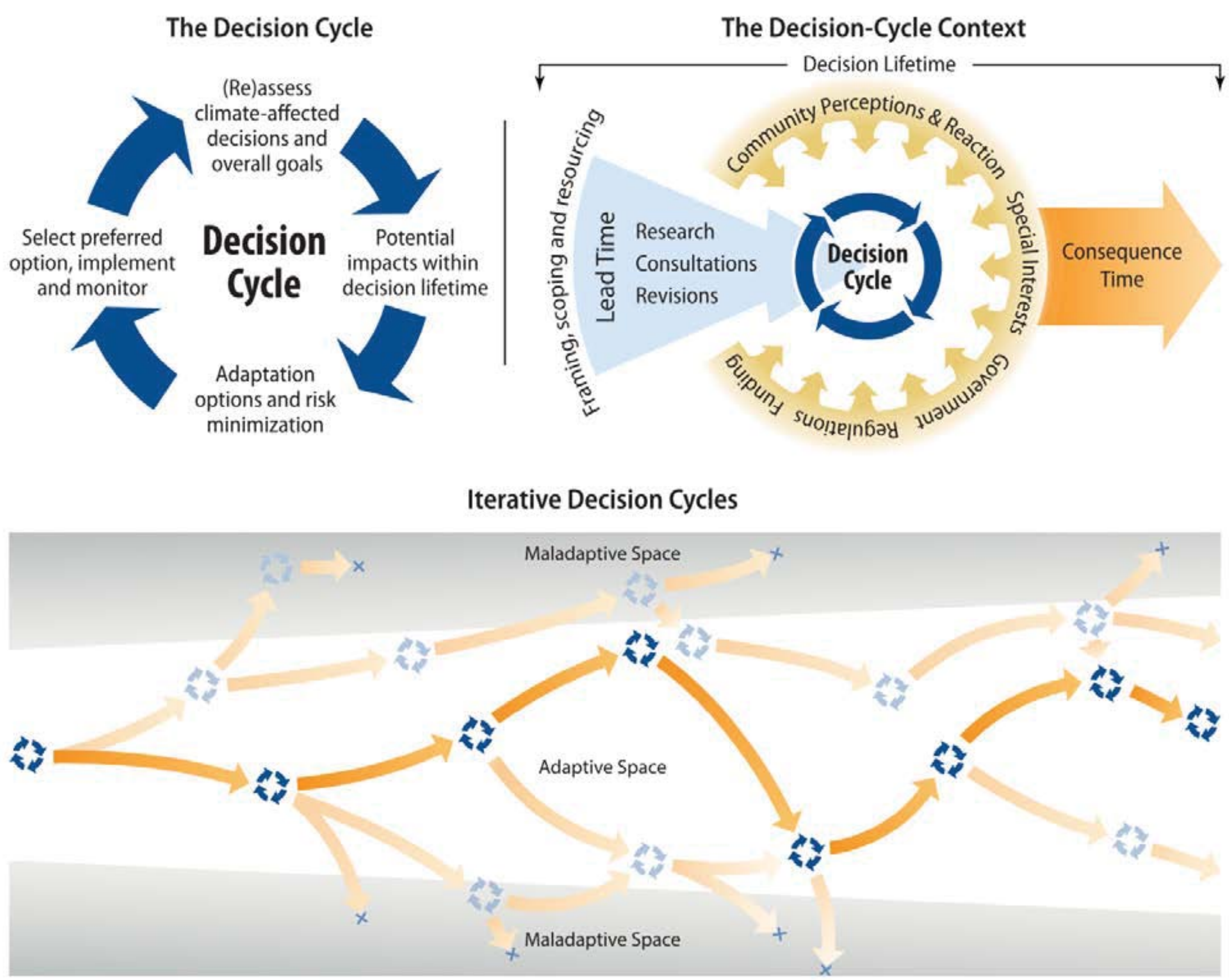


Figure TS.4: Schematic illustration of adaptation as an iterative risk management process. Each individual adaptation decision comprises well known aspects of risk assessment and management (top left panel). Each such decision occurs within and exerts its own sphere of influence, determined by the lead and consequence time of the decision, and the broader regulatory and societal influences on the decision (top right panel). A sequence of adaptation decisions creates an adaptation pathway (bottom panel). There is no single correct adaptation pathway, although some decisions, and sequences of decisions, are more likely to result in long-term maladaptive outcomes than others, but the judgment of outcomes depends strongly on societal values, expectations, and goals. [Figure 25-6]

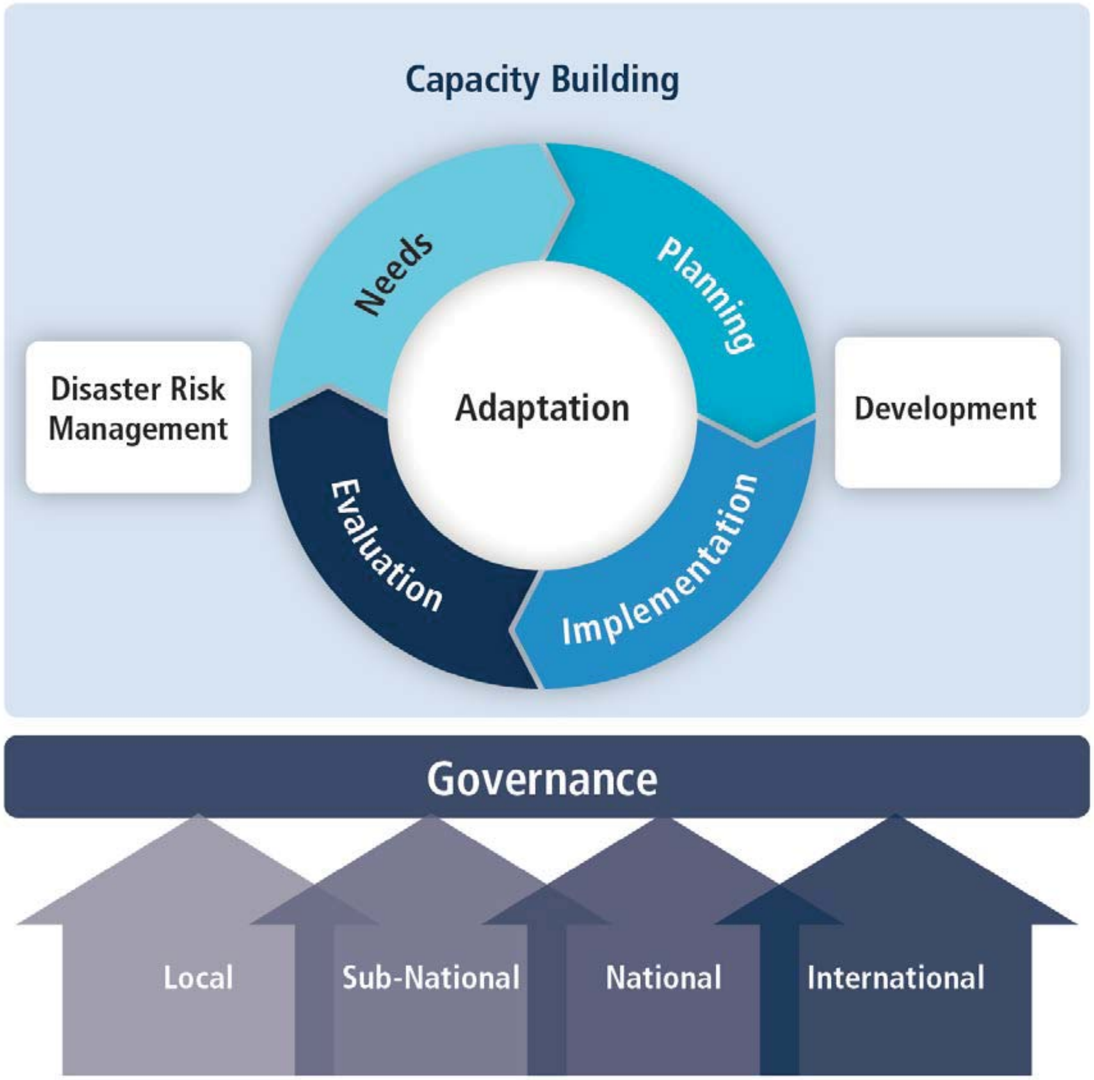


Figure TS.5: Four main phases of adaptation planning and implementation: needs, planning, implementation, and evaluation. This is a cyclic, iterative process. Building capacity to respond to change, whether expected or unexpected, creates resilience in societies to cope in the face of uncertainties in climate change projections. Efforts in adaptation can be linked with development or disaster risk management. Adaptation governance underlies capacity, and governance takes place at multiple scales: international, national, sub-national, and local. [Figure 15-1]

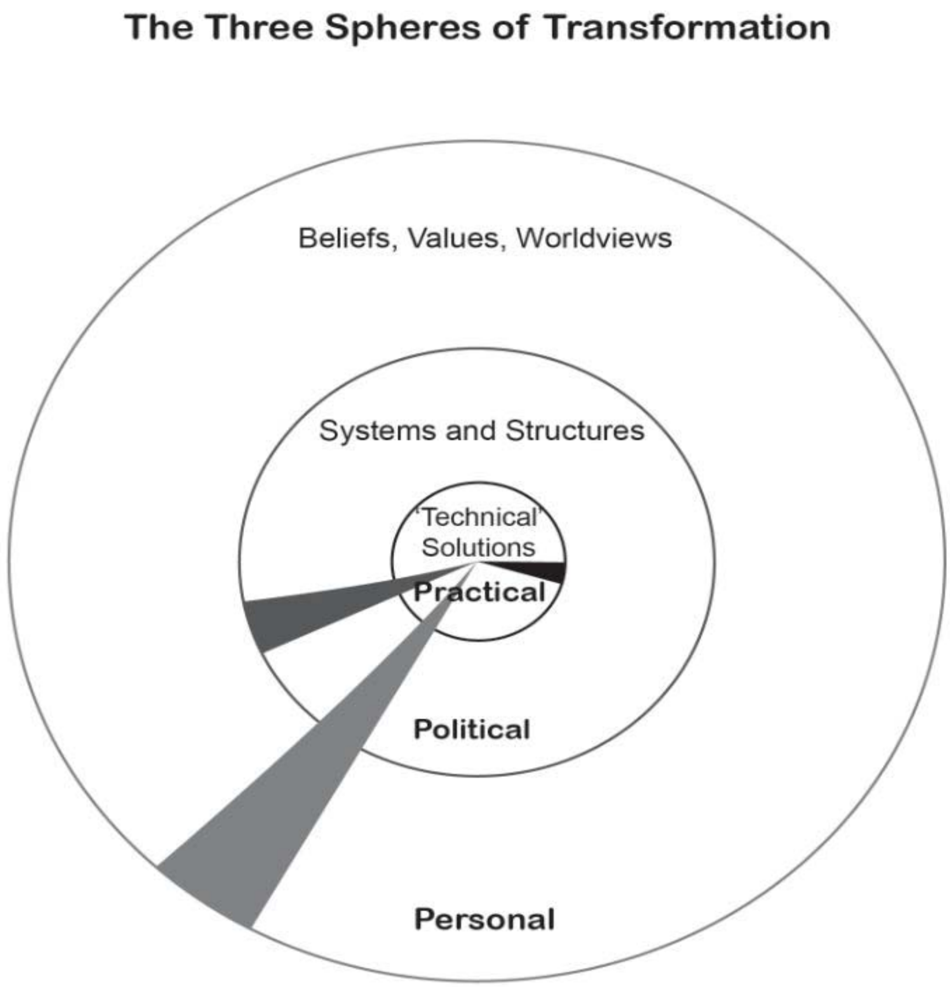
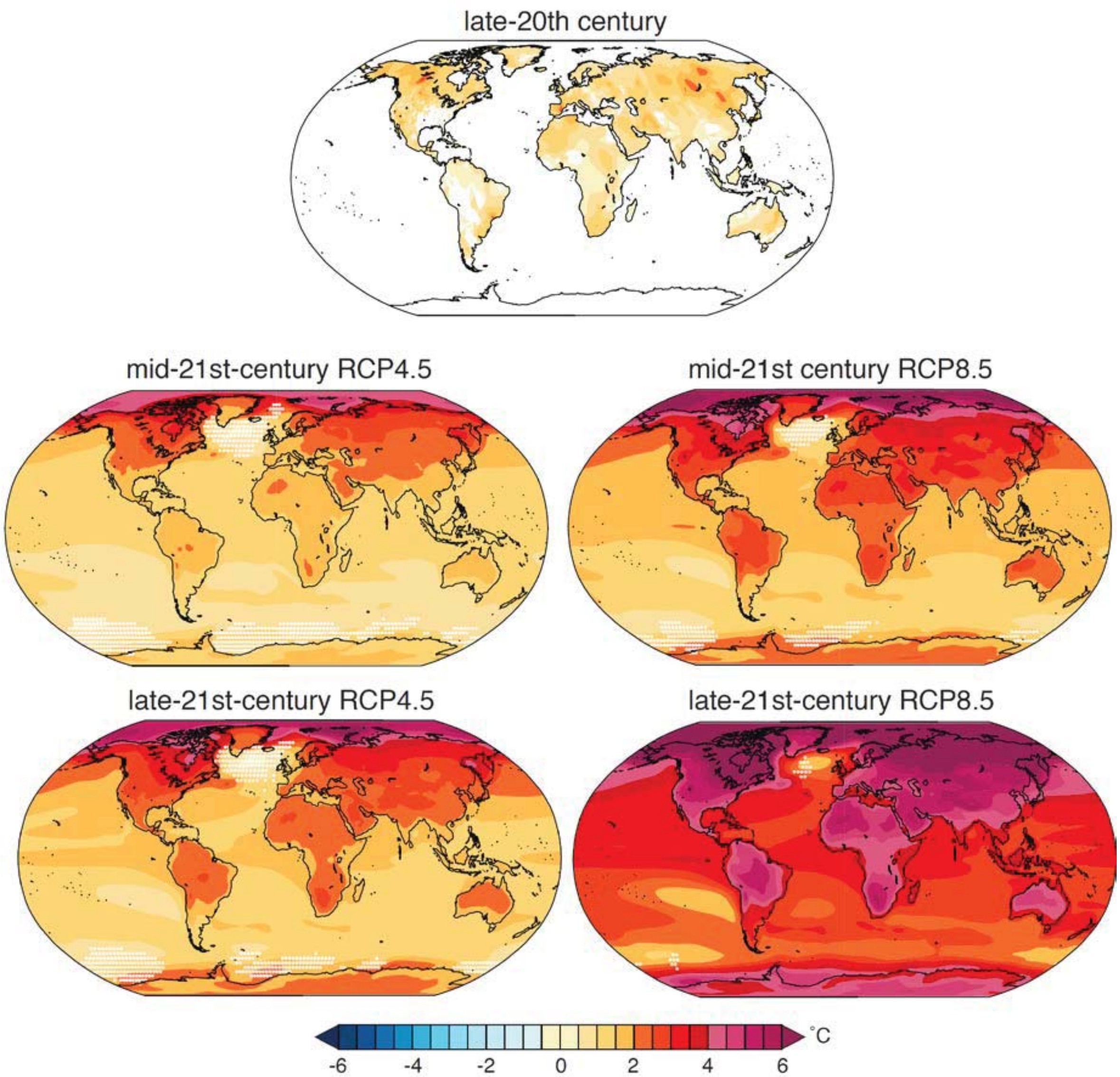


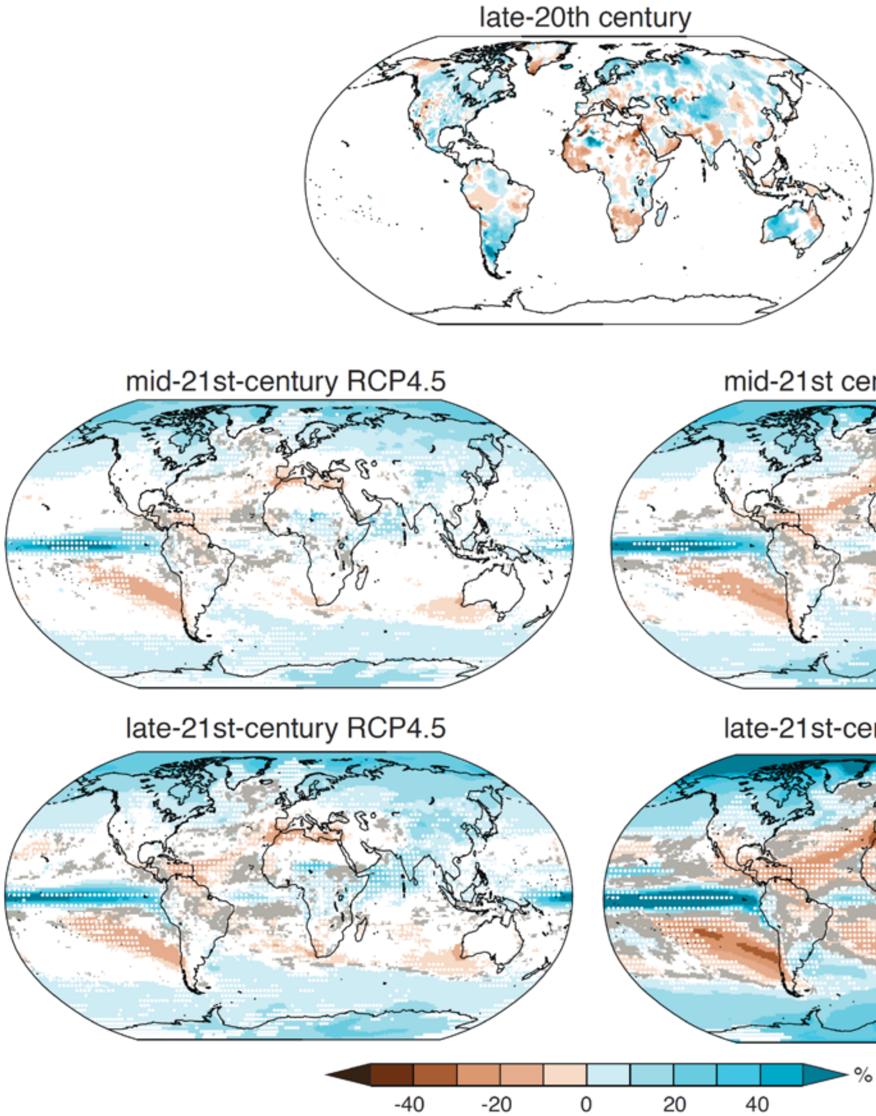
Figure TS.6: The practical, political, and personal spheres of transformation. [20.5.2, Figure 20-2]

A



Box TS.5 Figure 1: Change in annual average temperature (A) and precipitation (B). For observations (top map, A and B; CRU), differences are shown over land between the 1986-2005 and 1906-1925 periods, with white indicating areas where the difference between the 1986-2005 and 1906-1925 periods is less than twice the standard deviation of the 20 20-year periods beginning in the years 1906 through 1925. For projections (bottom four maps, A and B; CMIP5), four classes of results are displayed. (1) White indicates areas where for >66% of models the annual average change is less than twice the baseline standard deviation of the respective model's 20 20-year periods ending in years 1986 through 2005. Thus in these regions, more than 2/3 of models show no significant change, using this measure of significance, in the annual average, although this does not imply no significant change at seasonal or shorter time-scales such as months to days. (2) Gray indicates areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation, but <66% of models agree on the sign of change. In these regions, more than 2/3 of models show a significant change in annual average, but less than 2/3 agree on whether it will increase or decrease. (3) Colors with circles indicate the change averaged over all models where >66% of models exhibit a change greater than twice the respective model baseline standard deviation and >66% of models agree on whether the annual average will increase or decrease. In these regions, more than 2/3 of models show a significant change in annual average and more than 2/3 (but less than 90%) agree on whether it will increase or decrease. (4) Colors without circles indicate areas where >90% of models exhibit a change greater than twice the respective model baseline standard deviation and >90% of models agree on whether the annual average will increase or decrease. For models that have provided multiple realizations for the climate of the recent past and the future, results from each realization were first averaged to create the baseline-period and future-period mean and standard deviation for each model, from which the multi-model mean and the individual model signal-to-noise ratios were calculated. The baseline period is 1986-2005. The late-21st century period is 2081-2100. The mid-21st century period is 2046-2065. See also Annex I of WGI AR5. [Box CC-RC]

B



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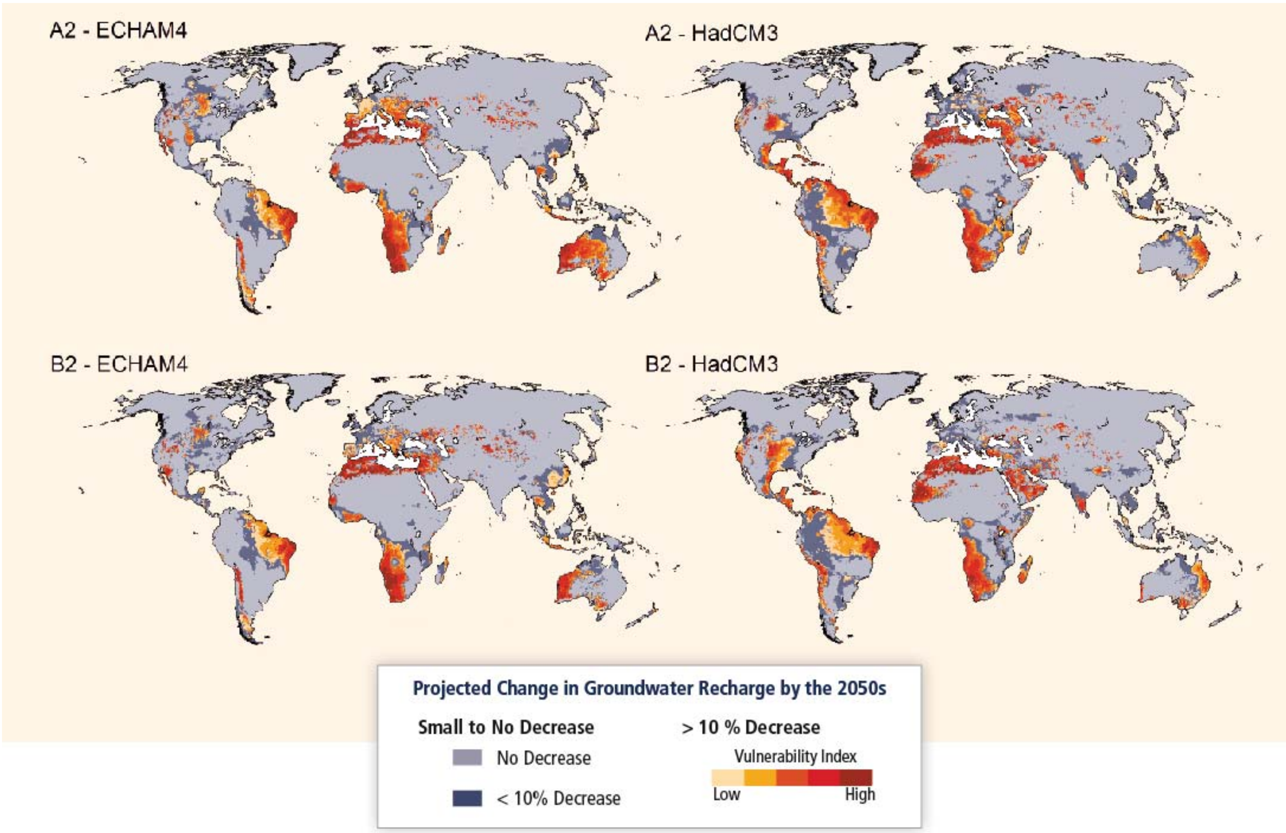


Figure TS.7: Human vulnerability to climate-change-induced decreases of renewable groundwater resources by the 2050s for lower (B2) and higher (A2) emissions pathways and two global climate models. The higher the vulnerability index (percent decrease of groundwater recharge multiplied by a sensitivity index), the higher the vulnerability. The index is computed for areas where groundwater recharge is projected to decrease by at least 10%, as compared to the reference period 1961-90. [Figure 3-9]

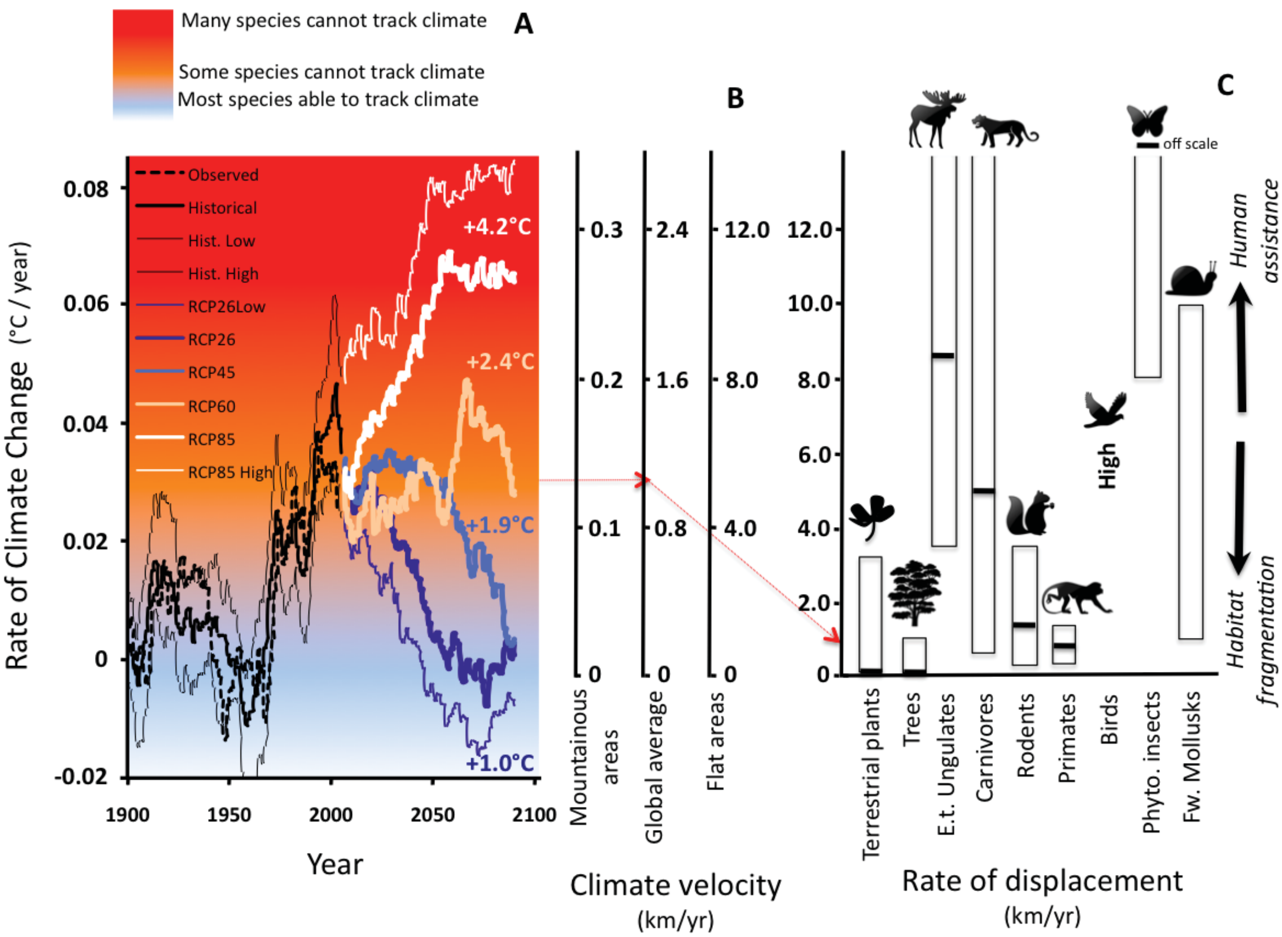


Figure TS.8: Rate of climate change (A), corresponding climate velocities (B), and rates of displacement of several terrestrial and freshwater species groups in the absence of human intervention (C). The thin dotted red arrows give an example of interpretation. Rates of climate change of 0.03 °C/yr correspond to ca. 1.1 km/yr global average climate velocity. When compared to rates of displacement, this would exceed rates for most plants, many primates, and some rodents. (A) Observed rates of climate change for global land areas are derived from CRUTEM4 climate data reanalysis; all other rates are calculated based on the average of the CMIP5 climate model ensembles for the historical period and for the future based on the four RCP emissions scenarios. The lower bound (17% of model projections are outside this bound) is given for the lowest emissions scenario and the upper bound for the highest emissions scenario. Data were smoothed using a 20-year sliding window, and rates are based on means of between 17 and 30 models using one member per model. Global average temperatures at the end of the 21st century are given for each RCP scenario. Colors in the background synthesize the ability of species to track climate through displacement. (B) Estimates of climate velocity were semi-quantitatively synthesized from seven studies using a diversity of analytical approaches and spatial resolutions. The three axes represent estimated climate velocities for mountainous areas (left), for global land area (center), and for regions that are flat or have high rates of climate change (right). (C) Rates of displacement for terrestrial plants, trees, mammals, birds, phytophagous insects, and freshwater mollusks. Each box represents ~95% of the estimates, and the bar is a qualitative estimate of the median. [Figure 4-6]

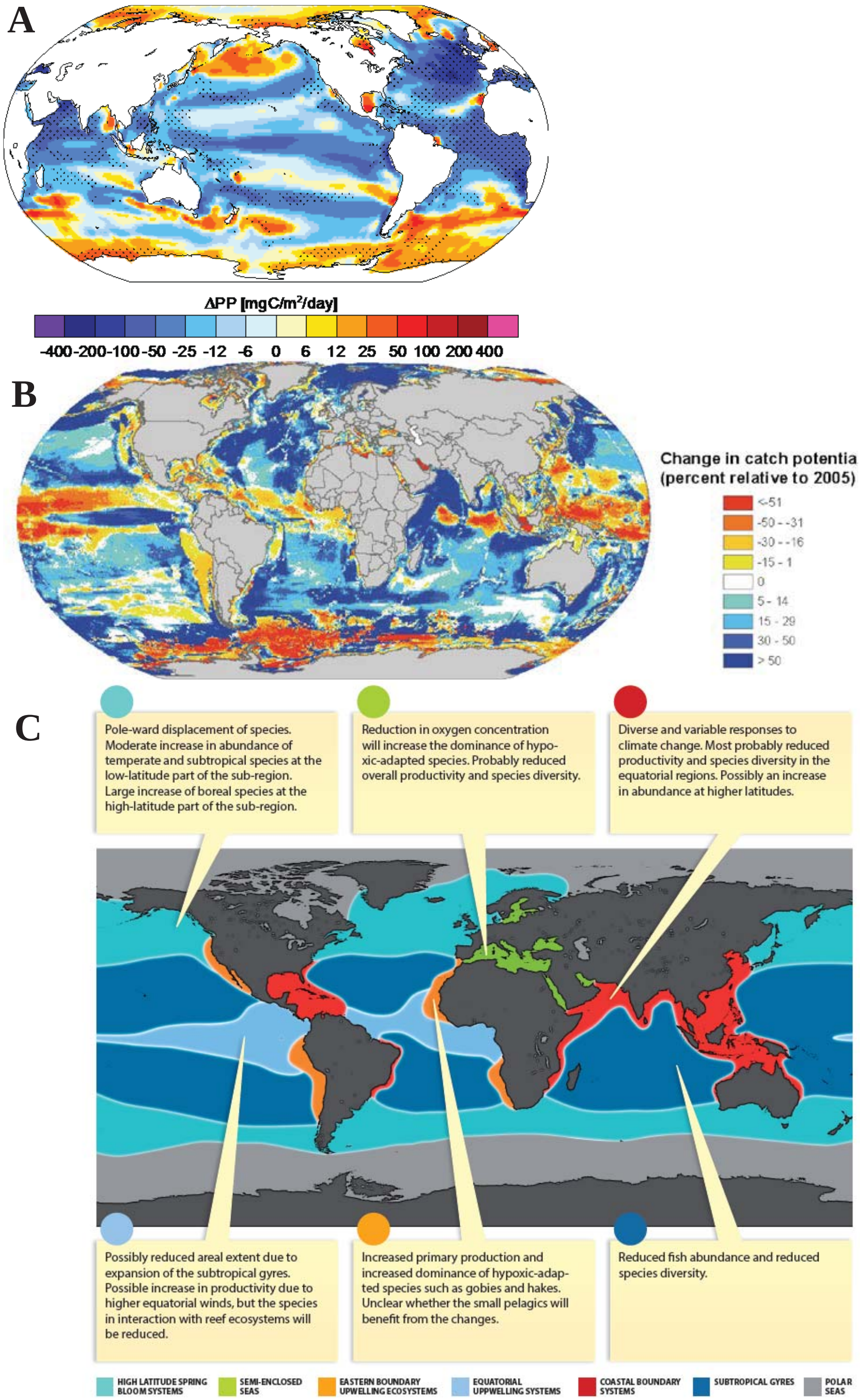


Figure TS.9: A) Multi-model mean changes of projected vertically-integrated net primary production (small and large phytoplankton). To indicate consistency in the sign of change, regions are stippled where all models (four in total) agree on the sign of change. Changes are annual means under the SRES A2 scenario (between RCP 6.0 and 8.5) for the period 2080 to 2099 relative to 1870 to 1889. B) A projection of maximum fisheries catch potential of 1000 species of exploited fishes and invertebrates from 2000 to 2050 under the SRES A1B scenario. C) Example of changes occurring within fisheries across the ocean. [Figures 6-14, 6-15, and 30-15]

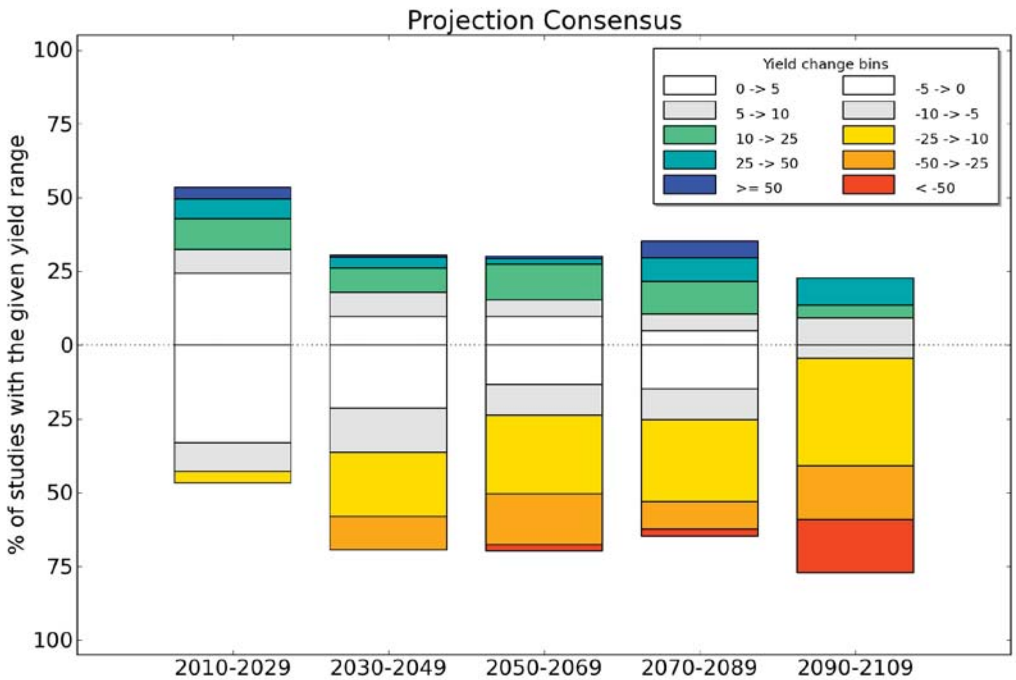


Figure TS.10: Projected changes in crop yield as a function of time. The y-axis indicates degree of consensus and the colors denote percentage change in crop yield. Data are plotted according to the 20-year period in which the center point of the projection period falls. [Figure 7-6]

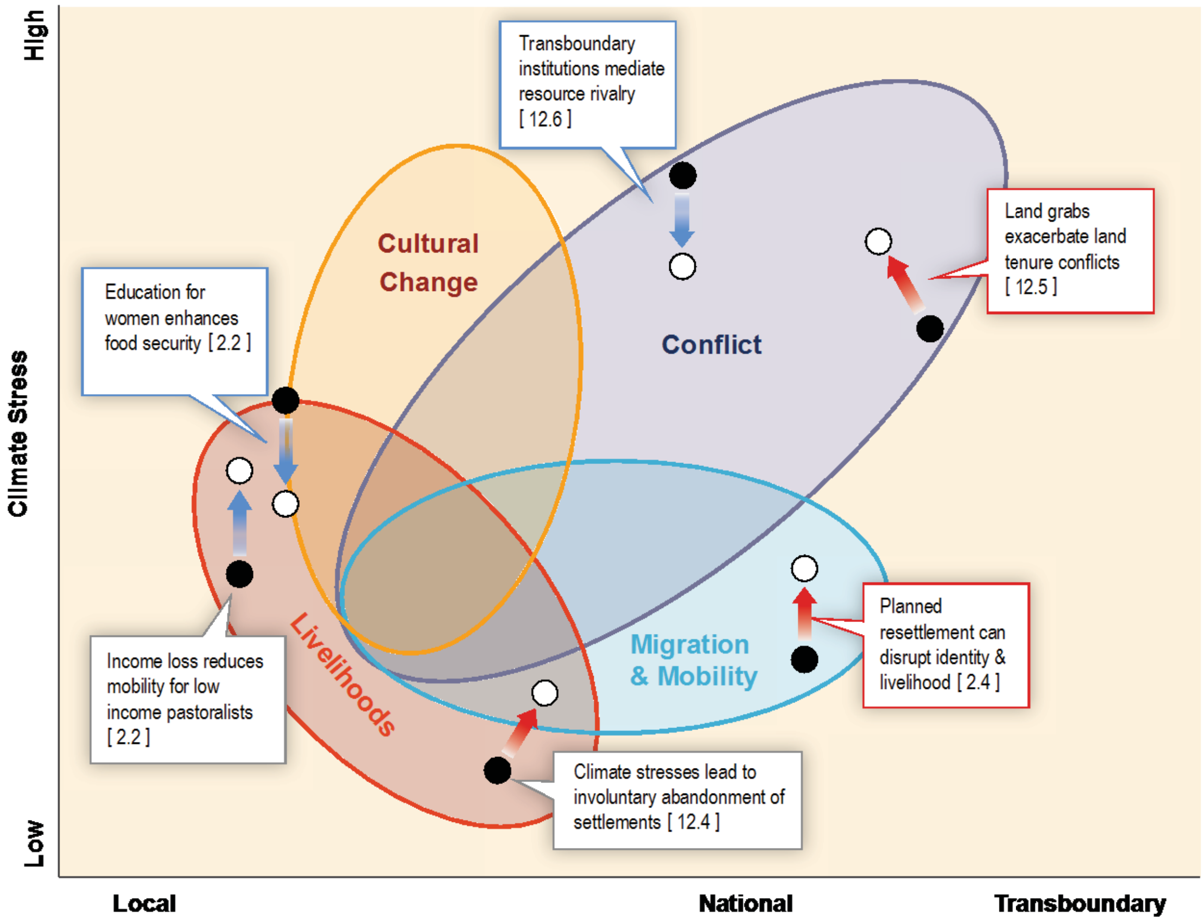


Figure TS.11: Synthesis of evidence on the impacts of climate change on elements of human security and the interactions between elements. Examples of positive and negative changes in security associated with interventions indicated by arrows. [Figure 12-3]

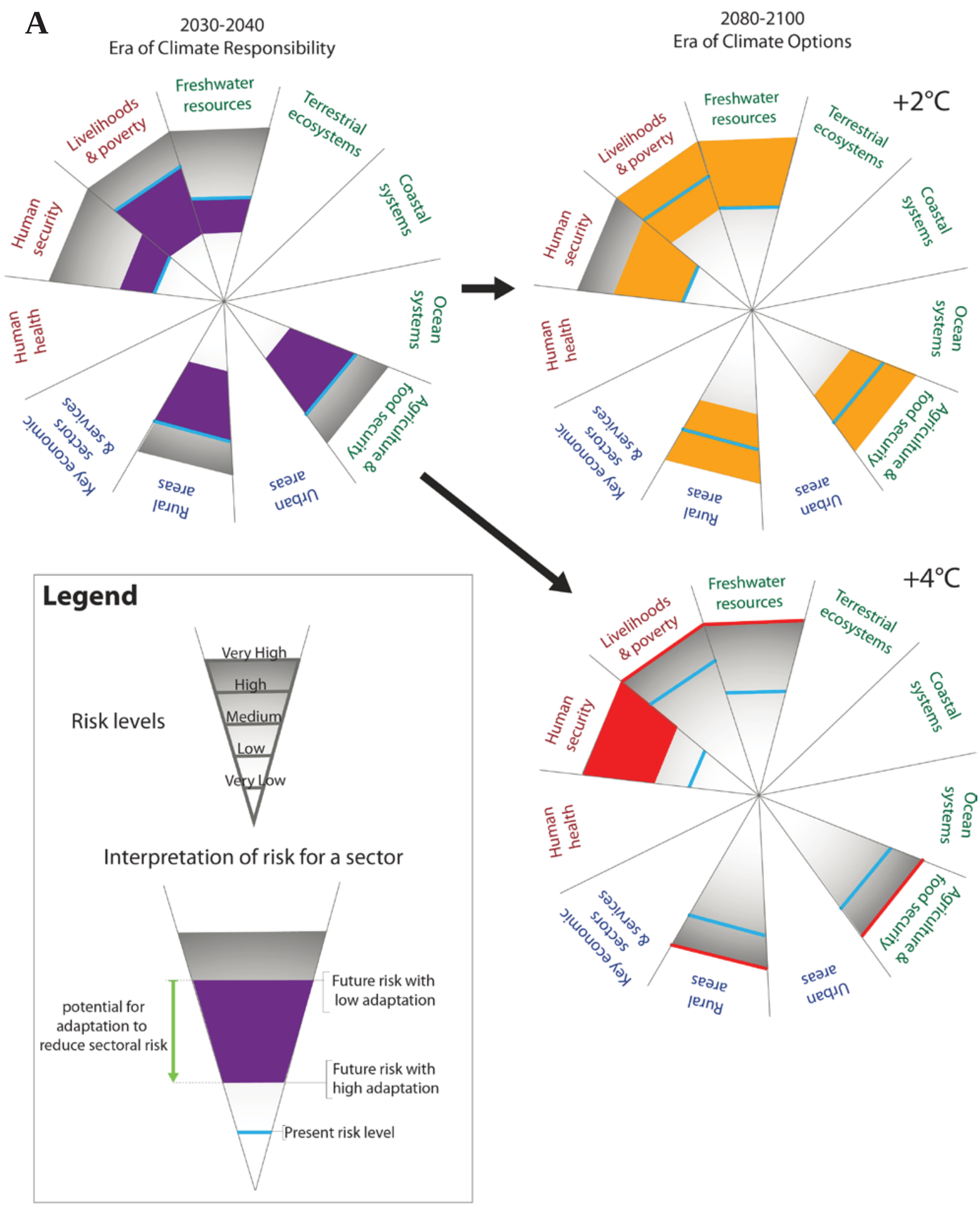


Figure TS.12: Estimated risk from climate change to selected sectors and systems in Africa (A), Europe (B), and North America (C), for different time frames (2030-2040 and 2080-2100), under two levels of global average warming above preindustrial (2°C and 4°C) and different assumptions about adaptation to manage these risks. Levels of risk and of adaptation are differentiated by colored shading, ranging from high adaptation to low adaptation. Estimated risks rely on expert judgments. The risk categories reflect the overall structure of Part A of the WGII AR5. [Figures 22-7 and 26-6]

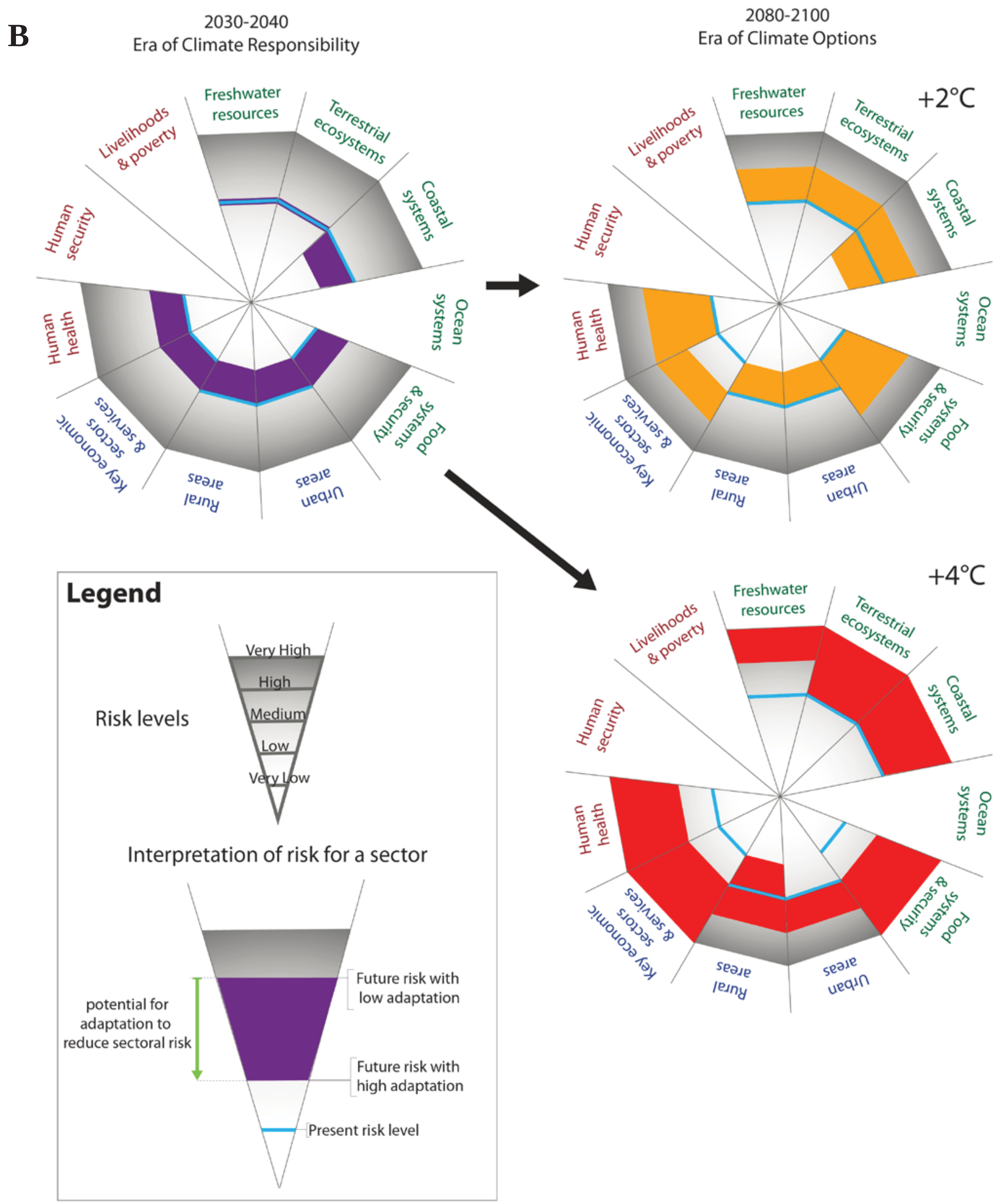


Figure TS.12: Estimated risk from climate change to selected sectors and systems in Africa (A), Europe (B), and North America (C), for different time frames (2030-2040 and 2080-2100), under two levels of global average warming above preindustrial (2°C and 4°C) and different assumptions about adaptation to manage these risks. Levels of risk and of adaptation are differentiated by colored shading, ranging from high adaptation to low adaptation. Estimated risks rely on expert judgments. The risk categories reflect the overall structure of Part A of the WGII AR5. [Figures 22-7 and 26-6]

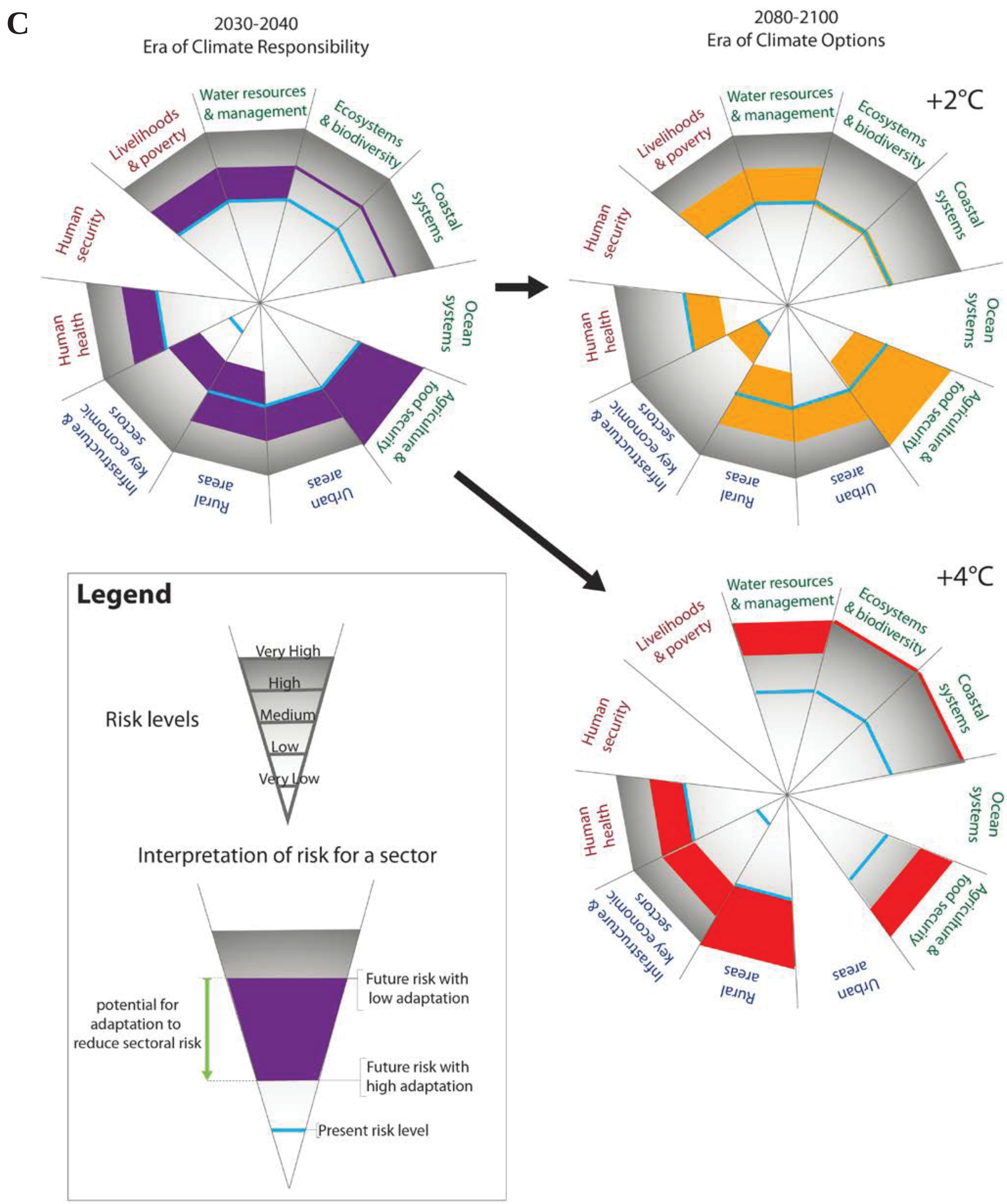


Figure TS.12: Estimated risk from climate change to selected sectors and systems in Africa (A), Europe (B), and North America (C), for different time frames (2030-2040 and 2080-2100), under two levels of global average warming above preindustrial (2°C and 4°C) and different assumptions about adaptation to manage these risks. Levels of risk and of adaptation are differentiated by colored shading, ranging from high adaptation to low adaptation. Estimated risks rely on expert judgments. The risk categories reflect the overall structure of Part A of the WGII AR5. [Figures 22-7 and 26-6]

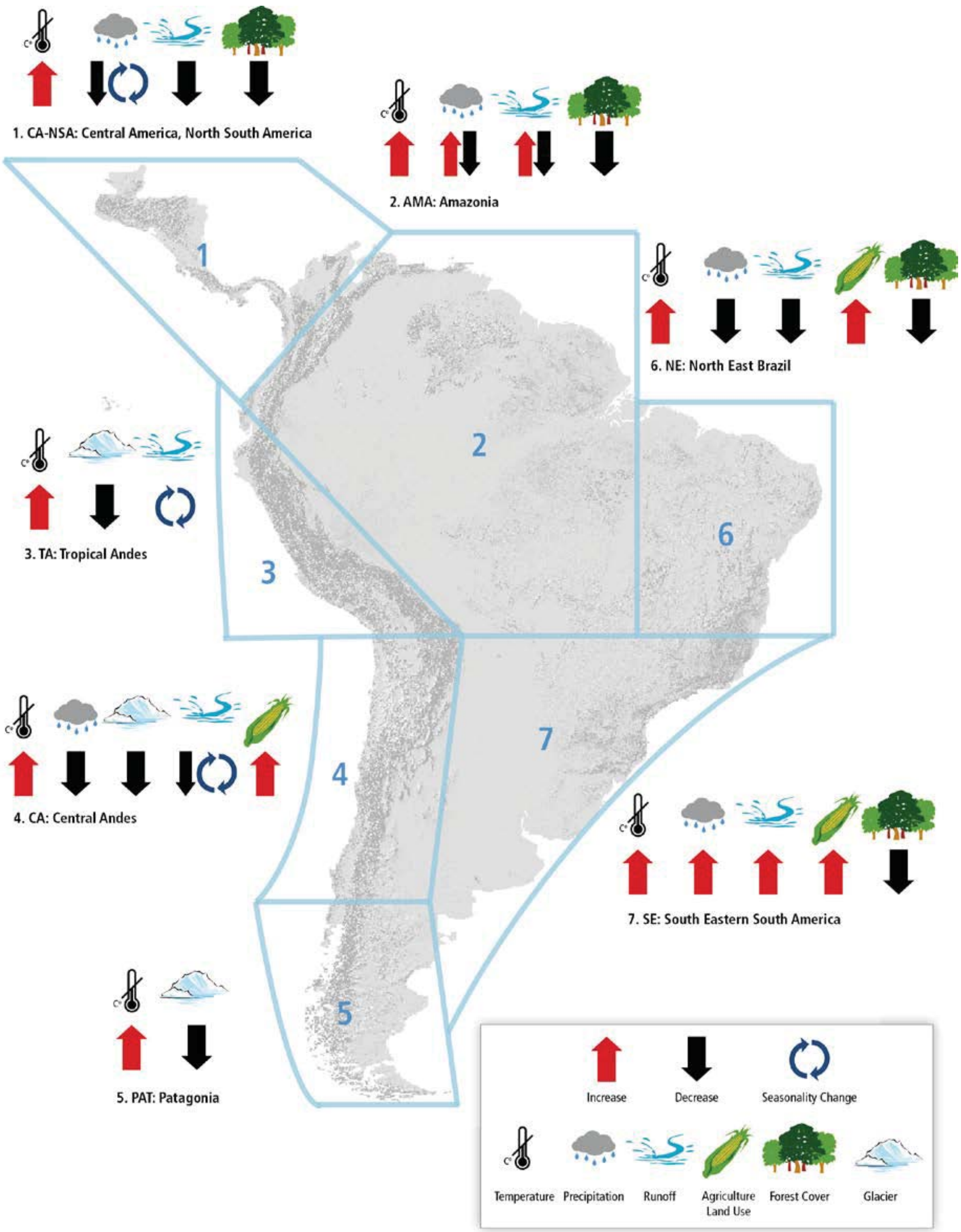


Figure TS.13: Summary of observed changes in climate and other environmental factors in representative regions of Central and South America. The boundaries of the regions in the map are conceptual (not precise geographic nor political) and follow those developed in SREX Figure 3-1. [Figure 27-7]

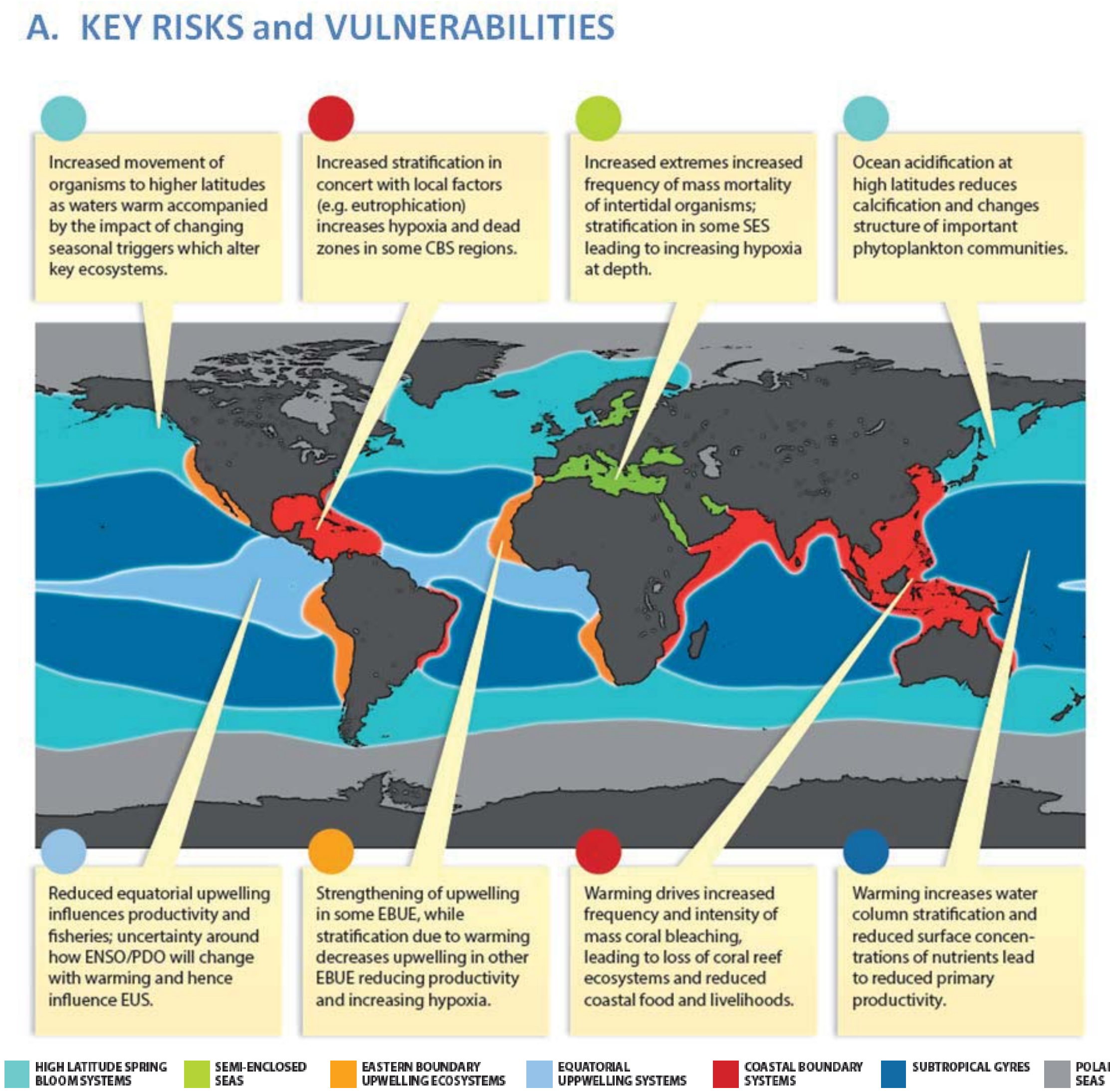


Figure TS.14: Summary of key risks and vulnerabilities associated with climate change on the world's ocean regions. [Figure 30-15]

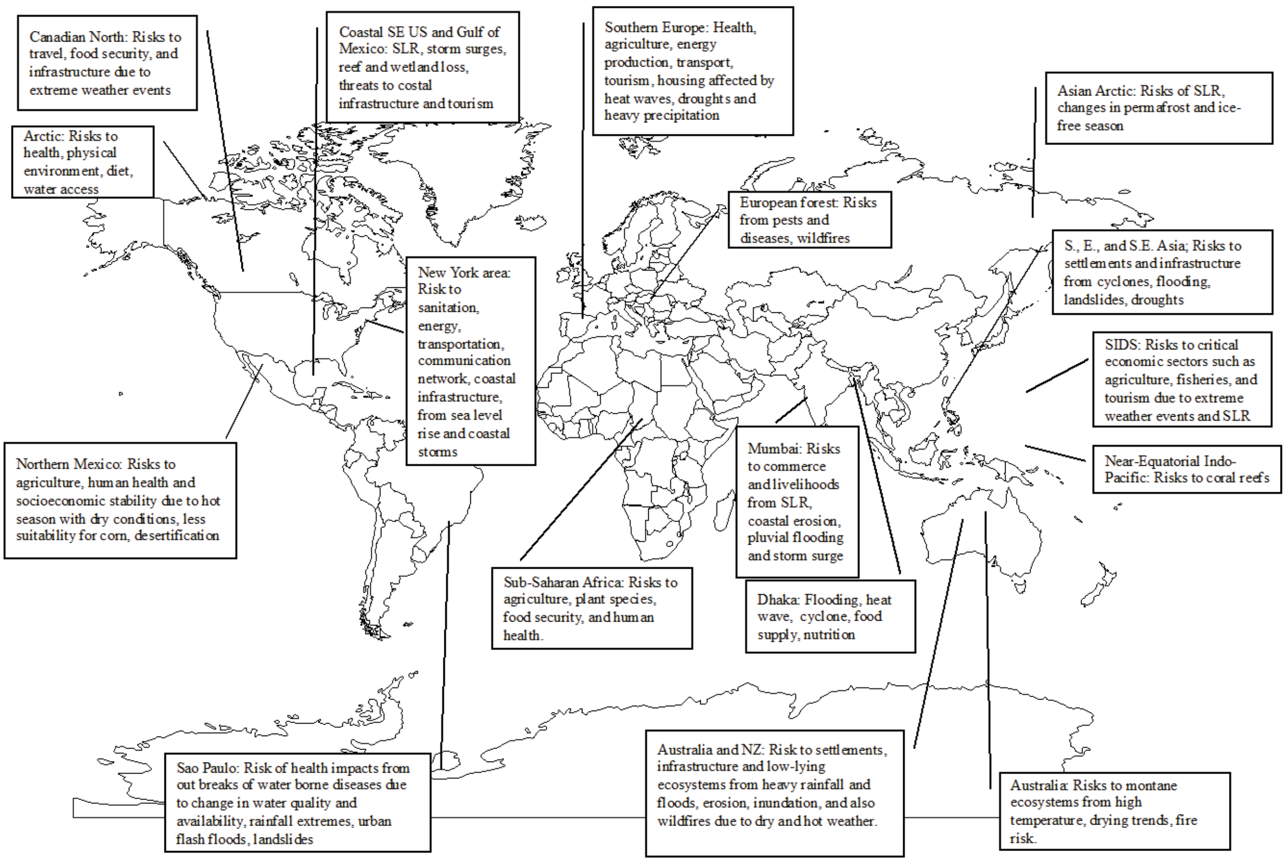
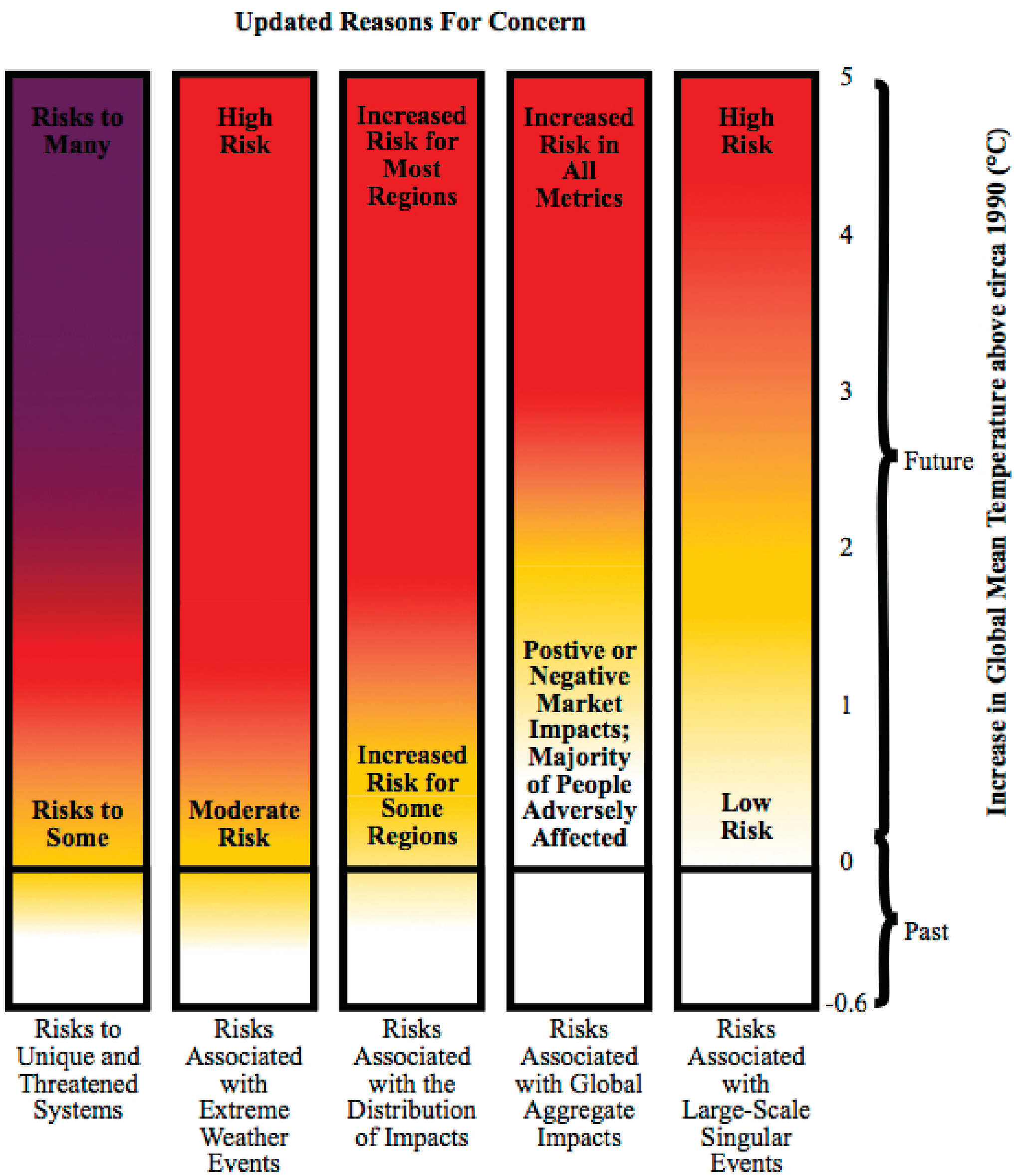
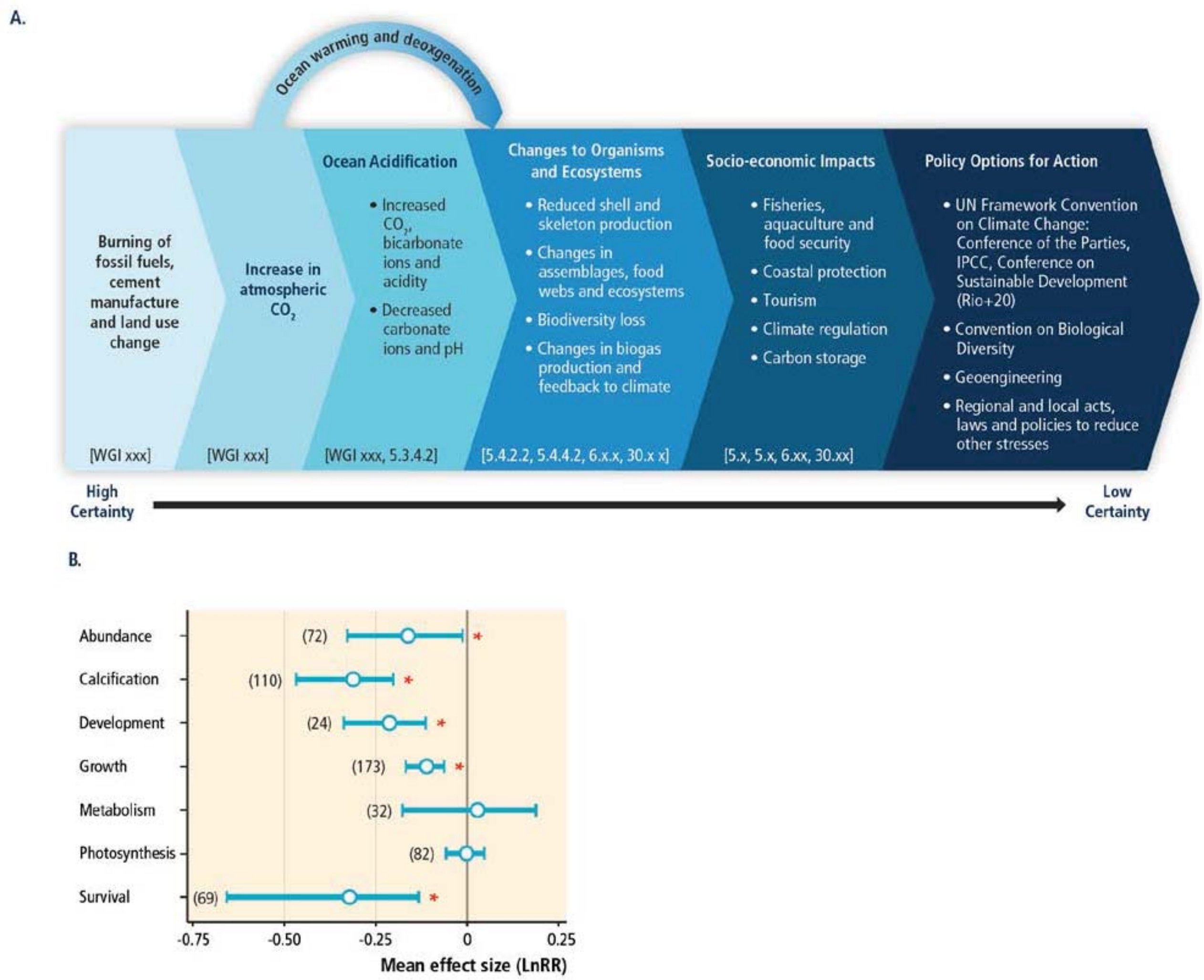


Figure TS.15: Some salient examples of multi-impacts hotspots identified in this assessment. [Figure 19-2]



Box TS.7 Figure 1: The dependence of risk associated with reasons for concern (RFCs) on the level of climate change, updated based on expert judgment in this assessment. The color scheme indicates the additional risk due to climate change (with white to purple indicating the lowest to highest level of risk, respectively). Purple color, introduced here for the first time, reflects the assessment that unique human and natural systems tend to have very limited adaptive capacity. [Figure 19-5]



Box TS.9 Figure 1: A) Overview of the chemical, biological, and socio-economic impacts of ocean acidification and of policy options. B) Effect of near future acidification on major response variables estimated using weighted random effects meta-analyses, with the exception of survival, which is not weighted. The effect size indicates which process is most uniformly affected by ocean acidification but large variability exists between species. Significance is determined when the 95% bootstrapped confidence interval does not cross zero. The number of experiments used in the analyses is shown in parentheses. * denotes a significant effect. [Box CC-OA]

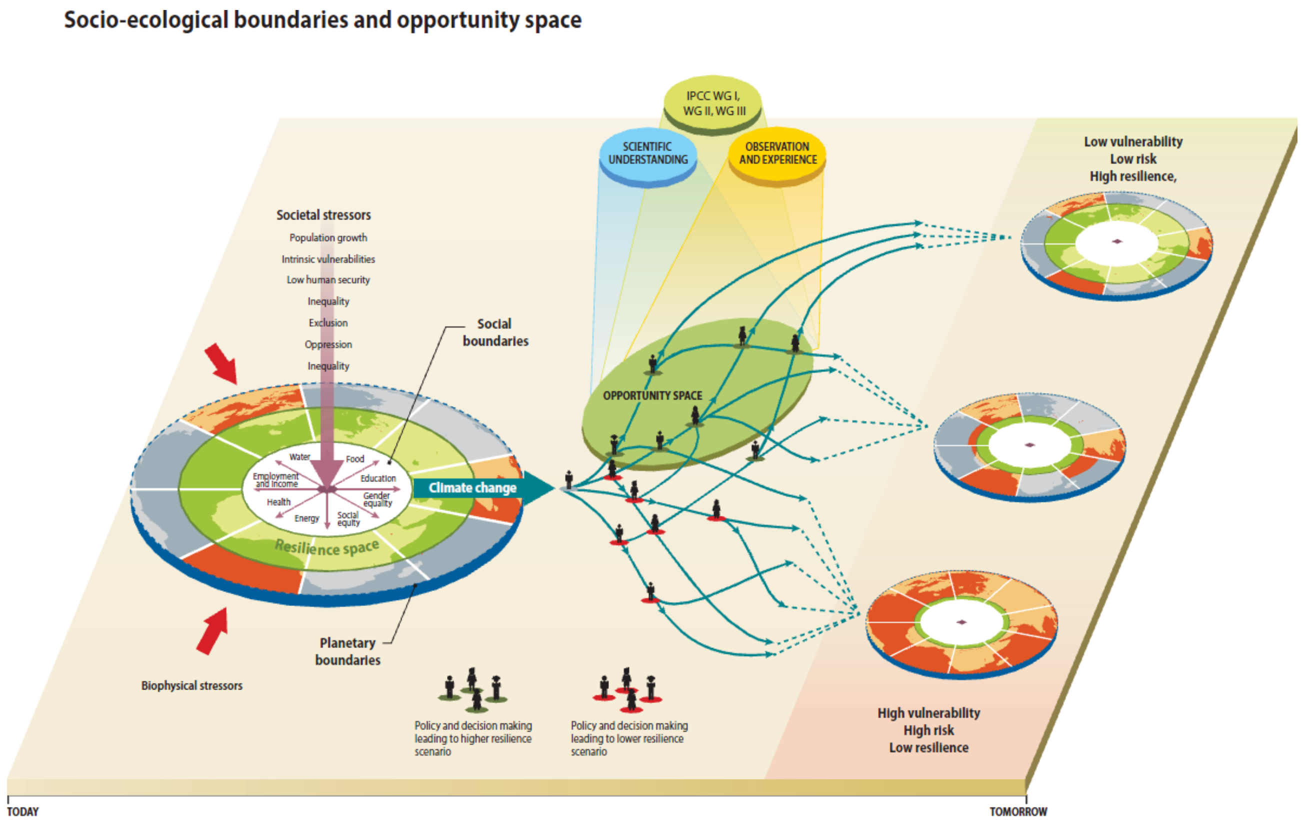
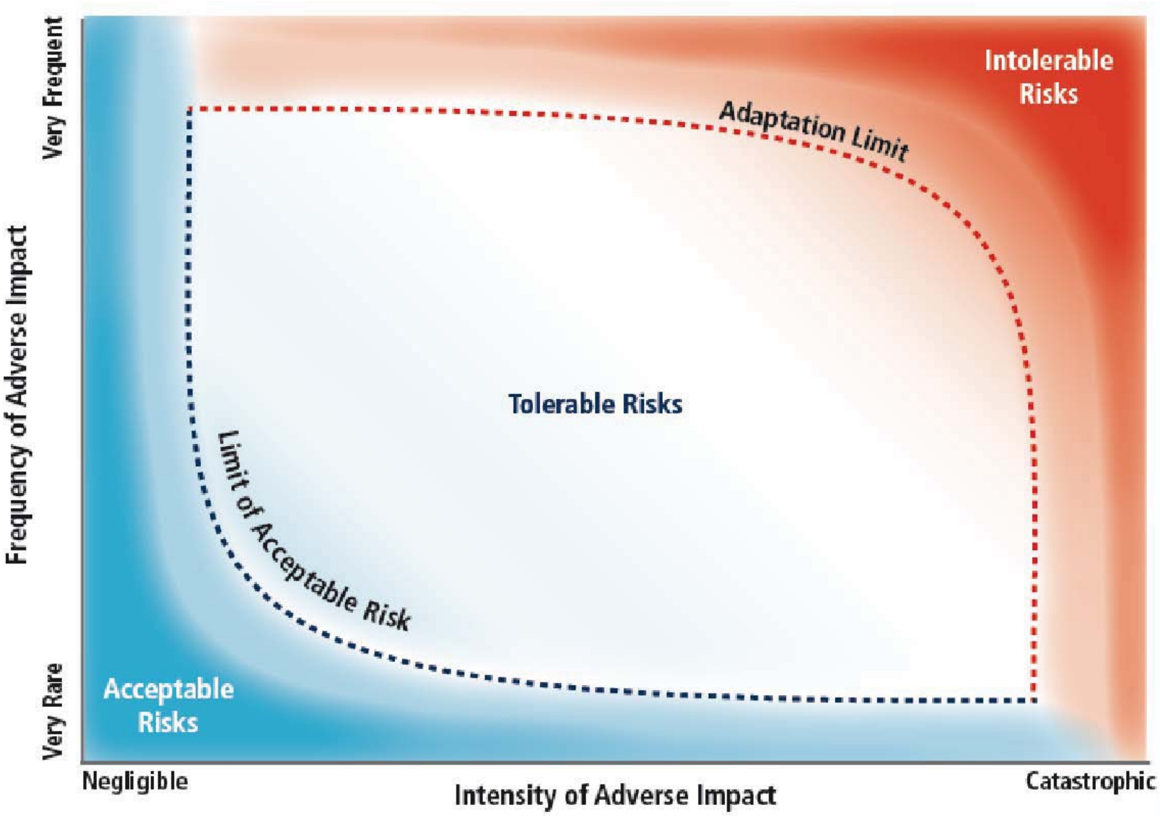


Figure TS.16: Conceptual framework for assessing interactions between biophysical and societal stressors that impact the resilience of natural and human systems today and in the future. Actions, including climate change adaptation and mitigation, taken in the opportunity space lead to a diverse range of pathways and outcomes—toward a future of high risk, high vulnerability, and low resilience space or toward a future of low risk, low vulnerability, and high resilience space. [Figure 1-7]



Box TS.10 Figure 1: Conceptual model of the determinants of acceptable, tolerable, and intolerable risks and their implications for limits to adaptation. [16.2, Figure 16-1]

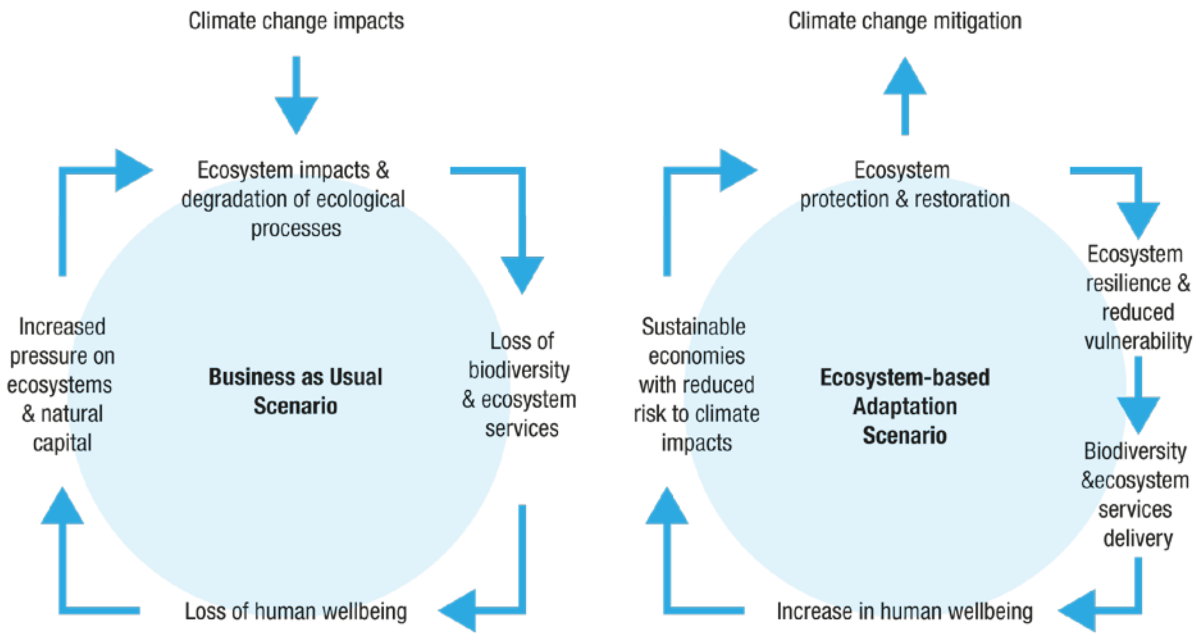


Figure EA-1: Adapted from Munang *et al.* (2013). Ecosystem based adaptation approaches to adaptation can utilize the capacity of nature to buffer human systems from the adverse impacts of climate change through sustainable delivery of ecosystems services. A) Business as Usual Scenario in which climate impacts degrade ecosystems, ecosystem service delivery and human well-being B) Ecosystem-based Adaptation Scenario which utilizes natural capital and ecosystem services to reduce climate-related risks to human communities.

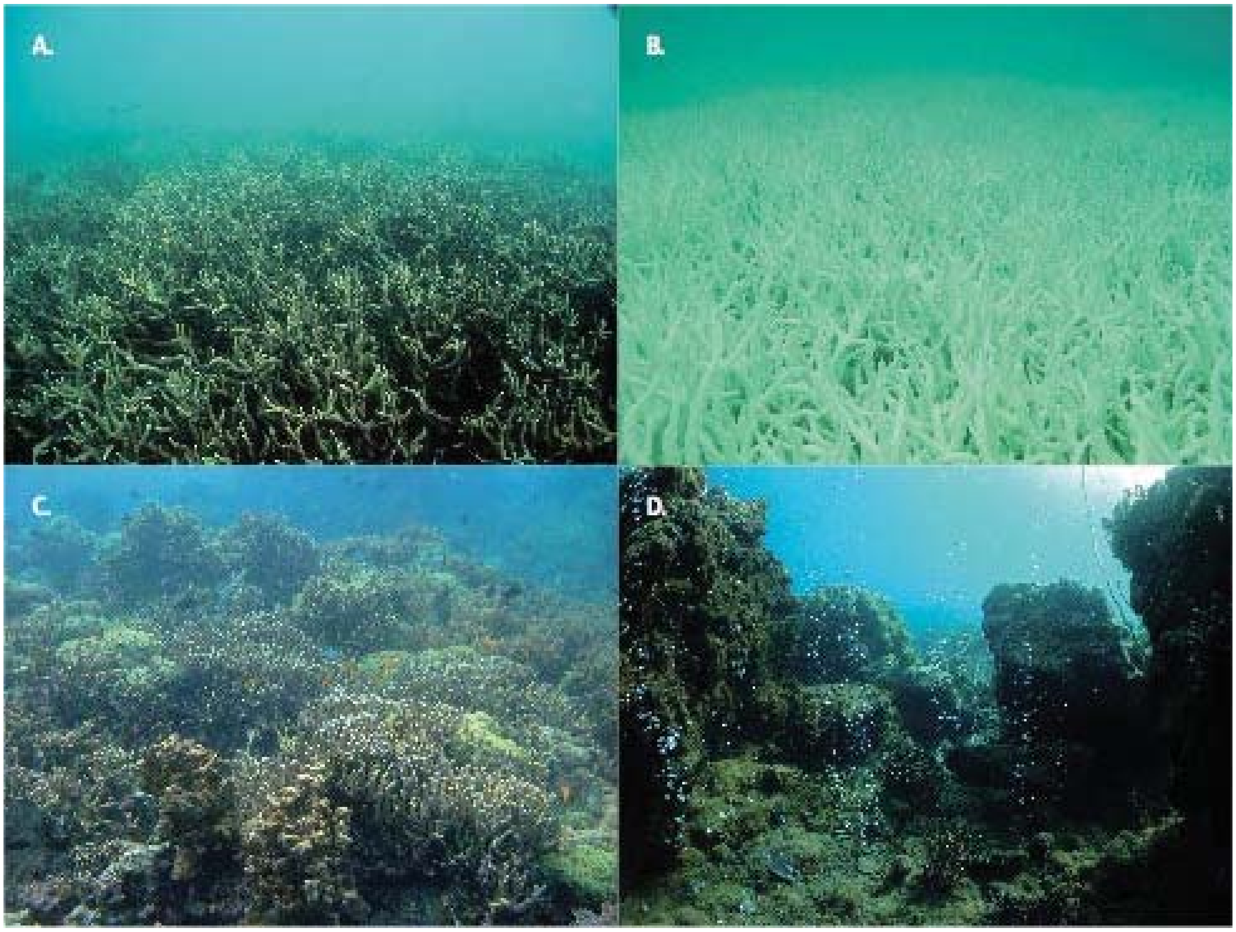


Figure CR-1: A and B: the same coral community before and after a bleaching event in February 2002 at 5 m depth, Halfway Island, Great Barrier Reef. Coral cover at the time of bleaching was 95% bleached almost all of it severely bleached, resulting in mortality of 20.9% (Elvidge et al., 2004). Mortality was comparatively low due in part because these communities were able shuffle symbiont types to more thermo-tolerant types (Berkelmans and van Oppen, 2006; Jones et al., 2008). C and D: three CO2 seeps in Milne Bay Province, Papua New Guinea show that prolonged exposure to high CO2 is related to fundamental changes in coral reef structures (Fabricius et al., 2011). Coral communities at three high CO2 (Fig. XB; median pHT 7.7, 7.7 and 8.0), compared with three control sites (Fig. XA; median pHT 8.02), are characterized by significantly reduced coral diversity (-39%), severely reduced structural complexity (-67%), low densities of young corals (-66%) and few crustose coralline algae (-85%). Reef development ceases at pHT values below 7.7. Photo credit: R. Berkelmans (A and B) and K. Fabricius (C and D).

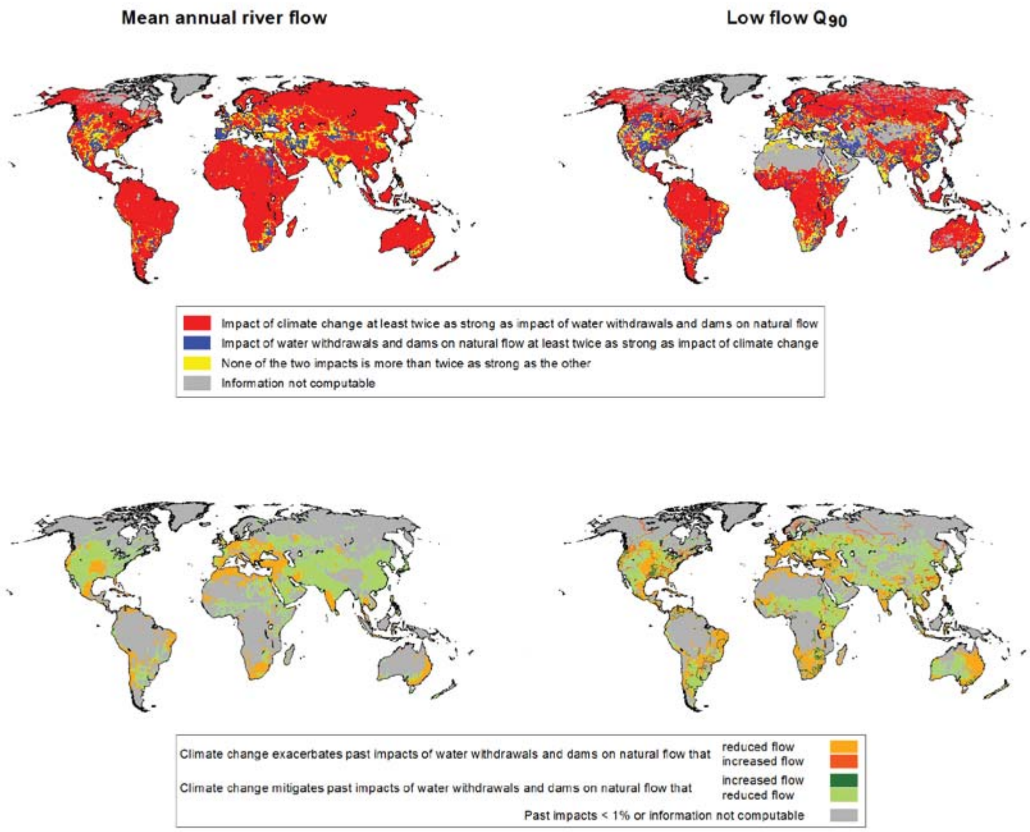


Figure RF-1: Impact of climate change on the ecologically relevant river flow characteristics mean annual river flow and monthly low flow Q_{90} as compared to the impact of water withdrawals and dams on natural flows, as computed by a global water model (Döll and Zhang, 2010). Impact of climate change is the percent change of flow between 1961-1990 and 2041-2070 according to the emissions scenario A2 as implemented by the global climate model HadCM3. Impact of water withdrawals and reservoirs is computed by running the model with and without water withdrawals and dams that existed in 2002.

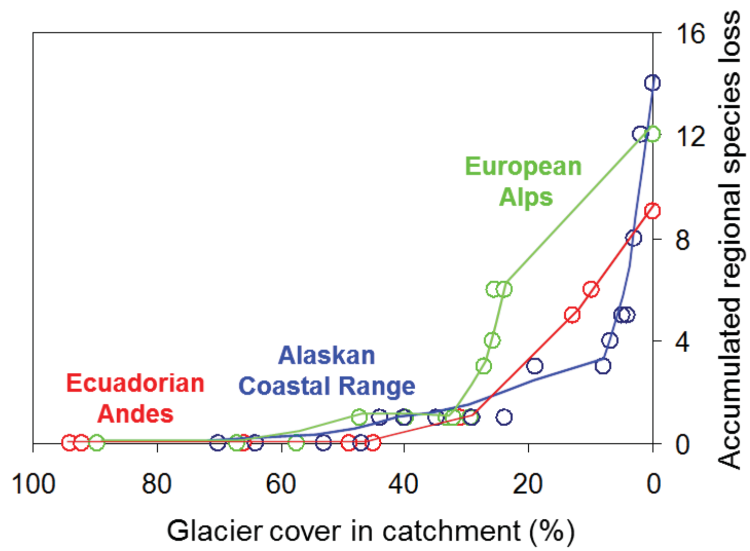


Figure RF-2: Accumulated loss of regional species richness (gamma diversity) as a function of glacial cover GCC. Obligate glacial river macroinvertebrates begin to disappear from assemblages when glacial cover in the catchment drops below approximately 50%. Each data point represents a river site and lines are Lowess fits. Adapted by permission from Macmillan Publishers Ltd: *Nature Climate Change*, Jacobsen *et al.*, 2012, © 2012.

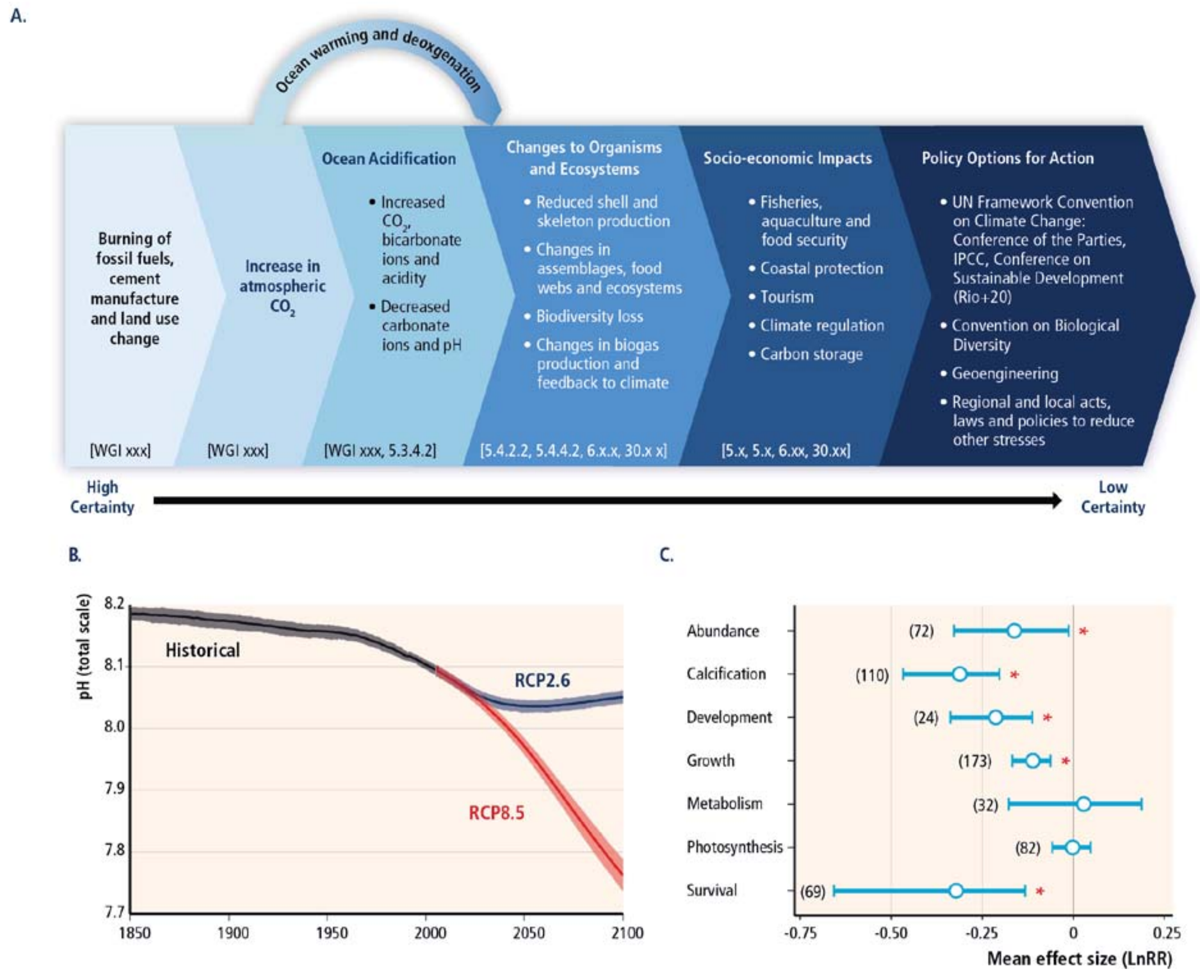


Figure OA-1: A: Overview of the chemical, biological, socio-economic impacts of ocean acidification and of policy options (adapted from Turley & Gattuso, 2012). B: Multi-model simulated time series of global mean ocean surface pH (on the total scale) from CMIP5 climate model simulations from 1850 to 2100. Projections are shown for emission scenarios RCP2.6 (blue) and RCP8.5 (red) for the multi-model mean (solid lines) and range across the distribution of individual model simulations (shading). Black (grey shading) is the modelled historical evolution using historical reconstructed forcings. The models that are included are those from CMIP5 that simulate the global carbon cycle while being driven by prescribed atmospheric CO_2 concentrations. The number of CMIP5 models to calculate the multi-model mean is indicated for each time period/scenario (IPCC AR5 WG1 report, Figure 6.28). C: Effect of near future acidification on major response variables estimated using weighted random effects meta-analyses, with the exception of survival which is not weighted (Kroeker et al., in press). The effect size indicates which process is most uniformly affected by ocean acidification but large variability exists between species. Significance is determined when the 95% bootstrapped confidence interval does not cross zero. The number of experiments used in the analyses is shown in parentheses. * denotes a significant effect.

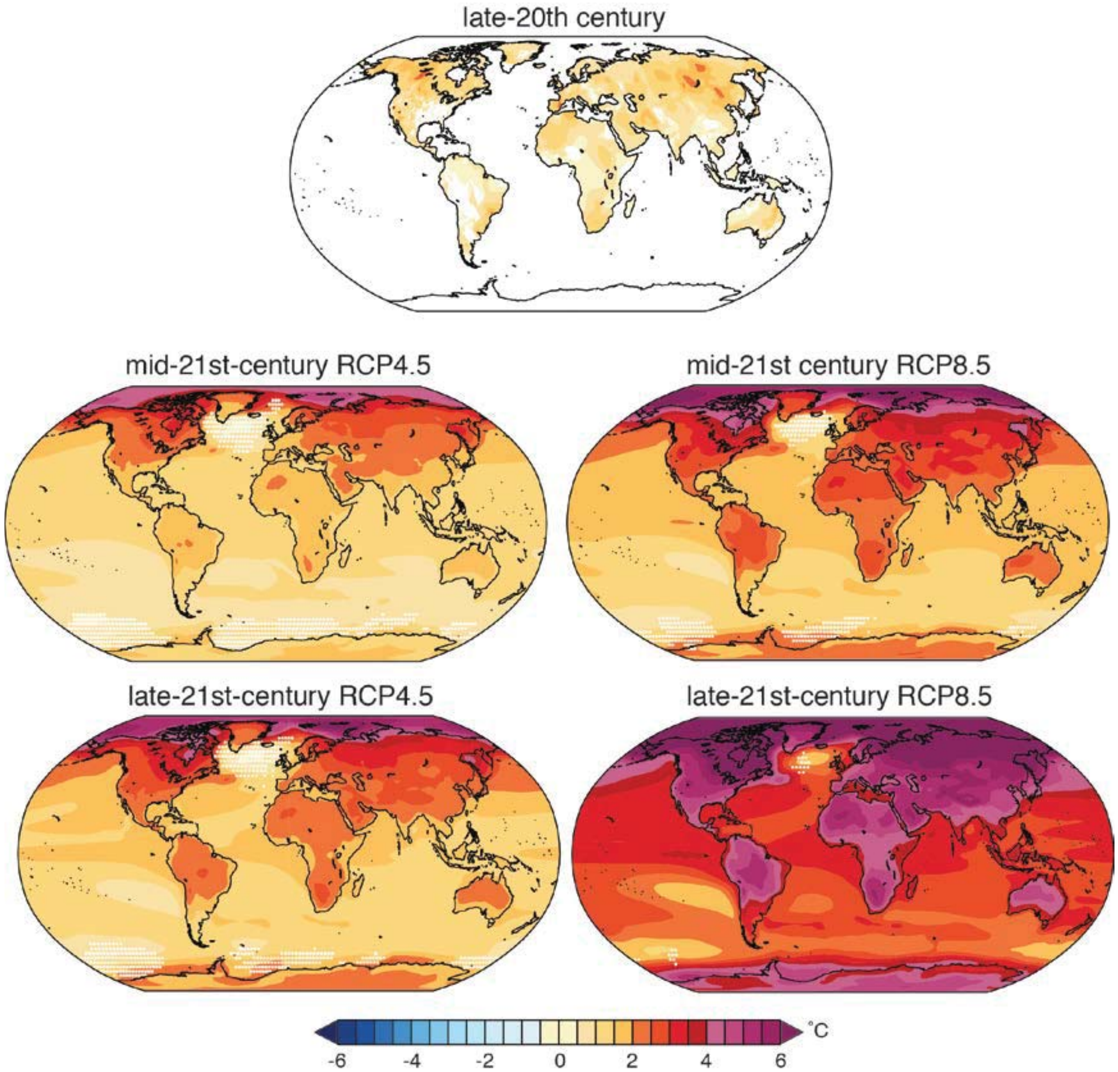


Figure RC-1: Change in annual temperature. For the CRU observations, differences are shown between the 1986-2005 and 1906-1925 periods, with white indicating areas where the difference between the 1986-2005 and 1906-1925 periods is less than twice the standard deviation of the 20 20-year periods beginning in the years 1906 through 1925. For CMIP5, white indicates areas where <66% of models exhibit a change greater than twice the baseline standard deviation of the respective model's 20 20-year periods ending in years 1986 through 2005. Gray indicates areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation, but <66% of models agree on the sign of change. Colors with circles indicate the ensemble-mean change in areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation and >66% of models agree on the sign of change. Colors without circles indicate areas where >90% of models exhibit a change greater than twice the respective model baseline standard deviation and >90% of models agree on the sign of change. The realizations from each model are first averaged to create baseline-period and future-period mean and standard deviation for each model, from which the multi-model mean and the individual model signal-to-noise ratios are calculated. The baseline period is 1986-2005. The late-21st century period is 2081-2100. The mid-21st century period is 2046-2065.

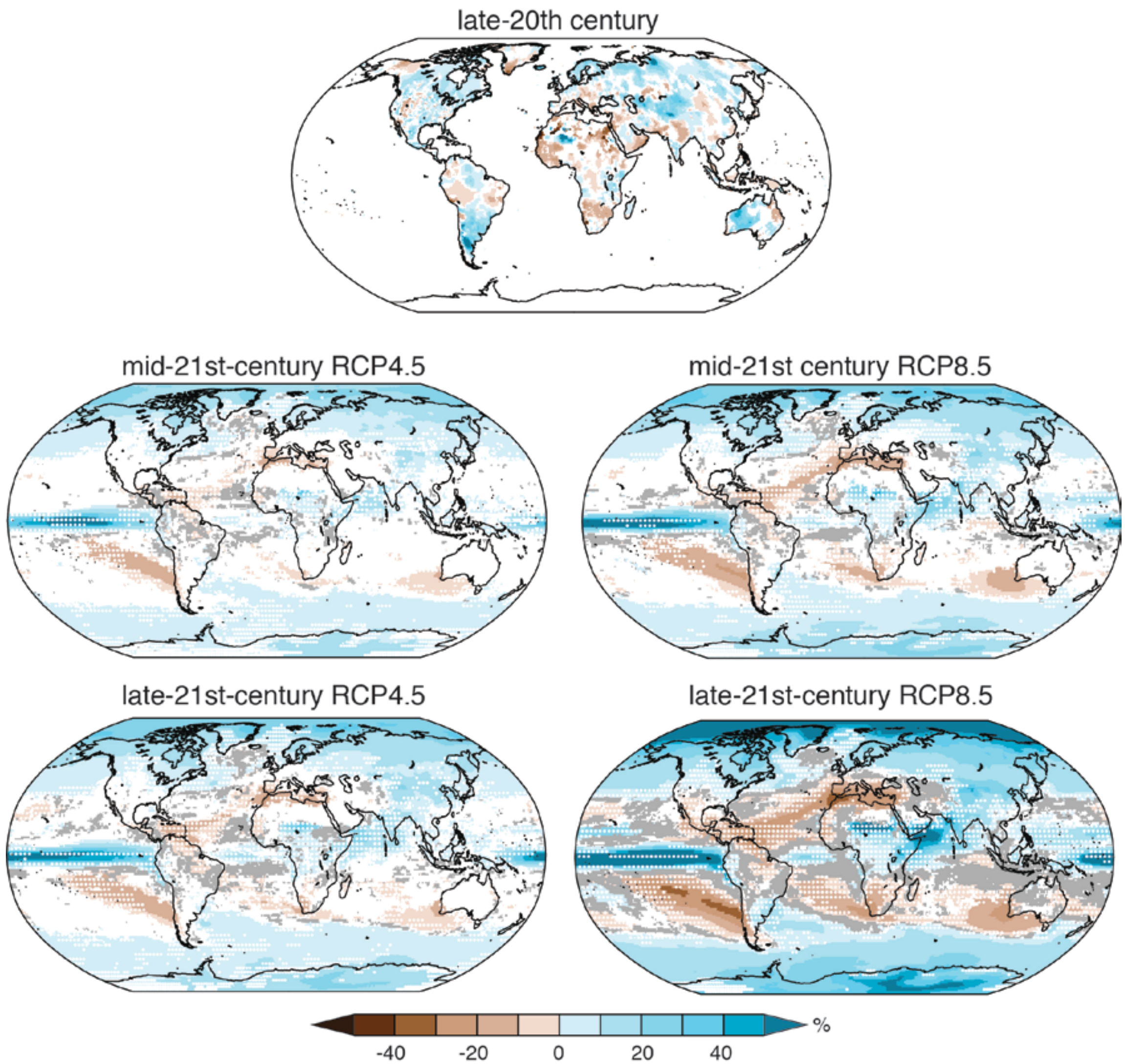


Figure RC-2: Change in annual precipitation. For the CRU observations, differences are shown between the 1986-2005 and 1906-1925 periods, with white indicating areas where the difference between the 1986-2005 and 1906-1925 periods is less than twice the standard deviation of the 20 20-year periods beginning in the years 1906 through 1925. For CMIP5, white indicates areas where <66% of models exhibit a change greater than twice the baseline standard deviation of the respective model's 20 20-year periods ending in years 1986 through 2005. Gray indicates areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation, but <66% of models agree on the sign of change. Colors with circles indicate the ensemble-mean change in areas where >66% of models exhibit a change greater than twice the respective model baseline standard deviation and >66% of models agree on the sign of change. Colors without circles indicate areas where >90% of models exhibit a change greater than twice the respective model baseline standard deviation and >90% of models agree on the sign of change. The realizations from each model are first averaged to create baseline-period and future-period mean and standard deviation for each model, from which the multi-model mean and the individual model signal-to-noise ratios are calculated. The baseline period is 1986-2005. The late-21st century period is 2081-2100. The mid-21st century period is 2046-2065.

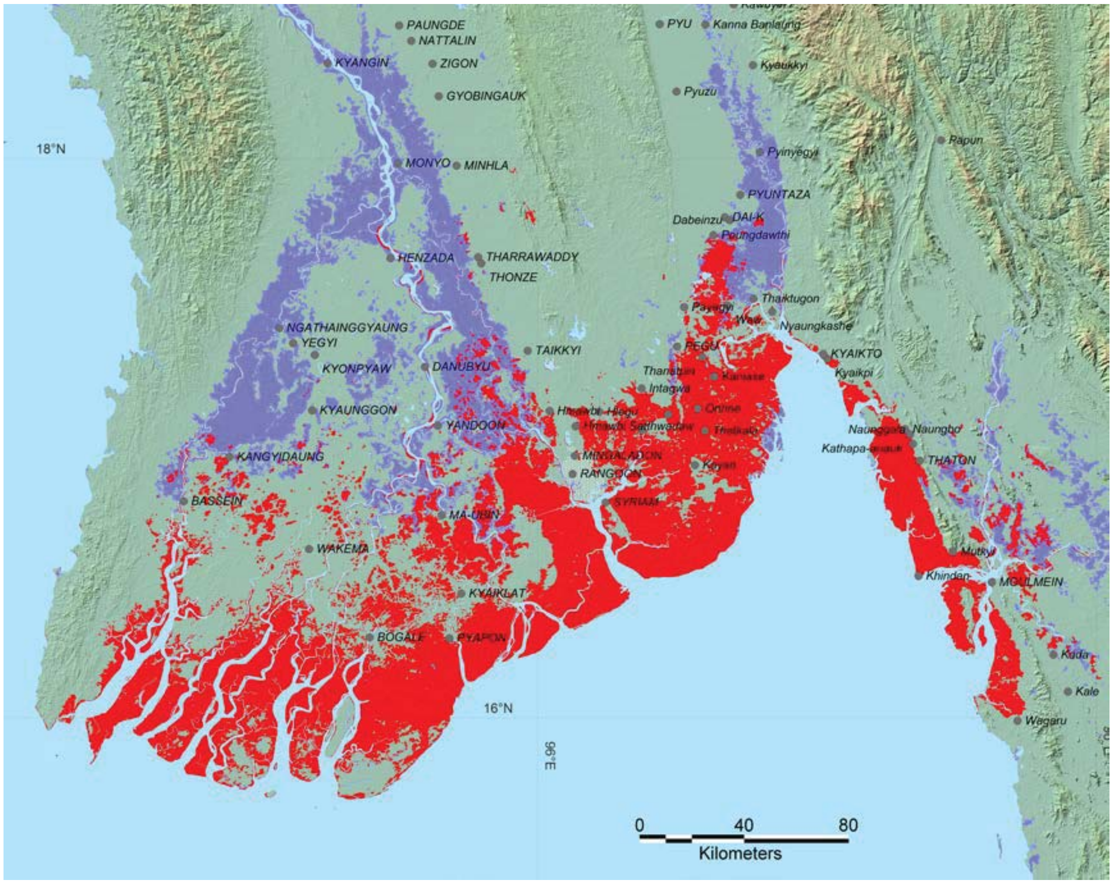


Figure TC-1: The intersection of inland and storm surge flooding. Red shows May 5, 2008 MODIS mapping of the tropical cyclone Nargis storm surge along the Irrawaddy Delta and to the east, Myanmar. The blue areas to the north were flooded by the river in prior years. (From Brakenridge *et al.*, 2012).

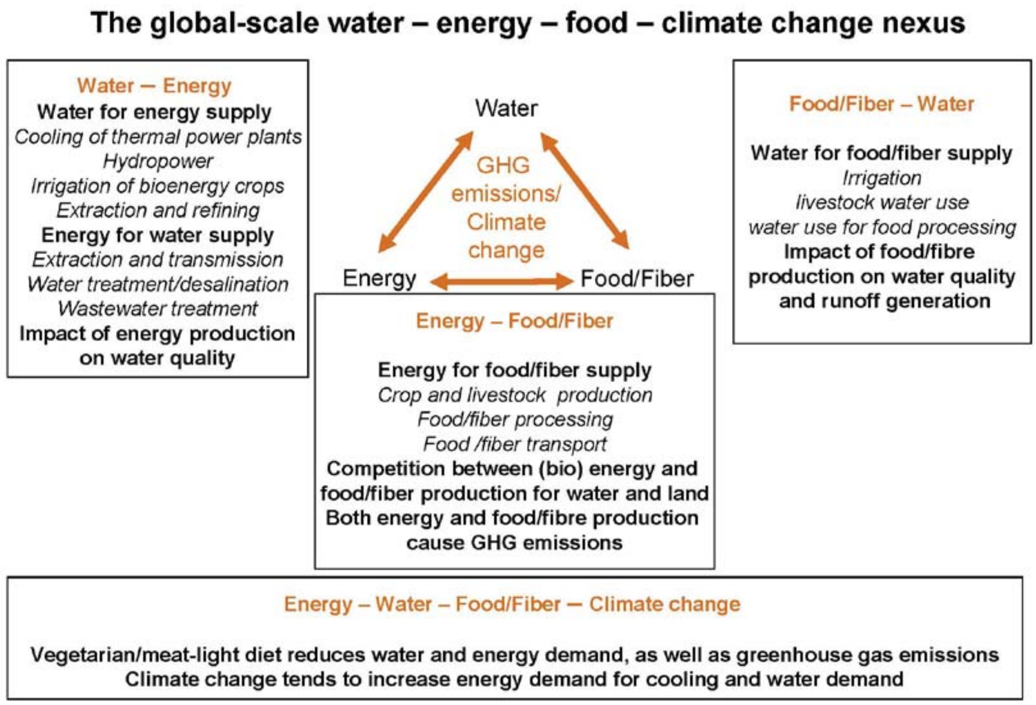


Figure WE-1: The water-energy-food nexus as related to climate change.

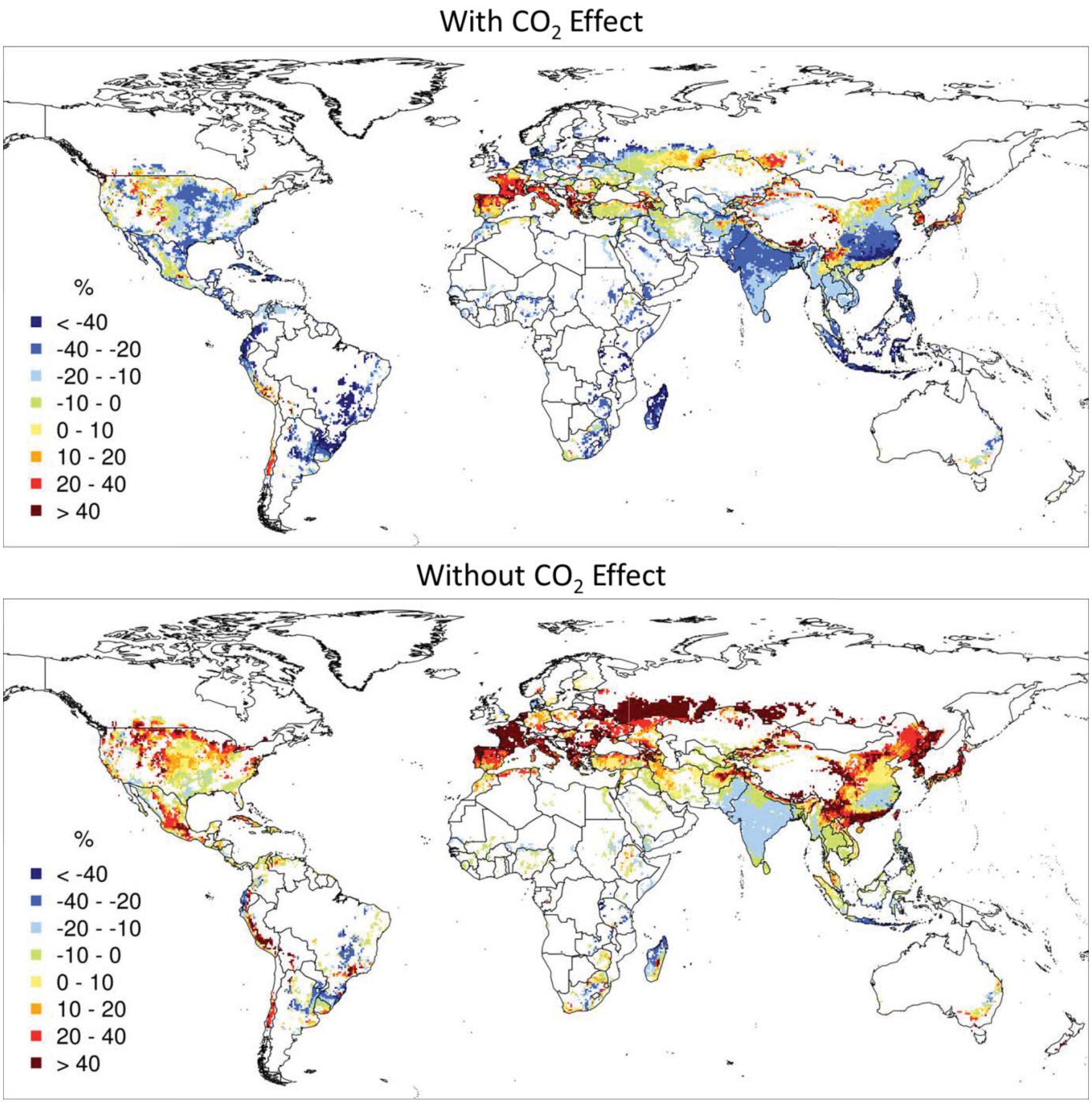


Figure VW-1: Percentage change (ensemble median across 19 GCMs used to force a vegetation and hydrology model) in net irrigation requirements of 12 major crops by the 2080s, assuming current extent of irrigation areas and current management practices. Top: impacts of climate change only; bottom: additionally considering physiological and structural crop responses to increased atmospheric CO_2 concentration. Taken from Konzmann *et al.* (2013).